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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 Europeon Union 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 series of lectures is to render a little more understanding to the phenomenon of EMC and to provide some practical guidelines and techniques to bring appliances into compliance with the EMC Directive. The lectures cover two major segments. While first part describes the fundamentals, terminology and basic concepts of EMC , second part briefly discusses some techniques and guidelines to design for EMC.

LECTURE 1

FUNDAMENTALS OF ELECTROMAGNETIC RADIATIONS

FUNDAMENTALS OF ELECTROMAGNETIC FIELDS

RADIATED ENERGY :

The electromagnetic or radiated energy propagates in the space by the movement of the electromagnetic waves. The energy which is radiated by the sun is one form of the electromagnetic energy in the nature. According to the wave theory the radiated sun energy propagates to the earth in the form of the waves through the space. In each part of the world space where the electromagnetic energy is propagating the periodical movements of the electric and magnetic fields exist. These forces are mutually connected with each other and are called electromagnetic oscillations. The space where these oscillations exist is called the electromagnetic field. Each electromagnetic field contains the electric field and the magnetic field. This mutual influence results in the propagation of the electromagnetic waves which carry the electromagnetic energy in the environment.

The radiated sun energy consists of very simple sine oscillations. It should be emphasized that the properties of each electromagnetic wave depend on its frequency. If we change the frequency of the electromagnetic oscillations gradually, we can also observe the changes in their character.

PROPAGATION OF ELECTROMAGNETIC ENERGY

The carrier of the electromagnetic energy is the electromagnetic field. The electromagnetic field is the part of the space where at any randomly located point the electric and magnetic energies mutually depending on each other are acting.

If we know the physical laws, which define the changes in the electric and magnetic field strengths at any randomly, located point, the electromagnetic field is then completely defined. We can then know the character of the propagation of the electromagnetic wave in space as well as the amount of energy these waves carry.

If we know the vector position of the electric and magnetic field strength **E** and **H** at a defined point in space, the direction of propagation of electromagnetic energy is perpendicular to the plane containing the **E** and **H** vectors. The sense is given by the direction in which a right-handed screw would move if it is turned around in the shortest path from the electric to the magnetic field vector.

Through the surface of I m^2 perpendicular to the propagation direction of an electromagnetic wave, an amount of energy defined by the following equation passes in one second.

$$\begin{aligned}
&P = E.H \sin(E \otimes H) \\
&P = EnergyDensity \\
&E \otimes H = AnglebetweenEandHvectors \\
&E, H = Electricandmagneticfieldstrength
\end{aligned}$$

The circuit theory is a special case of electromagnetic wave propagation. All equations and laws of circuit theory can be derived from the Maxwell’s equations at low frequencies. Maxwell’s equations are the unifying force of all electromagnetic phenomena. Electromagnetic waves can be shown to exist by solving these equations.

At low frequencies, the wavelength of the electromagnetic wave in the space is much higher than the distance between the conductors. It is very difficult to transmit the high frequency electromagnetic energy along the ordinary conductors. In the case when the wavelength is of the same order of magnitude as the distance between the conductors, the conductor functions as antenna and radiates the majority of energy into the environment. Due to this fact special cables or waveguides are used for the transmission of high frequency energy.

This theory directly points out the potential danger when long cable shield connections are used. They do not propagate the high frequency noise energy along the conductors. Instead this noise energy is radiated to the environment by means of the antenna effect with the risk of interference.

MATHEMATICAL RELATIONSHIP FOR THE ELECTROMAGNETIC FIELD

The relationship between the current and the magnetic field strength is defined by the following integral

$$\oint H.dl = I$$

The equation states that the integral of magnetic field on any closed contour is equal to the total current passing through the surface demarcated by this contour. This is the Maxwell's first equation when all currents including all currents in space is included. When this law is applied , the relationship between the electric and magnetic field is given.

The creation of the electric field during changes of the magnetic field is given by the following equation

$$\oint E.dl = -\frac{d\phi}{dt}$$

This is Maxwell's second equation. It states that each change of the magnetic field creates the electric field of that environment.

ELECTROMAGNETIC RADIATION FROM ANTENNAS

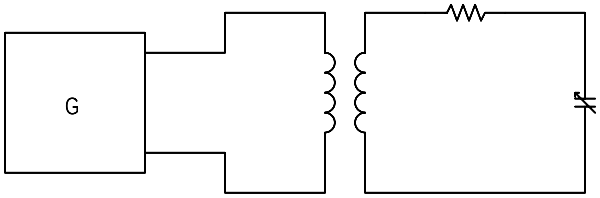
The electromagnetic waves that are transmitted from the radio stations are of the same kind as the light waves. The only difference is in the oscillation frequency with the radio waves in the range of 100KHz to 10GHz.

In order to effect the radio transmission, that is , to transmit the electromagnetic waves to the space, it is necessary to produce in an antenna such electromagnetic oscillations that can leave the antenna and pass into the environment.

The phenomenon of the formation of radio waves in the antenna as well as their transmission from the antenna to the environment is discussed in the following paragraphs.

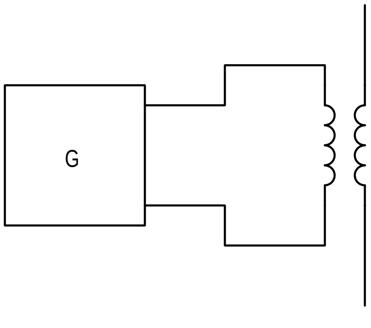
It is necessary to keep in mind that all electronic equipment using he signals changing their values in time can be a source of undesirable electromagnetic fields radiated to the environment. This process is promoted by all conducting connections, which can function as the antennas.

Shown below in the circuit is an electromagnetic generator connected to an LCR oscillator through a transformer.



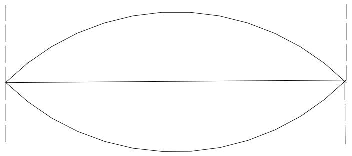
The oscillation produced by the generator is induced in the secondary circuit and is called as the forced oscillation. This differs from the self-oscillation of LCR circuit in the secondary. If the frequencies of the two oscillations match, the circuit will resonate in which case the current achieves the maximum value in the secondary circuit. The electromagnetic oscillations reach the maximum as well. However the above circuit is a closed oscillating circuit and the electromagnetic waves cannot propagate into the surrounding medium. In this case the electric energy changes into the magnetic energy in the oscillating circuit and vice versa. However it never leaves the circuit itself.

To make possible a transmission of electromagnetic oscillations, it is necessary to have an open circuit, which forms as an antenna of a certain type as shown in the following figure



In comparison with the closed circuit, the open circuit has the capacitance distributed over the entire length.

The generator of high frequency oscillations produces electromagnetic oscillations in the secondary circuit. This is made possible by the mutual inductive connections to the antenna coil. Compare with the closed resonance circuit, in which the current is equal in all parts, the antenna current is different in different parts of antenna as shown below for the case when antenna is in resonance.



The current as shown attains its maximum value in the middle of the antenna, being equal to zero at the antenna ends. The voltage attains values opposite to the current , the highest value at the antenna ends ,and is equal to zero in the middle.

An open antenna circuit of this type is called bipolar or a symmetrical antenna. When the electromagnetic oscillations are induced in such an antenna, the electromagnetic waves are transmitted to the environment.

If the electromagnetic oscillations exist in the antenna an alternating current of a corresponding frequency is produced in such an antenna. The free electrons in the antenna cause the oscillating movements and alternately charge the antenna ends positively or negatively. The movement of electric charges in the antenna is also connected with the movements of the electric lines of force, which are directed from the positive to the negative charges. The electric lines of force are located in the planes which cross each other in the antenna axis. Electric current produces a magnetic field with magnetic lines of force in the form of concentric rings having a center in the antenna axis.

The electric and magnetic fields depend on each other, changing their values during time and forming an indivisible part of the antenna electromagnetic field. Electric and magnetic fields act as two contrasts, their mutual influence being the basis of the electromagnetic process. The change of the electric field into the magnetic field and vice versa is basis for the propagation of electromagnetic energy into the environment.

In the next cycle of oscillation, the electrons in the negative end of the antenna flow towards the positive end to fill the void. During this process, the corresponding origin and ends of the electric lines of force approach each other. They penetrate each other forming closed rings. They are surrounded by the magnetic lines of force equally to the chain links. This configuration of electric and magnetic lines of force leaves the antenna and propagates into the environment in the form of electromagnetic waves. The vectors of the electric and magnetic field strengths are perpendicular to each other.

An electromagnetic wave is called a plane wave if all the values characterizing the electromagnetic process depend only on one of the coordinates in space.

The wave has the characteristics of a plane wave if it’s considered in the small space at a long distance from the antenna. The wave impedance of a plane wave is given by the following equation

$$\frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}}$$

The velocity of propagation of the electromagnetic wave front is

$$v = \sqrt{\frac{1}{\mu\varepsilon}}$$

From the above equations it is obvious that the propagation of electromagnetic waves depends on the electric and magnetic characteristics of the environment. In free space it is equal to the velocity of light.

There exists an analogy between the propagation of electromagnetic plane waves and the propagation of the voltage and the current waves on the long lines, provided that the losses in the lines are negligible.

The electric field strength is analogous to the voltage wave and magnetic field strength is analogous to the current wave.

The wave impedance of free space is analogous to the characteristic impedance of line given by

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

The velocity of propagation on the lines is given by,

$$v = \sqrt{1/LC}$$

SKIN EFFECT

Skin depth of any material is defined as the distance inside the material, over which the strength of any incident field decreases, by 63% of its boundary value. This distance is inversely proportional to the frequency, conductivity and permitivity of the material. For good conductors, the field will propagate along the skin of the conductor and not along its depth.

LECTURE 2

INTRODUCTION TO EMI/EMC

EMC FUNDAMENTALS

Electromagnetic Interference can be described as the degradation of a device or system caused by an electromagnetic disturbance. An electromagnetic disturbance is any 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, or Electromagnetic Compatibility. 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; 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.

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. Within the scope of man made noise sources, we can break it down even further into Intersystem interference and Intra-system interference. Intersystem 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.

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 manmade 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. Each of these three elements must be present at the same time in order to have an electromagnetic disturbance or EMI. Identifying at least two of these elements and eliminating or attenuating the interference from one of them can solve EMC problems.

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.

Their frequency, bandwidth and amplitude can characterize sources of interference.

The propagation medium of EMI below 30Mhz 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.

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).

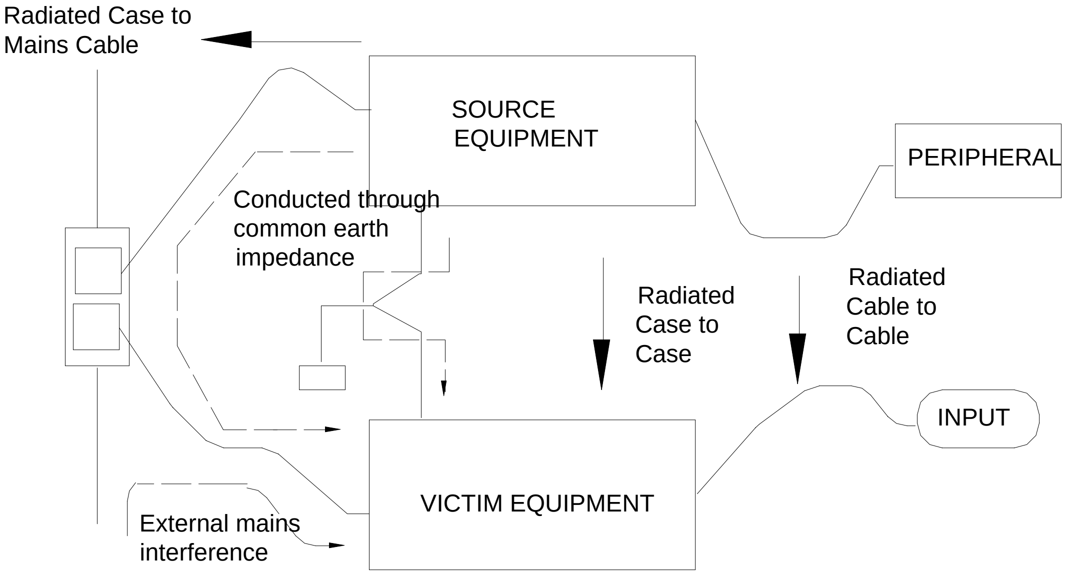
SOURCE VICTIM THEORY

Any situation, in which the question of electromagnetic compatibility arises, invariably has two complementary aspects as discussed above.

Any such situation must have a source of interference and a victim, which is susceptible to this interference. If either of these is not present, there is no EMC problem.

Knowledge of how the source emissions are coupled to the victim is essential, since a reduction in the coupling factor is often the only way to reduce interference effects, if a product is to continue to meet its performance specification. The two aspects are frequently reciprocal that is measures taken to improve emissions will also improve the susceptibility, though this is not always true. For an easy analysis, these two aspects are considered separately.

Putting source and victim together shows the potential interference routes that exists from one to the other. Some of the possibilities are shown in the following figure.

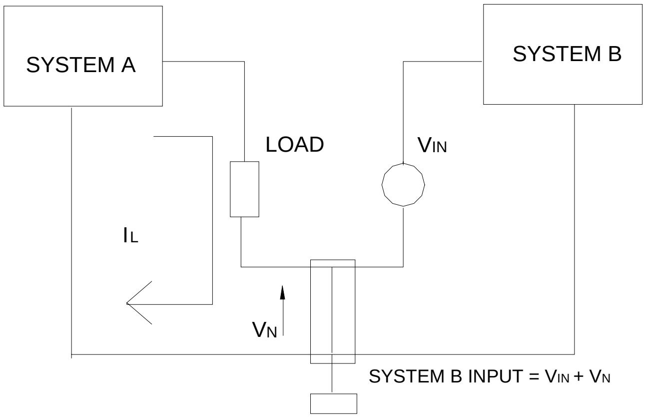


The most common culprit in EMC situation is the antenna like behavior of cables, PCB tracks, and internal wiring and mechanical structures. These elements can transfer energy via electric, magnetic or electromagnetic fields, which couple with the circuits. In practical situations, intra-system and external coupling between equipment is modified by the presence of screening and dielectric materials, and by the layout and proximity of interfering and victim equipment and especially their respective cables. Ground or screening planes will enhance an interfering signal by reflection or attenuate it by absorption. Cable-to-cable coupling can be either capacitive or inductive and depends on orientation, length and proximity. Dielectric materials may also reduce the field by absorption, though this is negligible compared with the effects of conductors in most practical situations.

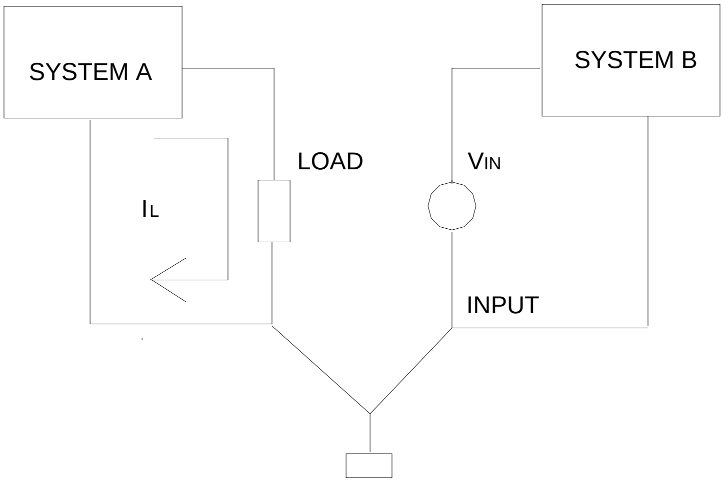
Some of the important modes of coupling will be discussed now.

1. When the victim shares common impedance with the source, any noise, which is produced in the source, will be coupled to the victim and may interfere with its working. Apart from conductively coupled to the victim, the noise produced in the source can also couple either inductively or capacitvely to the victim.

Shown below in the figure is common mode impedance coupling. As shown in the circuit, the source and the victim circuit share a common ground connection. This connection is inductive in nature. The change in current with time in the source circuit produces a voltage across this connection which is coupled to the victim circuit in series with its own source.



The solution is to avoid any common path between the source and victim and connect the circuit in such a way that there is no common impedance. Connection as shown in the following figure avoids having common impedance and hence solves the problem.



This problem and its solution tell the importance of proper layout of components while routing in them on the PCB.

2. The magnetic field formed around a conductor when current flows through it can couple to a conductor placed nearby. The magnitude of the voltage developed depends upon the mutual inductance of the conductors. The mutual inductance depends on the areas of the source and victim current loops, their orientation and separation distance and the presence of any magnetic screening. The equivalent circuit for magnetic coupling is a voltage generator in series with the victim circuit. The coupling is unaffected by whether or not there is a direct connection between the two circuits; the induced voltage would be the same if the circuits were isolated or connected to ground.

3. Changing voltage on one conductor creates an electric field, which may couple with a nearby conductor and induce a voltage on it. The magnitude of this voltage depends on the mutual capacitance of these conductors.

Both mutual capacitance and mutual inductance are effected by the physical separation of source and victim conductors. An optimal placement must be decided to minimize the effects of these stray impedances.

4. Apart from inductive and capacitive coupling at single point as discussed above, coupling also occurs on the PCB traces through distributed inductance and capacitance. This type of coupling of noise is more common and closer to reality. The phenomenon is also called as crosstalk.

5. Interference can propagate from source to victim via the main distribution network to which both are connected. This is not well characterized at high frequencies especially since connected electrical loads can present virtually any RF impedance at their point of connection.

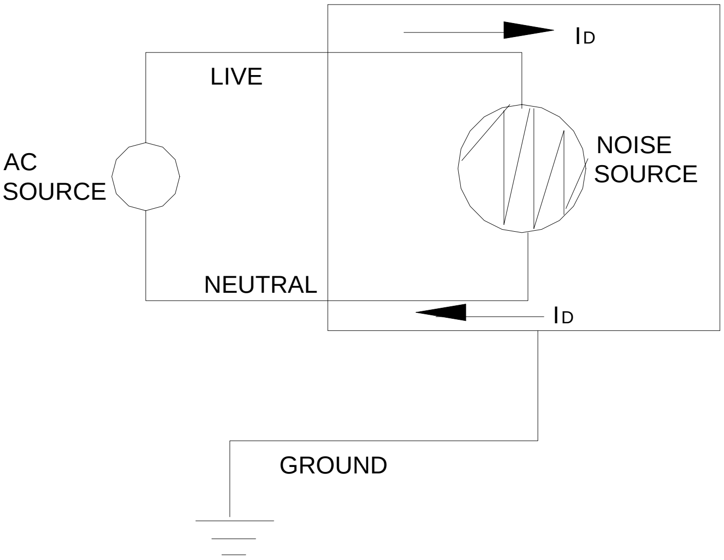
6. Even when there is no conductor nearby through which noise can couple either inductively or cpacitvely, interference can exist with the conductors behaving as antenna and generating electromagnetic waves which can be picked up by any other conductor. This mode of interference has been discussed in detail in a later lecture.

COUPLING MODES

Understanding how any stray noise generated in a source circuit is coupled to the victim circuit is key to solving any EMC problem. The basic modes of coupling are the differential and common modes as explained in the following paragraphs.

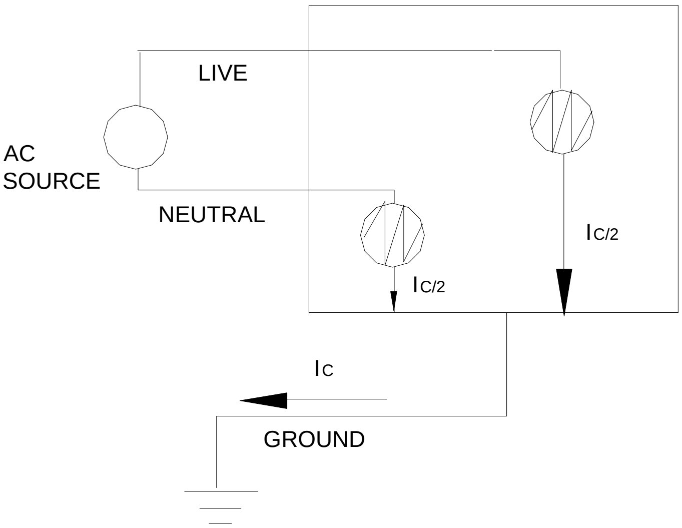
1. Differential Mode

As shown in the figure above the currents carried in differential mode flows in one cable from one block to another and returns through the another. A radiated field can couple to this system and induce differential mode interference between the two wires; similarly, the differential current will induce a radiated field of its own.



2. Common Mode

The cable also carries current in common mode, that is, all flowing in the same direction on each wire. These currents very often have nothing at all to do with the signal currents. They may be induced by external field coupling to the loop formed by the cable, the ground plane and the various impedances connecting the equipment to ground, and may then cause internal differential currents to which the equipment is susceptible. Alternatively, they may be generated by internal noise voltages between the ground reference point and the cable connection, and be responsible for radiated emissions. The existence of RF common mode currents means that no cable, whatever signal it may be intended to carry can be viewed as safe from EMC point of view.



Although it was said above that common mode currents may be unrelated to the intended signal currents, there may also be a component of common mode current which is due to the signal current. Conversion occurs when the two-signal conductors present differing impedance to their environment, represented by the external ground. These impedance are dominated at RF by stray capacitance and inductance related to physical layout, and are only under the circuit designer’s control if that person is also responsible for physical layout.

LECTURE 3

RADIATED EMISSION

MATHEMATICAL MODELLING OF SOURCES OF RADIATED EMISSIONS:

Most of the practical cases of radiation can be assimilated to one of the following basic configurations:

1. the closed loop(i.e. magnetic excitation)
2. the straight open wire(i.e. electric excitation)

Calculation of E and H fields of some practical cases is a very complex mathematical process. However much simplification can be achieved with the following assumptions:

1. Retain the value of field in only the operational direction
2. Aligning of receiving antenna with maximum polarization
3. Assume a uniform current distribution over the wire length
4. Ignore dielectric and resistive losses in traces.

Z in all equations given below represents the free space wave impedance.

1.Field radiated by loops:

It is further assumed that the loop size is very much less than the wavelength and the observation distance (D). Further, it is not close to any metallic surface.

With these assumptions various components of electric and magnetic fields in spherical coordinates are given by the following expressions:

$$H_r = \frac{IA}{\lambda}\left[\frac{j}{D^2} + \frac{\lambda}{2\pi D^3}\right]\cos\sigma$$

$$H_\sigma = \frac{\pi IA}{\lambda^2 D}\sqrt{1 - \left(\frac{\lambda}{2\pi D}\right)^2 + \left(\frac{\lambda}{2\pi D}\right)^4}\,\sin\sigma$$

$$E\varphi = \frac{Z\pi IA}{\lambda^2 D}\sqrt{1 + \left(\frac{\lambda}{2\pi D}\right)^2}\,\sin\sigma$$

We find from the above expression that along the z-axis only H_r exists and is of very little interest to us as it decreases very rapidly with distance.

In contrast to this, along the equatorial plane H_r is null and E_φ and H_σ get their maximum values. They do not get attenuated as fast as H_r with observation distance. So for most of the practical purposes we consider these components.

Near Field(D < λ/2π)

The expression for the components of the fields can be found out by neglecting the second and third order terms from the expression and can be given by the following expressions.

$$H = \frac{IA}{4\pi D^3}$$

$$E = \frac{ZIA}{2\lambda D^2}$$

It can be seen from the above expressions that the field strengths in the near region are strongly dependent on distance. Any movements in this region change the field drastically.

Far Field (D > λ/2π)

In this region the expressions for the field can again be found out by neglecting the second and third order terms. The expressions for the field strengths are given by:

$$H = \frac{\pi IA}{\lambda^2 D}$$

$$E = \frac{Z\pi IA}{\lambda^2 D}$$

In this region it can be seen from the above expressions that the fields reduce as 1/D.

Their ratio which is also called as the wave impedance is a constant. The value of impedance in free space is equal to 377ohms. This impedance can be regarded as real impedance as the fields can be multiplied to find out the radiated power density.

2. Fields radiated by straight wire:

Current carrying straight wire can also create an electromagnetic field. All the assumptions for the closed loop case hold in this case as well. Expression for fields expressed in terms of the spherical coordinates are as follows:

$$E_r = 60Il\left(\frac{1}{D^2} - \frac{j\lambda}{2\pi D^3}\right)\cos\sigma$$

$$H = \frac{Il}{2\lambda D}\sqrt{1+\left(\frac{\lambda}{2\pi D}\right)^2}\sin\sigma$$

$$E_\sigma = \frac{ZIl}{2\lambda D}\sqrt{1-\left(\frac{\lambda}{2\pi D}\right)^2+\left(\frac{\lambda}{2\pi D}\right)}^{4}\sin\sigma$$

Where I is the current carried by the wire and l is its length.

We find that only E_r exists along the axis of the wire. But it is of little significance as reduces significantly with distance.

For σ = 90°, E and H have their maximum values and are the components which will be considered from now onwards.

Near Field (D < λ/2π)

Neglecting the second and third order terms as in the loop case the expression for fields are as given below:

$$H = \frac{Il}{4\pi D^2}$$

We again find that the fields are strongly dependent on distance in this region.

$$E = \frac{ZIl\lambda}{8\pi^2 D^3}$$

Far Field (D > λ/2π)

In this region the expression for fields reduces to:

$$H = \frac{Il}{2\lambda D}$$

$$E = \frac{ZIl}{2\lambda D}$$

We again find that the fields decrease with distance and their ratio is a constant at 377ohms.

Although the intention of the lecture is not to arrive at a working mathematical model of the radiated emissions, the reader should know that such models could be arrived at for a more precise analysis of radiated emissions. For an advanced treatment of this topic the reader is referred to **[ ].**

GENERATION AND COUPLING OF RADIATED EMISSIONS

Radiated emissions can be generated either in differential or common mode.

A differential mode emission can be associated with:

. Printed circuit traces

. wire wrapping or any hard wired card or backplane

. ribbon cables

. discrete wire pairs

The culprit source existing in such circuits can be a digital or analog signal, a switching transistor, a relay, a motor creating transient spikes etc.

There is also a possibility that the differential pair is simply a carrier of an EMI signal that has been generated in the vicinity and coupled to it through the power supply conduction or nearby crosstalk.

Common mode emissions are associated with the unbalanced nature of ordinary transmitting and receiving circuits, the imperfect symmetry of the differential links and more generally, the impossibility of some common mode return path due to the loops formed by the circuit references grounded at both ends to the chassis and/or earth.

At VHF, the radiated coupling tends to be dominated by cable emissions rather than by direct emissions from the PCB as their radiating efficiency is higher than those of PCBs at such frequencies. A short length cable, with length less than a quarter wavelength can be modeled as a monopole antenna.

METHODS TO CONTROL RADIATED EMISSIONS

For a comprehensive analysis of the sources of radiated emissions a designer should proceed in the following four areas:

1. High frequency generating components
2. Printed Circuit board
3. Internal Packaging
4. Housing design and shielding

These methods can basically be grouped into primary, secondary and tertiary methods of controlling radiation. Control at the primary level involves circuit design measures such as developing balanced configurations, bandwidth and speed limitations and especially board layout and grounding.

At secondary level the interface between the internal circuits and the external cables is considered which is invariably a major route for interference both into and out of circuits.

Shielding, the tertiary level measure should be applied only when all other measures have been applied.

Now all the issues involved in controlling the radiated emissions will be discussed one by one.

1. GROUNDING AND LAYOUT

Before start of routing a careful consideration should be given to the layout and grounding. This is the most effective approach to control EMI.

Entire process can further be subdivided into the following steps:

1.Partition the entire system into critical and non-critical parts from the point of view of EMC. Critical sections are those which contain radiating sources or which are particularly susceptible to interference. Non critical sections are those whose signal levels, bandwidth and circuit functions are such that they are not susceptible to interference nor are capable of causing it.

2.Instead of treating the ground as an equipotential plane from which the references for the circuit are derived, treat it as a low impedance path from which the current can return to its source. Identify critical points along the ground plane which are the points along the ground path where significant interference voltage can develop. Place components to avoid drawing references from such points.

3.The PCB tracks exhibit what is called as self inductance which defines the counter electromotive force caused by magnetic field around a wire or trace when current is changing rapidly. Any stray field coupled to PCB will appear as voltage drop across ground impedance. The impedance can be minimized either by minimizing the length of the conductor, and if possible increasing its width or by running its return path parallel and close to it.

The logical extension to paralleling the round tracks is to form the ground layout in the grid structure. This minimizes the number of different paths that ground return current can take and therefore minimizes the ground inductance for any given signal route. The limiting case of a gridded ground is when an infinite number of parallel paths are provided and the ground conductor is continuous, and it is then known as a ground plane.

4.The geometrical center of ground plane can be treated as isolated from any stray magnetic field so that its self-inductance can be neglected. But as we move away from the center towards the periphery, the impedance becomes markedly inductive. The moral of the lesson is never place critical tracks or devices near the outside edge of the ground plane.

5.A plane can be implemented by simply adding a copper layer around the ground track. This ensures a minimum possible area for each circuit path and thus minimizes magnetic coupling to the circuit. It acts as an electric field screen as well by reducing the effect of capacitive coupling to the tracks.

6.The-ground plane should be positioned under (or over) the tracks to provide a low inductance return. This is achieved by the maximization of the mutual inductance, which is proportional to the spacing of the tracks.

2.MINIMIZING CROSSTALK

Crosstalk occurs when a wire or track carrying fast signals run parallel to another conductor. By mutual capacitance or inductance, the”culprit” conductor induces a certain voltage into the “victim” conductor. Crosstalk increases with the proximity of the culprit and the victim wires, increasing frequency and higher victim impedance. It also increases when the culprit and the victim conductors are more distant from the return wire or plane.

Crosstalk is a significant player in the generation of radiated EMI. High speed clocks and high frequency circuits that are used only for internal functions

may unintentionally couple into I/O lines by crosstalk, then radiate.

Inductive and capacitive crosstalks exist simultaneously, but the later predominates in PCBs because of high dielectric constant of epoxy.

The magnitude of the crosstalk in the capacitive crosstalk phenomena is determined by trace to ground and interface parasitic capacitances. The capacitive crosstalk can be reduced by:

1. Increasing culprit-to-victim spacing. However there is not much scope of doing this in a given sized PCB.
2. Decreasing the length of the parallel run which decreases crosstalk in proportion.
3. Running the culprit and/or victim traces above the return plane or traces.
4. Inserting a grounded trace between the culprit and the victim traces.

The magnetic contribution to crosstalk cannot be neglected for traces carrying larger currents. The two significant players in this type of cross talk are the mutual and the self-inductance of the trace under consideration. The mutual inductance depends upon the distance to the nearest ground trace and is approximately independent of the trace width. But the trace width plays a role in the self-inductance, which governs the characteristic impedance and the maximum possible crosstalk.

3. GROUNDING THE 0V REFERNCE TO CHASSIS

Usually in low frequency circuits ground is kept floating with respect to the chassis. This is done to prevent common mode interference development through the ground loop. But in high frequency circuits this cannot be done. The stray capacitance between the PCB and chassis comes into picture and an excellent LCR resonating structure is formed. This is sometimes worse than actual grounding. Considering this it is better to connect the ground reference point to the chassis. One more fact that should be known is where to make this connection.

4.I/O CONNECTOR AREAS

It is important from the point of view of minimizing the effects of any spurious emissions picked up by cables going in and coming out of the PCB, that all I/O connectors and cable entries should preferably be grouped together on

the same side of the equipment. It is even better if a clean ground area, not contaminated by the internally generated noise is provided. This reduces the common mode currents appearing on the cable. The interface ground as the area will be called is a separate area on the PCB and is connected to the internal ground through a single point. This prevents the contamination of the interface area by the noise currents flowing in the circuit ground. It is important to note that filtering at high frequencies is next to useless without such ground.

5. EMI FILTERING

In order to further suppress the ill effects of radiated emissions, one should make it a point not to allow the entry and exit of a cable unless it is perfectly shielded at the very point of penetration. Decoupling at the I/O port level can be done using either of two approaches:

1. Apply discrete filtering at each individual conductor, especially when there is a permanent connection rather than pluggable contacts. It can be done by using either the purchased original filters or with discrete capacitors.
2. Use filtered connectors whereby each contact is filtered by miniature ferrites and multilayer capacitor arrays. PCBs permit some economical and efficient mounting of filter components. If one pole filtering is deemed sufficient, simple ceramic capacitors are enough. SMT components allow for economical and non-inductive mounting. The preferred method is to connect such capacitors to the ground plane, which itself should be connected to chassis , nearest to the I/O ports. But one should be careful enough to rely solely on capacitive filtering. A single capacitor across an I/o trace will shunt the high frequency current back to its source, returning through the PCB ground network. This will reduce high frequency contents escaping to the driven line, but may increase the PCB common mode ground noise, in the same proportion. Therefore capacitive filters should be used when :

. a good low impedance ground plane exists between the high frequency source and the I/O interface areas.

. if the PCB ground is tied to the metal chassis plate very close to the I/O filtering point

6. BOX SHIELDING

Shielding involves placing a conductive surface around the critical parts of the circuit so that the electromagnetic field, which is coupled to it, is attenuated by a combination of reflection and absorption. The shield can be an all-metal enclosure if protection down to low frequencies is needed, but if only high frequency will be enough then a thin conductive coating deposited on plastic is adequate.

Decision to do shielding should be taken as early as possible in a project based on a rough calculation of fields generated by PCB, because many other factors like aesthetic, tooling, accessibility work against it.

SHIELDING THEORY OF AN INFINITE BARRIER

An AC electric field impinging on a conductive wall of infinite extent will induce a current flow in that surface of the wall, which in turn will generate a reflected wave of the opposite sense. This is necessary in order to satisfy the boundary condition at the wall, where electric field must approach zero. The reflected wave amplitude determines the reflection loss of the wall. Because shielding walls have finite conductivity, part of this current flow penetrates into the wall and a fraction of it will appear on the opposite side of the wall where it will generate its own field. The ratio of the impinging to the transmitted fields is one measure of the shielding effectiveness of the wall.

The thicker the wall, the greater the attenuation of the current through it. This absorption loss depends upon the number of “skin depths” through the wall. Fields are attenuated by around 63% for each skin depth of penetration. Skin depth becomes less as the frequency, conductivity or permeability increases.

This explains why thin conductive coating are effective at high frequencies-the current flows only on the surface, and the bulk of material does not effect the shielding properties.

REFLECTION LOSS:

The reflection loss R depends upon the ratio of wave impedance to barrier impedance. The impedance of a barrier is a function of its conductivity and permeability, and frequency. Materials of high conductivity such as copper and aluminum have a higher electric field reflection loss than do lower conductivity material such as steel. Reflection losses decrease with increasing frequency for the electric field and increase for the magnetic field. In the near field region the distance between source and barrier also reflects the reflection loss.

ABSORPTION LOSS:

Absorption loss depends on the barrier thickness and its skin depth and is the same whether the field is electric, magnetic or plane wave. The skin depth in turn depends on the barrier material's properties; in contrast to reflection loss, steel offers high absorption than copper of the same thickness.

SHIELDING EFFECTIVENESS:

Shielding effectiveness of a solid conductive barrier describes the ratio between the field strength without the barrier in place, to that when it is present. It can be expressed as the sum of reflection, absorption, and re-reflection loss.

LOW FREQUENCY MAGNETIC FIELDS:

Shielding against magnetic fields at low frequencies is to all intents and purposes impossible with purely conductive materials. This is because the reflection loss to an impinging magnetic field depends on the mismatch of the field impedance to the barrier impedance. The low field impedance is well matched to the low barrier impedance and the field is transmitted through the barrier with only a few dB of attenuation or absorption. Fortunately, the requirements of the EMC directive generally do not extend to the magnetic shielding at low frequencies; with the possible exception of some types of apparatus that may be susceptible to power frequency fields.

THE EFFECT OF APERTURES:

The practical shielding effects is not determined by material characteristics but is limited by necessary apertures and discontinuities in the shielding.

Apertures are needed for ventilation, for control and interface access, and for viewing indicators. Seams and discontinuities at joints between individual conductive members act also as apertures.

There are different theories for determining shielding effectiveness degradation due to apertures. The simplest assumes that shielding effectiveness is directly proportional to the ratio of largest aperture dimension and frequency. Thus the shielding effectiveness increases linearly with decreasing frequency ; upto the maximum determined by the barrier material, with a greater degradation for larger apertures. Another theory, which has come into picture recently models the rectangular screening, box with a single slot in one of its faces as a shorted waveguide. The slot itself is modeled as a length of transmission line shorted at either end and the incident field is represented as voltage source with an impedance equal to that of free space.

ENCLOSURE RESONANCE:

The enclosure can also form a resonant cavity, if its dimension between the opposite sides is a multiple of half wavelength. This result in the formation of standing waves between the sides with enhanced electric field in the middle of this cavity and enhanced magnetic fields at the sides. The effect of the resonance is to worsen the shielding effectiveness at the resonant frequencies. At these frequencies the field distribution within the cavity peaks, maximum current flows within the walls and hence maximum coupling occurs through the apertures of an imperfect enclosure. However loading the enclosures with components, conducting surfaces and PCBs will reduce the amplitude of the resonance quite significantly.

THE EFFECT OF SEAMS:

An electromagnetic shield is normally made from several panels joined together at the seams. This makes the electrical conductivity at the joints imperfect. This may be because of distortion, so that surface does not mate properly, or because of painting, anodizing or corrosion, so that an insulating layer is present on one or both metal surfaces. Consequently seams reduce the shielding effectiveness almost as much as it is by apertures.

Ventilation holes can be covered with a perforated mesh screen, or the conductive panel may itself be perforated. If individual equally sized perforations are spaced close together then the reduction in shielding over a single hole is approximately proportional to the square root of the number of holes. On the other hand, for fixed open area, the shielding effectiveness improves proportionally to the square root of the number of holes: in other words, ventilation is always better provided by a mesh of many small holes, rather than a few large ones.

MEASUREMENTS OF RADIATED EMISSION

A brief discussion of the instruments and the transducers involved in the measurement will be done before actual procedure is discussed.

1. INSTRUMENTATION

A. SPECTRUM ANALYZER :

It is widely used for a quick testing and diagnostics. The analyzer displays the entire spectrum, which gives the amplitude of various spectral components. Hence it can be used to easily find out the frequencies and nature of offending emissions. It can also be used to narrow in on a small part of the spectrum if desired.

B. DETECTOR FUNCTIONS :

There are three detectors in common use in RF emissions measurements: peak, quasi-peak, average.

Interference emissions are rarely continuous at a fixed level. A carrier signal may be amplitude modulated and either a carrier or a broadband emission may be pulsed. The measured level, which is indicated for different types of modulation, will depend on the type of detector in use.

PEAK DETECTOR

The peak detector responds near instantaneously to peak value of the signal and discharges fairly rapidly. If the receiver dwells on a single frequency the peak detector output will follow the “ envelope “ of the signal, hence it is sometimes called an envelope detector.

AVERAGE

The average detector as the name implies, measures the average value of the signal. For a continuous signal this will be the same as its peak value, but a pulsed or modulated signal will have an average level lower than the peak.

QUASI PEAK

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. It 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 the longer and higher the detector stays charged, therefore, higher the level recorded.

The actual value of an interference signal that is measured at a given frequency depends on the bandwidth of the receiver and its detector response. These parameters are rigorously defined in a separate standard that is referenced by all the commercial emissions standards.

CISPR 16-1 splits the measurement range of 9kHz to 1GHz into four bands, and defines a measurement bandwidth for quasi-peak detection, which is constant over each of these bands. Sources of emissions can be classified into narrowband, usually due to oscillator and signal harmonics, and broadband due to discontinuous switching operation, commutator motors and digital data transfer.

The indicated level of a broadband signal changes with the measuring bandwidth. As the measuring bandwidth increases, more of the signal is included within it and hence the indicated level rises. The indicated level of a narrowband signal is not affected by measuring bandwidth. Noise, of course, is inherently broadband and therefore there is a direct correlation between the ”noise floor” of a receiver or spectrum analyzer and its measuring bandwidth: minimum noise (maximum sensitivity) is obtained with the narrowest bandwidth.

2. TRANSDUCERS

Transducers are needed to couple the measured variable, which in this case is the radiated electromagnetic field into the input of the measuring instrumentation.

A. ANTENNAS

An antenna is needed to couple the radiated electromagnetic field to the receiver. Electric field strength limits are specified in terms of volts/meter at a given distance from EUT(equipment under test), whilst measuring receivers are calibrated in volts at the 50 ohms input. The antenna must therefore be calibrated in terms of volts output into 50ohms for a given field strength at each frequency. The two most common antennas have been the biconical, for the frequency range 30-300MHz and the log periodic for the frequency range of 300-1000MHz.

With respect to EMC measurements the gain and directional response of an antenna are of little importance. The antenna is always oriented for maximum response and the antenna factor is the most important parameter. Each calibrated broadband antenna is supplied with a table of its antenna factor vs frequency. To convert the measured voltage at the instrument terminals into actual field strength at the antenna, the antenna factor and the cable attenuation are added. Cable attenuation is also a function of frequency.

B. LOOP ANTENNA

These are basically used to measure low frequency radiated emission (below 30 MHz). At these frequencies the magnetic field strength is measured. Measurements of the magnetic field give better repeatability in the near field region than do measurements of electric field, which is easily perturbed by the nearby objects. The loop is merely a coil of wire, which produces a voltage at its terminals proportional to frequency. A preamplifier is used to match the low impedance of the loop to the 50ohm impedance of typical test instrumentation.

C. NEAR FIELD PROBES

They are used to locate the source of emissions from a product and are used like a “sniffer”. They detect field strength in the near field and are of two types: one for electric field (rod construction) and the other for the magnetic field (loop construction). They can be connected to spectrum analyzer for a frequency domain display or to an oscilloscope for time domain display.

3. FACILITIES

Radiated emissions compliance testing should be done on an open area test site (OATS). The characteristics of a minimum standard OATS are defined in EN55022 (refer last lecture) and in clause 5.6 of CISPR16-1. Such a site offers a controlled RF attenuation characteristics between the emitter and the measuring antenna. In order to avoid influencing the measurement there should be no objects that could reflect RF within the vicinity of the site.; because its impossible to avoid ground reflections , these are regularized by the use of a ground plane.

An extension beyond these dimensions will bring the site attenuation closer to theoretical; scattering from edge contributes significantly to the inaccuracies, although terminating the edges into the surrounding soil can minimize these. The ground plane should preferably be made of solid metal sheets welded together, which however is impractical. Bonded wire mesh is suitable, since it drains easily and resists warping in high temperatures if suitably tensioned.

The measurement distance d between EUT and receiving antenna determines the overall dimensions of the site and hence the expenses. There are three commonly specified distances: 3m, 10m and 30m.

Before performing the emissions testing the validity of the site needs to establish. This is done by measuring the site attenuation by measuring the insertion loss between the terminals of two antennas on a test site, when one antenna is swept over a specified height range and both antenna have the same polarization. This gives an attenuation value in dB at each frequency for which the measurement is performed. Transmit and receive antenna factors are subtracted from this value to give normalized site attenuation (NSA), which should be an indication of the performance of the site, without any relation to the antennas or instrumentation. A measurement site is considered acceptable when the measured vertical and horizontal NSAs are within 4 dB of the theoretical normalized attenuation.

Alternative sites to the standard CISPR open area test site are permitted provided that the errors due to their use do not invalidate the results. Their adequacy is also judged by performing a NSA measurement, which is checked over the volume to be occupied by the largest EUT. As before the acceptability criteria is that none of the measurements shall exceed above 4dB from the theoretical. In order to make measurement valid in screened chamber the walls and ceilings of the chamber must be damped. Covering these surfaces with radio absorbing material does this.

4. TEST METHODS

Test methods are the major part of all basic standards. Because the values obtained from the measurements at RF are so dependent on layout and method, these have to be specified in some detail to generate a standard result. Radiated emissions to EN55022 require the EUT to be positioned so that its boundary is at the specified distance from the measuring antenna. " Boundary" is defined as an imaginary straight-line periphery describing a simple geometric configuration, which encompasses the EUT. A non-floor-standing EUT should be 0.8m above the ground plane. The EUT will need to be rotated through 360º to find the direction of the maximum emission, and this is usually achieved by standing it on a turntable. If it's too big for a turntable, then the antenna must be moved around the periphery while the EUT is fixed.

The catchall requirement in all standards is that the layout, configuration, and operating mode shall be varied so as to maximize emissions. This means some exploratory testing once the significant frequencies have been found, varying all the relevant parameters to find the maximum point. For a complex EUT or one made up of several interconnected sub-systems this operation is time consuming. Even then we must be prepared to justify the final configuration we choose to write in the test report.

5. TEST PROCEDURE

The procedure, which is followed for an actual compliance test, once the configuration, which maximizes emissions, is found out, is straightforward, if somewhat lengthy. Radiated emissions require a quasi-peak sweep from 30Mhz to 1GHz with 120 kHz bandwidth, with the receiving antenna in both horizontal and vertical polarization. EN55022 requires that the six frequencies of highest emission level be reported.

For each significant radiated emission frequency, that is, where the measured level is within say 10 dB of the limit, the EUT must be rotated to find the maximum emission direction and the receiving antenna must be scanned in height from 1 to 4m to find the maximum level. If there are many emission frequencies near the limit this can take a very long time. But the entire operation can also be brought under complete control, which removes the one source of operator error and reduces the test time.

One method to reduce the test time is to do a fast pre-scan using a peak detector. It will take only a few seconds and all frequencies at which the level exceeds some pre-set value can be recorded. These frequencies can then be measured individually, with a quasi peak and/or average detector, and subjecting each one to a height and azimuth scan.

LECTURE 4

CONDUCTED EMISSION

DISCUSSION OF SOURCES OF CONDUCTED EMISSION

Apart from the direct transmission of noise generated inside a system through radiation, it can also be transmitted as conducted energy flowing in either the input, output or control lines connecting the system to its outside environment, where these lines can then become secondary radiators.

This type of emission is predominant at low frequencies; below 30MHz where noise coupling through this mode is highly efficient. Conducted noise is primarily driven by current but is measured by a noise voltage using a 50-ohm shunt.

Interference sources within the equipment circuit or its power supply are coupled onto the power cable to the equipment. Interference may also be coupled either inductively or capacitively from another cable onto the power cable.

The resulting interference may appear as differential mode (between line and neutral, or between signal wires) or as common mode (between line/neutral/signal and earth) or as a mixture of both.

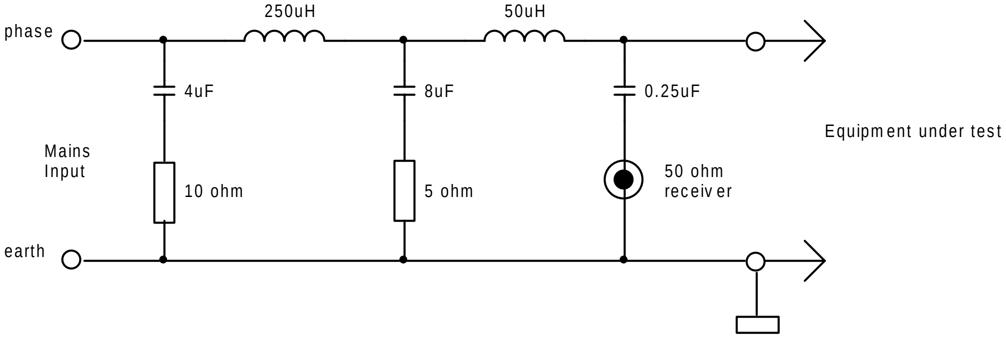
For signal and control lines, only common mode currents are of interest. For the main port, the voltages between each phase/neutral and earth at the far end of the main cable are measured. Differential mode emissions are normally associated with low frequency switching noise from the power supply while common mode emissions can be due to the higher frequency switching components, internal circuit sources or inter-cable coupling.

The contributors to these modes are inherent to the basic operation of a switching power supply. The action of the internal power switches causes rapid di/dt changes in the differential current at both the inputs and outputs of the power supply. Input and output filters ideally would eliminate any high frequency noise external to the power supply but neither can do the job completely. So residual ripple and switching spikes exist as a differential mode noise source with current flow bidirectionally into one terminal and out the other.

There are also sources of rapidly changing voltage within the power supply which can couple noise through parasitic capacitance through earth ground. This type of noise in the ground path, which can be seen as common mode noise on all power supply terminals, is measured with respect with ground. The coupling is dominated by the interwinding capacitance of the isolating transformer and the stray capacitance of the noise sources, both in the power supply (example, from heat sinks) and the operating circuit. These capacitances are referred to earth, either directly or via the enclosure if it is conductive. A well-shielded enclosure will “ minimize “ the leakage of this capacitive coupling and hence reduced conducted emission. Other impedance may appear in the coupling path: an example is the leakage inductance of the isolating transformer.

LISN (Line Impedance Stabilizing Network)

To make conducted voltage emissions tests on the mains port, an LISN is needed to provide a defined impedance at RF across the measuring point, to couple the measuring point to the test instrumentation and to isolate the test circuit from unwanted interference signals on the supply mains. The most widespread type of LISN is defined in CISPR 16-1 and presents an impedance equivalent to 50 ohm in parallel with 50 micro Henry across each line to earth. The impedance of this circuit is not defined above 30MHz, because commercial conducted measurements are not required above this frequency.



Using a spectrum analyzer to measure the noise current through 50-ohm source impedance does diagnostics-using LISN. Typically an LISN network is added to each of the input power lines and noise signals are measured with respect to ground. The LISN on the power lines measures the sum of the common mode and differential mode current while that on the neutral return measures their difference.

METHODS TO CONTOL CONDUCTED EMISSIONS

A. MINIMIZATION OF DIFFERENTIAL MODE NOISE

The conducted noise in differential mode can be controlled by the use of filters. A basic inductor-capacitor filter will be quite effective however there are certain practical aspects of this filter, which needs to be considered.

The first point we need to remember is that the filter is connected across the differential lines. The negative terminal of the filter capacitor is not connected to the ground. One should also keep in mind that the actual filter working would be effected by various parasitic components like ESL and ESR of the capacitor used. In order to reduce the parasitic inductance and resistance of the capacitor used, it is advisable to use many small capacitors in parallel instead of one large one. Parasitic capacitance of the inductor can be reduced if the design accommodates a single layer winding that achieves maximum spacing between the start and finish ends of the coil.

The filter may also resonate resulting in the capacitor voltage to ring to a value that could approach twice the input voltage, possibly damaging the equipment connected. To minimize this effect the filter needs to be damped by using a series RC across the filter’s capacitor.

B. MINIMIZING COMMON MODE GROUND NOISE

Same considerations as discussed above apply to the filter used to minimize the common mode ground noise. An example for the generation and coupling of common mode noise can be the switching transistors in the SMPSs. Presence of parasitic capacitance between drain and ground can generate a significant amount of noise current which flows through the ground to power supply. The problem can be minimized by adding an LC filter in the path of the common mode ground noise with due considerations to the parasitic components. However, the drain terminals of the power switches are certainly not the only place where high dv/dt signals might introduce ground noise. Heat sinks and the transformers are another potential area. In many power supply designs, the secondary side output circuitry is ground referenced, and it therefore follows that any high voltage AC potential on the primary side, which is coupled through the transformer by parasitic capacitance, can become common mode noise.

Providing appropriate electrostatic screens in the transformer and the heat sinks can reduce this type of capacitive coupling. Even if the transformer is not screened, its construction can aid or hinder capacitive coupling from primary to secondary. Separating the windings onto different bobbins reduce their capacitance but increases leakage inductance. An external foil screen connected to 0V will also reduce coupling of the high dv/dt on the outside of the windings to other parts of the circuit.

MEASUREMENT OF CONDUCTED EMISSIONS

A brief discussion of the instruments and the transducers involved in the measurement will be done before actual procedure is discussed.

6. INSTRUMENTATION

C. SPECTRUM ANALYZER :

It is widely used for a quick testing and diagnostics. The analyzer displays the entire spectrum, which gives the amplitude of various spectral components. Hence it can be used to easily find out the frequencies and nature of offending emissions. It can also be used to narrow in on a small part of the spectrum if desired.

D. DETECTOR FUNCTIONS :

There are three detectors in common use in RF emissions measurements: peak, quasi-peak, average.

Interference emissions are rarely continuous at a fixed level. A carrier signal may be amplitude modulated and either a carrier or a broadband emission may be pulsed. The measured level, which is indicated for different types of modulation, will depend on the type of detector in use.

PEAK DETECTOR

The peak detector responds near instantaneously to peak value of the signal and discharges fairly rapidly. If the receiver dwells on a single frequency the peak detector output will follow the “ envelope “ of the signal, hence it is sometimes called an envelope detector.

AVERAGE

The average detector as the name implies, measures the average value of the signal. For a continuous signal this will be the same as its peak value, but a pulsed or modulated signal will have an average level lower than the peak.

QUASI PEAK

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. It 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 the longer and higher the detector stays charged, therefore, higher the level recorded.

The actual value of an interference signal that is measured at a given frequency depends on the bandwidth of the receiver and its detector response. These parameters are rigorously defined in a separate standard that is referenced by all the commercial emissions standards.

CISPR 16-1 splits the measurement range of 9kHz to 1GHz into four bands, and defines a measurement bandwidth for quasi-peak detection, which is constant over each of these bands. Sources of emissions can be classified into narrowband, usually due to oscillator and signal harmonics, and broadband due to discontinuous switching operation, commutator motors and digital data transfer.

The indicated level of a broadband signal changes with the measuring bandwidth. As the measuring bandwidth increases, more of the signal is included within it and hence the indicated level rises. The indicated level of a narrowband signal is not affected by measuring bandwidth. Noise, of course, is inherently broadband and therefore there is a direct correlation between the ”noise floor” of a receiver or spectrum analyzer and it’s measuring bandwidth: minimum noise (maximum sensitivity) is obtained with the narrowest bandwidth.

2.TRANSDUCERS

Transducers are needed to couple the measured variable, which in this case is the conducted noise into the input of the measuring instrumentation.

ARTIFICIAL MAINS NETWORK

An artificial mains network is needed or Line Impedance Stabilizing Network is needed to make conducted voltage emissions tests on the main port. It is used to provide a defined impedance at RF across the measuring point, to couple the measuring point across the rest instrumentation and to isolate the test circuit from unwanted interference signals on the supply mains. (Refer earlier section of the lecture for details of LISN).

7. FACILITIES

By contrast with radiated emissions, conducted measurements need the minimum of extra facilities. The only vital requirement is for a ground plane plane of at least 2m by 2m, extending at least 0.5m beyond the boundary of EUT. It is convenient but not essential to make measurements in a screened enclosure, since this will minimize the amplitude of the extraneous ambient signals, and one wall or floor of the room can then be used as ground plane. Non-floor-standing equipment should be placed on an insulating table 40 cm above the ground plane.

8. TEST METHODS

Test methods are the major part of all basic standards. Because the values obtained from the measurements at RF are so dependent on layout and method, these have to be specified in some detail to generate a standard result.

For conduced emissions, the principal requirement is placement of the EUT with respect to the ground plane and the LISN, and disposition of the mains cable and earth connections. Placement affects the stray coupling capacitance between EUT and the ground reference, which is part of the common mode coupling circuit, and so must be strictly controlled.

It should be kept in mind while testing that the layout, configuration and operating mode will be such as to maximize the emissions. This means some exploratory testing once the significant emission frequencies have been found, varying all of the above parameters –and any other which might be relevant – to find out the maximum point. For a complex EUT or one made up of several interconnected subsystems this operation is time consuming. Even then we must be prepared to justify the configuration we choose.

9. TEST PROCEDURE

The procedure, which is followed for an actual compliance test, once the configuration, which maximizes emissions, is found out, is straightforward, if somewhat lengthy. Conducted emissions require a continuous sweep from 150Khz to 30MHz with 9KHz bandwidth, once with a quasi peak detector and once with average detector. If the average limits are met with the quasi-peak detector there is no need to perform the average sweep. EN55022 requires that the six frequencies of highest emission level be reported.

One method to reduce the test time is to do a fast pre-scan using a peak detector. It will take only a few seconds and all frequencies at which the level exceeds some pre-set value can be recorded. These frequencies can then be measured individually, with a quasi peak and/or average detector, and subjecting each one to a height and azimuth scan.

LECTURE 5

IMMUNITY

All types of electronic equipment will be susceptible to environmental electromagnetic fields and the disturbances, which are coupled into its ports via, connected cables. The potential threats to the electronic equipment are:

- Radiated RF fields
- Conducted transients
- Electrostatic discharge
- Magnetic fields
- Supply voltage disturbances

Apart from satisfying legal requirements, a design which complies with the requirements for immunity from the above mentioned effects will save the manufacturer from considerable costs.

A discussion of these factors will be considered one by one.

1. Radiated Field

An external stray electromagnetic field can couple either directly with the internal circuitry and wiring in differential mode or with cables to induce common mod current. Coupling with internal wiring and the PCB tracks is most efficient at frequencies above a few hundred MHz, since wiring lengths of a few inches approach resonance at these frequencies.

RF voltages or currents in analogue circuits can induce nonlinearity, overload or DC bias and in digital circuits can corrupt data transfer. Modulated fields can have greater effect than unmodulated ones. Likely sources of the radiated electromagnetic fields are walkie-talkies, cellphones, high-power broadcast transmitters and radar. Field strengths between 1 and 10 V/m from 20MHz to 1GHz are typical, and higher field strengths can occur in environments close to such sources.

Cables are most efficient at coupling RF energy into equipment at the lower end of the vhf spectrum. The external field induces a common mode current on the cable shield or on all the cable conductors together, if it is unshielded.

A cable connected to grounded victim equipment can be modeled as a single conductor over a ground plane, which appears as a transmission line. The current induced in such a transmission line by an external field increases steadily with frequency until the first resonance is reached, after which it exhibits a series of peaks and nulls at higher resonance. The coupling mechanism is enhanced at the resonant frequency of the cable, which depends on its length and on the reactive loading of whatever equipment is attached to its end.

A convenient method for testing the RF susceptibility of equipment without reference to its cable configuration is to inject RF as a common mode current or voltage directly onto the cable port. The route taken by the interference currents, and hence their effects on the circuitry, depends on the various external and internal RF impedance to earth.

2. Transients

Transient overvoltages occur on the mains supply leads due to switching operations, fault clearance or lightning strikes elsewhere on the network. Transients over 1kV account for about 0.1% of the total number of transients observed.

High-energy transients may threaten active devices in the equipment power supply. Fat rising edges are most disruptive to the circuit operations, since they are attenuated least by the coupling paths and they can generate large voltages in the inductive ground and signal paths.

Analog circuits are almost immune to isolated short transients, whereas they easily corrupt digital circuits.

Mains transients are may appear in differential mode or common mode. Coupling between the conductors in a supply network tends to mix the two modes. Differential mode spikes are usually associated with relatively slow rise times and high energy, and require suppression to prevent input circuit damage but do not, provided this suppression is incorporated, affect circuit operation significantly. Common mode transients are harder to suppress because they require connection of suppression components between live and earth, or in series with the earth lead, and because stray capacitances to earth are harder to control. Their coupling paths are very similar to those followed by common mode RF signals. They are also more disruptive because they result in transient current flow in the ground traces.

Transient interference is inherently broadband, and its amplitude spectral density describes its frequency distribution: that is, the amplitude over a defined bandwidth vs frequency. This makes the definition of energy content of transients and surges not very simple to define.

3. Electrostatic discharge

When two non-conductive materials are rubbed together or separated, electrons from one material are transferred from one material to the other. This results in the accumulation of triboelectric charge on the surface of the material. The amount of charge caused by the movements of the materials is a function of the separation of the materials in the triboelectric series. Additional factors are the closeness and area of contact, and rate of separation.

The voltage to which an object can be charged depends on its capacitance. The rate at which the charge will bleed off a charged body to its surroundings, and so become neutralized, depends on the surface resistivity of the body and its surroundings. This in turn is a function of the relatively humidity: the more moisture there is in the air, the lower the surface resistivity of insulators and hence quicker that charges bleed away.

When the body approaches a conductive object, the charge is transferred to that object normally via a spark, when the potential gradient across the narrowing air gap is high enough to cause breakdown. The energy involved in the charge transfer may be low enough to be imperceptible to he subject; at the other extreme it can be extremely painful. It is not essential that the target object is grounded. Charge transfer can occur between any two capacitive objects as long as there is a static potential difference between them, and a disruptive discharge current pulse will flow.

When an electrostatically charged object is brought close to a grounded target the resultant discharge current consists of a very fast edge followed by a comparatively slow bulk discharge curve. The characteristics of the hand/metal ESD current waveform are a function of the approach speed, the voltage, the geometry of the electrode and the relative humidity.

The discharge current pulse di/dt and its indirect effects produce the principal effects of an ESD in terms of equipment malfunction. The rate of change of electric field dE/dt when the local static charge voltage collapses can also couple capacitively into high impedance circuits, and in some circumstances the high static electric field itself, before a discharge happens, may cause undesirable effects.

The resultant sub-nanosecond transient equalizing current of several tens of amps follows a complex route to ground through the equipment and is very likely to upset digital circuit operation if it passes through the circuit tracks. The paths are defined more by stray capacitance, case bonding and track or wiring inductance than by the designer’s intended circuit. The high magnetic field associated with the current can induce transient voltages in nearby conductors that are not actually in the path of the current. Even if not directly discharged to the equipment, a nearby discharge such as to metal desk or chair will generate an intense radiated field, which will couple onto the unprotected equipment.

Critical areas, which can act as sink points for the ESD are, exposed metalwork, apertures, front panel components and connectors. Components and apertures can allow a discharge to take place via creepage across a surface to the circuits inside an enclosure, even if the enclosure itself is insulating.

A common problem arises when a product enclosure is connected externally to ground at a different point and via a different route than the internal circuit. Because of the inductance of the various connections, a transient voltage will appear inside the enclosure, between the enclosure and the circuit. This voltage can then cause a secondary discharge to occur at unpredictable points inside the enclosure, which can be much more damaging and disruptive than the source discharge, since there is a lower impedance to limit the current, and also because a higher induced voltage occurs on a PCB track when an ESD occurs within a resonant structure.

4. LF Magnetic fields

Magnetic fields at low frequencies can induce interference voltages in closed wiring loops, their magnitude depending on the area that is intersected by the magnetic field. Non-toroidal mains transformers and switch mode supply transformers are prolific sources of such fields and they will readily interfere with sensitive circuitry or components within the same equipment. Any other

equipment needs to be immune to the proximity of such sources.

50 Hz currents in supply conductors are typical sources of magnetic fields. If the currents in the cable are balanced, that is, the cable carries live and neutral together or all three phases together, then at a distance the magnetic fields from each conductor cancel and the net field is near zero. Close in to the cable though, the fields do not cancel perfectly since their source conductors are located at slightly different positions. The fields also will not cancel if the currents are not balanced, that is, there is some return path outside the cable.

It is rare for such fields to affect digital or large signal analog circuits, but they can be troublesome with low level circuits where the interference is within the operating bandwidth, such as audio or precision instrumentation.

Conventional screening is ineffective against LF magnetic fields, because it relies on reflection rather than absorption of the field. Due to the low source impedance of the magnetic fields reflection loss is low. Since it is only the component of flux normal to the loop, which induces a voltage, changing the relative orientation of source and loop may be effective. LF magnetic shielding is only possible with materials, which exhibit a high absorption loss such as steel, mu-metal or permalloy. As the frequency rises these materials lose their permeability and hence shielding efficiency, while non-magnetic materials such as copper or aluminum become more effective.

5. Supply voltage disturbances

Voltage dips and interruptions are a feature of all mains distribution networks, and are usually due to fault clearing or load switching elsewhere in the system. Such events will not be perceived by the ordinary electronic equipment if its input reservoir hold up time is sufficient, but if this is not the case then restarts and output transients can be experienced. Thyristor inverters may experience commutation failure and synchronous devices may lose synchronism.

Heavy industrial loads such as resistance and arc welding machines, large motors and arc furnaces can cause short term step or random fluctuations and can effect many consumers fed from the same source. The main effect of these disturbances is flicker of lamp loads, which can cause physiological discomfort. Electronic power supply circuits can normally be designed to ignore them, although other circuits which use the 50Hz signal should have their operating bandwidth severely restricted by a 50Hz bandpass filter to ensure immunity from low-amplitude step changes.

ANALOG DESIGN METHODS TO ENHANCE IMMUNITY

Analog circuits are susceptible to demodulation of RF energy, which results in measurement non-linearities or non-operation due to shift in DC bias. Improvements in RF immunity result from attention to the following four areas.

- Minimize circuit bandwidth
- Maximize signal levels
- Ensure a good circuit stability margin
- Use balanced circuit configuration
- Isolate particularly susceptible path

A discussion of all the factors involved will be done now.

A. EFFECT OF WIDE BANDWIDTH

When a circuit is fed an RF signal that is well outside its normal bandwidth, the circuit can respond either linearly or nonlinearly. If the signal level is low enough for it to stay linear, it will pass from input to output without affecting the wanted signals or the circuit’s operation. If the level drives the circuit into non-linearity, then the envelope of the signal will appear on the circuit’s output. At this point it will be inseparable from the wanted signal and the wanted signal will be affected by the circuit’s forced non-linearity. The response of the circuit depends on its linear dynamic range and on the level of the interfering signal. All other factors being equal, a circuit which has a wide dynamic range will be more immune to RF than one which has not.

Restricting the operating bandwidth of the minimum acceptable can reduce the level of the interfering signal. Input RC or LC filtering, feedback RC filtering and low value capacitors or resistors directly at the input terminals can achieve this. If an increased input resistance would consequently be too high and might affect circuit dc conditions, a lossy ferrite cored choke or bead is an alternative series element.

B. STABILITY

If a given circuit is close to oscillation but not actually unstable at a particular radio frequency, this is equivalent to saying that it has a peak in its frequency response at that frequency and the circuit is said to quasi stable. If an interfering RF signal is applied at this peak the amplifier will happily respond to it, most probably saturating and corrupting its desired signal. This is not n uncommon occurrence particularly on conducted immunity test.

Apart from the inadequate design of the feedback circuitry, amplifier instability is usually a result of bad circuit layout or poor supply decoupling. Particular attention needs to be paid to these aspects in wideband devices.

C. ISOLATION

Signals may be isolated at input or output with either an optocoupler or a transformer. Isolation breaks the electrical ground connection and therefore substantially removes common mode noise injection, as well as allowing a DC or low frequency AC potential difference to exist. However there is still a residual coupling capacitance between primary and secondary which will comprise the isolation at high frequencies or high rates of common mode dv/dt.

Electrostatically screened transformers and opto-couplers are available where the screen reduces the coupling of common mode signals into the receiving circuit, and hence improves the common mode transient immunity of that local circuit. This improvement is gained at the expense of increasing the overall capacitance across the isolation barrier and hence reducing the impedance of the transient or RF coupling path to the rest of the unit. A somewhat expensive solution to this problem is to use two unscreened transformers in series, with the intervening coupled circuit separately grounded.

LECTURE 6

STANDARDS

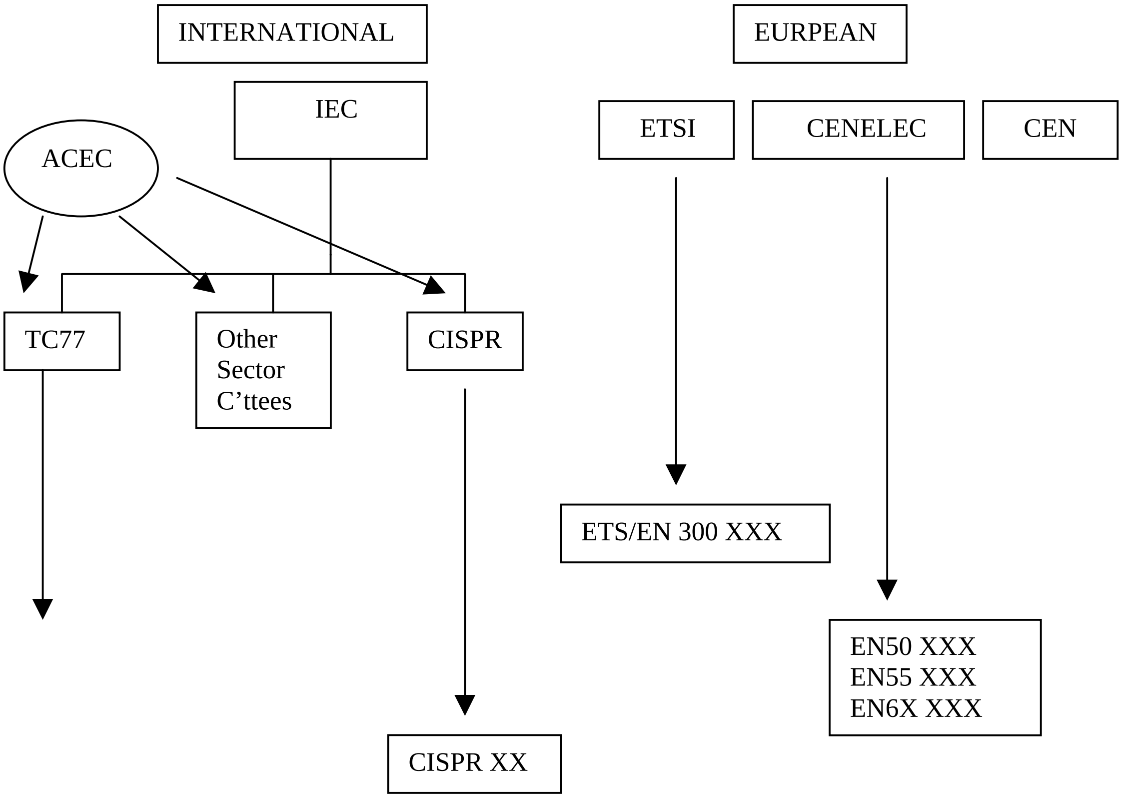
The relaxed EMC regime that had hitherto existed throughout most of Europe's now been totally overturned with the adoption on 1st January 1992 by the European commission of the EMC directive, 89/336/EEC. This is widely regarded as the most comprehensive, complex and possibly contentious Directive ever to emanate from Brussels. The provisions of the Directive are discussed in brief herein.

Of the various aims of the creation of the Single European market, the free movement of goods between European states is fundamental. All the member states impose standards and obligations on the manufacture of goods in the interests of quality, safety, consumer protection and so forth. Because of detailed differences in procedures and requirements, these act as technical barriers to trade, fragmenting the market and increasing costs because manufacturers have to modify their products for different national markets.

For many years the commission tried to remove these barriers by proposing Directives which gave the detailed requirements that products had to satisfy before they could be freely marketed, but this proved difficult because of the detailed nature of each Directive and the need for unanimity before it could be adopted. In 1985 the council of ministers adopted a resolution setting out a " New approach to technical harmonization and Standards".

Under the new approach, directives are limited to setting out the essential requirements which must be satisfied before products may be marketed anywhere inside the EU. The technical details are provided by the standards drawn up by the European standard bodies CEN, CENELEC and ETSI. Compliance with these standards will demonstrate compliance with the essential requirements of each Directive. All products covered by each Directive must meet its essential requirements, but all products, which do comply, and are labeled as such, may be circulated freely within the community; no member state can refuse them entry on technical grounds. Qualified majority voting, eliminating the need for unanimity and speeding up the process of adoption takes decisions on new approach directives.

The structure of the bodies, which are responsible for defining EMC standards for the purposes of the EMC directive, is shown below:



1. **The International Electrotechnical Commission**

The IEC operates in close co-operation with the International Standards Organization and in 1990 had 41 member countries. It is composed of National Committees, which are expected to be fully representative of all electrotechnical interests in their respective countries. Work is carried out in technical committees and their subcommittees addressing particular product sectors. Two IEC technical committees are devoted full time to EMC work. They are TC77 and CISPR. Co-ordination of the IEC's work on EMC between the many committees involved is the responsibility of ACEC, which is expected to prevent the development of conflicting standards.

2. CENELEC and ETSI

CENELEC is the European standards making body, which has been mandated by the Commission of the EC to produce EMC standards for use with the European EMC Directive. For telecommunications equipment ETSI is the mandated standards body. ETSI generates standards for telecomm network equipment that is not available to the subscriber, and for radio communications equipment and broadcast transmitters.

Various standards put forward by CENELEC relevant to emissions are as follows:

1. **EN 50081 part 1 : 1992**

Generic Emission Standard, part 1: Residential, commercial and light industry environment.

2. **EN 50081 part 2 : 1993**

Generic emission standard, part 2: industrial environment.

3. **EN 55011: 1998 + A1: 1999**

Industrial, scientific and medical radio-frequency equipment-radio disturbance characteristics – Limits and methods of measurement

4. **EN 55014-1:1993 +A1:1997+A2:1999**

Electromagnetic compatibility – requirements for household appliances, electric tools and similar apparatus

5. **EN55022: 1998**

Information technology equipment – radio disturbance characteristics

Some of the standards relevant to the immunity are as follows:

1. **EN 50082 part1: 1997**

Generic immunity standard, part1: residential, commercial and light industry environment

2. **EN50082 part2 : 1995**

Generic immunity standard, part2: industrial environment

Some of the product related standards are as follows:

1. **Broadcast receivers and associated equipment**

Emissions: EN 55013: 1990 + A12, A13, A14

Immunity: EN 55020: 1994 + A11, A12, A13, A14

2. **Household appliances, electric tools and similar apparatus**

Emissions: EN55014-1
Immunity: EN 55014-2: 1997

3. Lighting Equipment

Emissions: EN 55015 : 1996 + A1,A2
Immunity: EN61547: 1995

4. Information technology Equipment

Emissions: EN 55022: 1998
Immunity: EN 55024: 1998

5. Professional AV and entertainment lighting equipment

Emissions: EN 55103-1:1996
Immunity: EN 55103-2: 1996

6.Equipment for measurement, control and laboratory use

Emissions and Immunity: EN 61326: 1997 + A1: 1998

7.Fire, intruder and social alarm systems

Emissions: No explicit standard

Immunity: EN 50130-4: 1995 + A1: 1998

8. Telecommunication network equipment

Emissions and Immunity: En 300386-2: 1997

9. Radio equipment

Emissions and Immunity: EN 301489-1: 2000

10. Adjustable speed electrical power drive systems

Emissions and Immunity: En 61800-3: 1996 + A11: 2000

11. Medical electrical equipment

Emissions and immunity: EN 60 601-1-2: 1993

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