DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

EMC TESTING TECHNIQUES AND SIMPLE MODIFICATION METHODS FOR DECREASING THE INTERFERENCE AT TELEVISIONS

by
Emre GÖKSAL

May, 2011
İZMİR

EMC TESTING TECHNIQUES AND SIMPLE MODIFICATION METHODS FOR DECREASING THE INTERFERENCE AT TELEVISIONS

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"EMC TESTING TECHNIQUES AND SIMPLE MODIFICATION METHODS FOR DECREASING THE INTERFERENCE AT TELEVISIONS"** completed by **EMRE GÖKSAL** under supervision of **Asst. Prof. Dr. GÜLDEN KÖKTÜRK** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Emre GÖKSAL

EMC TESTING TECHNIQUES AND SIMPLE MODIFICATION METHODS FOR DECREASING THE INTERFERENCE AT TELEVISIONS

ABSTRACT

In this thesis, a guide for the headline of electromagnetic compatibility (EMC) has tried to be successfully exhibited. Electromagnetic compatibility is the branch of electrical sciences which study the unintentional generation, propagation and reception of electromagnetic energy with reference to the unwanted effects (Electromagnetic interference, or EMI) that such energy may induce. The goal of EMC is the correct operation, in the same electromagnetic environment, of different equipment which uses electromagnetic phenomena, and the avoidance of any interference effects. In order to achieve this, EMC pursues two different kinds of issues.

Most of the thesis and documents focuses on special aspects of EMC; in this thesis I have tried to explain EMC towards more general and more useful information. I used to gather the special resources including my personal experience which was gained while my working time in Vestel Electronics. Within this thesis I attempted to provide a source for engineers to have quick discovery for focus of the problem and apply corrective actions. EMC troubleshooting is both a skill and an art that must be mastered over the course of time as the other engineering branches. In spite of specialty, all designers must research and develop the most suitable product for production. In the world, system merging is generally allocated to research and development (R-D) engineers, industrial and mechanical engineers, and the EMC engineer always the last person who has participated in the product design. I also try to accomplish a design procedure for electronics applications. Thus it becomes a useful guide for the design for ensuring the compliance for EMC with minimal cost. Thesis is prepared for general application of electronics, but the main property and specialty of this thesis is the clear procedure for a specific topic that is EMC which takes a big role in consumer electronics.

Keywords: electromagnetic, interference, electromagnetic compatibility, troubleshooting, engineering, design, modification, EMC testing, emission, immunity.

ELEKTROMANYETİK UYUMLULUK TEST TEKNİKLERİ VE TELEVİZYONLARDA GÜRÜLTÜYÜ AZALTMAK İÇİN BASİT MODİFİKASYON METODLARI

ÖZ

Bu tezde, elektromanyetik uyumlandırma (EMU) ve uyumlandırma organizasyonu başlıkları altında bir kılavuz başarılı bir şekilde sunulmaya çalışılmıştır. Elektromanyetik uyumlandırma elektromanyetik enerjinin, böylesine bir enerjinin endükleyebileceği istenmeyen etkiler (Elektromanyetik kirlilik , veya EMK) referans alınarak üretimi, yayılımı ve tepkilerini inceleyen elektriksel bilimin bir dalıdır. EMU'nun amacı, aynı elektromanyetik ortamda bulunan elektromanyetik fenomeni üzerine çalışan değişik ekipmanların düzgün çalışmasını sağlamak ve doğabilecek herhangi bir girişim etkisini önlemektir. Bunu başarmak adına EMU'yu iki farklı ana başlık altında sürdürürüz.

Çoğu tez ve makale EMU'nun özel yönleri üzerine odaklanmıştır; ben bu tez ile EMU'yu daha genel ve kullanılabilir bilgiler doğrultusunda anlatmaya çalıştım. Vestel Elektronikte çalışırken edindiğim kişisel deneyimlerde dahil olmak üzere özel kaynakları birarada toplamayı uygun buldum. Bu tez ile birlikte mühendislere problemlerin kaynağını hızlı bir şekilde araştırmak ve düzeltici aksiyonları uygulayabilmek adına bir kaynak sağlamaya çalıştım. EMU sorunlarını gidermek diğer mühendislik alanlarında olduğu gibi belirli bir zaman diliminde uzmanlaşılabilecek bir yetenek ve sanattır. Tüm tasarımcılar özellikli bir ürün yerine üretmek için en uygun ürünü araştırmalı ve geliştirmelidir. Dünyada sistem entegrasyonu sırasında genellikle Ar-Ge mühendisleri, endüstri ve makine mühendisleri ve maalesef EMU mühendisleri, ürün dizaynı sırasında ilişkilendirilen son kişiler olarak, yayılım göstermektedir. Bunun yanı sıra elektronik uygulamalar için bir dizayn prosedürü oluşturmaya çalıştım. Bu sebeple minimum maliyet ile EMU' ğu sağlamak için önemli bir kaynak haline geliyor. Tez genel olarak elektronik uygulamalar için yazılmış olsa da, bu tezin temel özelliği ve uzmanlık alanı tüketici elektroniği konusunda önemli bir rol oynayan EMU başlığı altında basit bir prosedür oluşturmaktır.

Anahtar Sºzc¿kler: elektromanyetik, kirlilik, elektromanyetik uyumlandırma, sorun giderme, mühendislik, dizayn, EMU testleri, ışınım, bağışıklık.

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CHAPTER ONE
INTRODUCTION

EMC means nothing more than "an electronic or electrical device shall work as intended in its environment". The electronic or electrical product shall not generate electromagnetic disturbances, which may influence other products". In other words, EMC deals with problems of noise emission as well as noise immunity of electronic and electrical products and systems. Electromagnetic disturbances can occur like conducted interference as well as radiated emissions and immunity problems. (What is emv, emc basics, (2009). www.emtest.com)

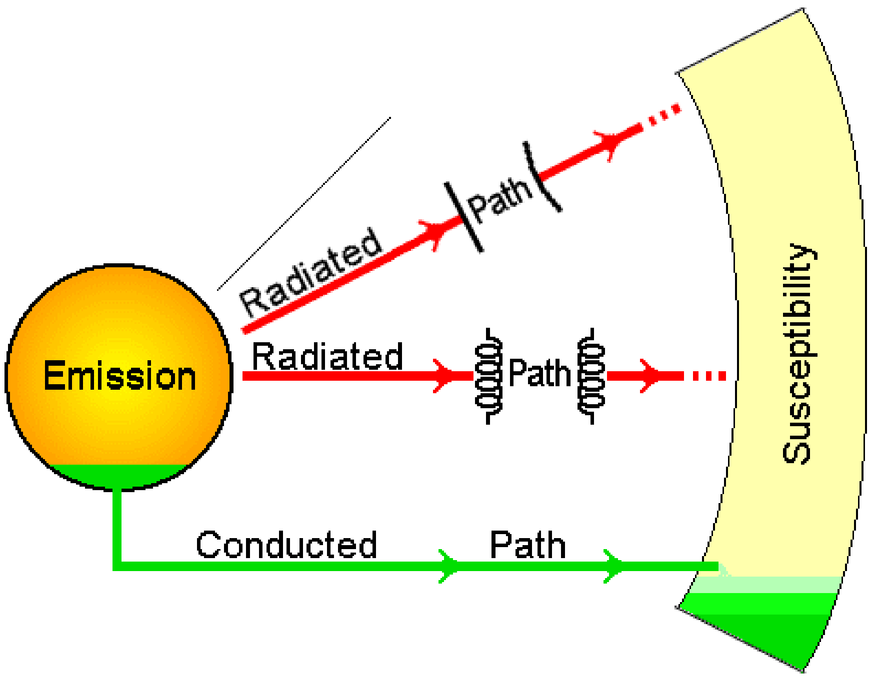


Figure 1.1 Block diagram depicting the EMC paradigm (emc-11, http://www.williamson-labs.com/ltoc/glencoe-.htm)

When we started to travel in the history of EMC, we can easily observe that EMC is older and detailed than all we experienced in our daily and working life. We are all living with our history. The same is for EMC. You may not know, as many EMC experts also do not know, how everything was started. We want to give you a short summary of the history of EMC in Europe. The following is not given in great detail, but it does illustrate why we are where we are today in the EMC world.

More than 110 years ago EMC was not a big matter but this was changed immediately in the evening of December 22, at 1920. On this night, the radio station of König Wusterhausen southeast of Berlin broadcasted the Christmas concert of the German mail officials. The concert was a live event and the audience included the German Chancellor Hermann Müller, who was close to the concert location in the famous castle of König Wusterhausen. The Chancellor was not very amused by the electrical noise interference generated by vehicles passing by and he gave strict orders to immediately prevent such disturbances. The hour of "Radiated Emission" had come and was then later on called EMC. The history of the effects of EMI leans to 2nd World War. It was also a problem in the war while those times it was called as Radio Frequency Interference (RFI). Spectrum of communication transmitters and receivers were developed along with radar systems. Because of the size and expense of the equipment that military owned, the high-technology electronic systems started to have unstable operations. (What is emc, (2010). http://www.emtest.com)

Germany was among the first to recognize the need to prevent and solve the problems of radiated emissions. In 1933, the international committee for radiated emissions, better known as CISPR was founded. Late in the 60's, concrete investigations were made to deal with the immunity of electrical products. In 1973 the International Electro technical Commission, the IEC, founded the technical committee TC77 whose function is to develop standards related to EMC.

In the 2nd World War knowledge of electromagnetic waves and their ability to create disturbances was used. During the war, radar technology was developed. Not only did the new communication technologies of radio, television and telephone require electromagnetic compatibility, they were the driving force in changing from tube technology to transistors. The evolution of highly integrated chip technologies requires a broad understanding and use of EMC design experience.

No electrical product or installation can be designed seriously unless all aspects of EMC are taken into account. This is not only important for common products such as radios, television sets, computers, telephones, washing machines, etc., but it is also especially important for complex products such as vehicles, aircraft, and ships. These are very sensitive to EMC problems and no one wants to accept serious disturbances within a big chemical plant. Because of all the efforts made and being made to insure EMC compatibility, people start to believe that, after a time, all products are safe and immune. Of course this has not come true as yet. Each generation of engineers and technicians are again challenged by the issue of EMC with each new product. Practical solutions to EMC problems are not taught at universities. This can only be achieved with many years of experience in the field and testing sites. (http://www.emtest.com/what_is/emv-emc-basics.php)

1.1 Why Electromagnetic Compatibility

All the electrical and electronic products unwontedly produce radio frequency (RF) energy. Every digital product has the possibility of inducing accidental interference to other devices. We are using electrical products in every part of our lives, such as all communication types, all types of entertainment, transportation and life support, are a few examples. From all these items listed, communication systems and life support are listed as highest ranked in the areas interested when disturbance from unintentional sources of electromagnetic energy.

Controlling the EMC issue is an increasing necessity. Correct application of design rules ensures reliable operation, minimizes conditional risk, reduces timescales, and helps meeting directory requirements. The best time to think about all aspects of EMC is during the preliminary design cycle, a long time before the first step of the circuit have been taken on a schematic, the first instruction written for a software program, or the outline of a mechanical chassis drawn. Management must also buy into the EMC arena if an early product shipment date is desired.

As digital logic devices were increasingly developed for consumer systems, EMI became a wider concern. Research was started to characterize EMI in consumer electronics that included TV sets, common amplitude and frequency modulated (AM/FM) radios, medical devices, audio and video recorders, and similar products. Comparatively few of these products were digital, but were becoming so. Analog systems are more susceptible to problems than digital equipment.

In the late 1970s, problems associated with EMC became an issue for additional products. These products include home entertainment systems (TVs, VCRs, and camcorders), personal computers, communication equipment, household appliances with digital features, intelligent transportation systems, sophisticated commercial avionics, control systems, audio and video displays, and numerous other applications. (Testing For EMC Compliance Approaches and Testing - Mark I. Montrose, Edward M. Nakauchi)

After the clearance of the concept, product testing makes people feel more comfortable during the design. Understanding how testing system works and which measured data are valid and accurate will guide the design for defending the electronic devices from some kind of tests.

1.2 The Necessary Definitions

Electromagnetic Compatibility is the capability of electrical and electronic systems, equipment, and devices to operate in their intended electromagnetic environment within a defined margin of safety and at design levels or performance without suffering or causing unacceptable degradation as a result of electromagnetic interference.

Electromagnetic Interference is the routine which disturbing electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths (or both). In common usage, the term refers particularly to RF signals; however, EMI is observed throughout the EM spectrum.

Radio Frequency is a frequency range containing coherent EM radiation of energy useful for communication purposes roughly the range from 9 kHz to 300 GHz. This energy may be emitted as a "by product" of an electronic device's operation. Radio frequency is emitted through two basic mechanisms:

Radiated E missions: The component of RF energy that is emitted through a medium as an EM field. Although RF energy is usually emitted through free space, other modes of field transmission may be present.

Conducted Emissions: The component of RF energy that is emitted through a medium as a propagating wave generally through a wire or interconnect cables.

Susceptibility – Immunity is a relative measure of a device or a system's propensity to be disrupted or damaged by EMI exposure to an incident field. It is the lack of immunity. Immunity is a relative measure of a device or system's ability to withstand EMI exposure while maintaining a predefined performance level.

Electrostatic Discharge (ESD) is a transfer of electric charge between bodies of different electrostatic potential in proximity or through direct contact. This definition is observed as a high-voltage pulse that may cause damage or loss of functionality to susceptible devices.

Radiated Immunity is a product's relative ability to withstand EM energy that arrives via free - space propagation.

Conducted Immunity is a product's relative ability to withstand EM energy that penetrates through external cables, power cords, and input - output (I/O) interconnects.

Spectrum Analyzer is an instrument primarily used to display the power distribution of an incoming signal as a function of frequency, useful in analyzing the characteristics of electrical waveforms.

Oscilloscope is an instrument primarily used for making visible the instantaneous value of one or more rapidly varying electrical quantities as a function of time.

Impedance Stabilization Network (LISN) is a network inserted in the supply mains load of a device to be tested that provides, in a given frequency range, a specified load impedance for the measurement of disturbance voltages. And which may isolate the apparatus from the supply mains in that frequency range also identified as an “artificial mains network.”

Antenna is a device used for transmitting or receiving EM signals or power which is designed to maximize coupling to an EM field. In the list below there are some antenna types.

1.3 Basics of Interference

Basically EMC separated into two categories: internal and external. The internal part is the result of signal humiliation on a transmission road, field coupling between internal subassemblies (such as a power supply to a disk drive) and also including parasitic coupling between circuits (i.e., crosstalk).

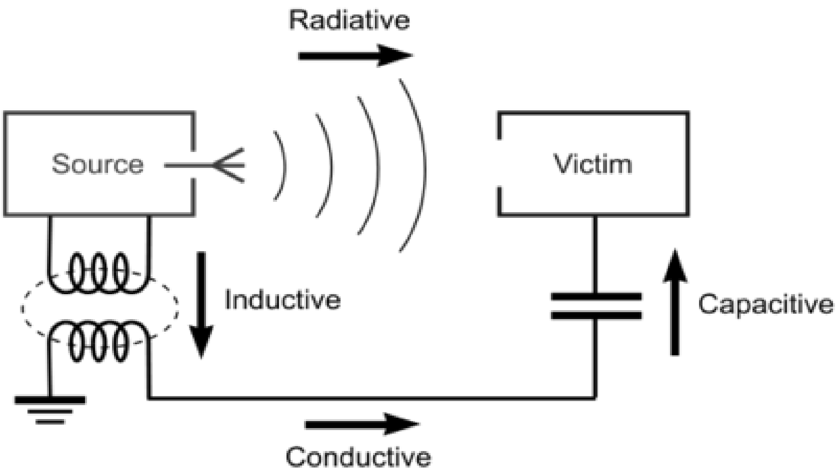


Figure 1.2 The four electromagnetic interference coupling modes (Coupling Mechanisms, (2009). http: en.wikipedia.org/wiki)

External reciprocal actions are divided into emission and immunity. Emissions are produced, for example, from harmonics of clocks or other periodic signals. The cures focuses on containing the periodic signal to as small an area as possible, trying to block parasitic coupling paths to the outside world.

Susceptibility to outer influences such as ESD or RFI is directly related to propagation of fields that couple into I/O lines which are transferred to the inside of the unit and after that to case shielding. As a summary electromagnetic interference has to be prevented on a PCB for two basic reasons; one of the reasons is to provide signal integrity. Parasitic coupling between circuits including crosstalk and field coupling between other internal assemblies in the product have to be reduced for signal integrity. Other reason is the external interactions which are related to emission testing of a product. Studies should concentrate on containing the periodic and high frequency signals to as small area as possible, and blocking parasitic sources and coupling paths from the outside world.

There are five major headlines when performing EMC on a product or design:

- *Frequency:* In which part of the frequency spectrum is the problem observed?
- *Amplitude:* What is the magnitude of the source energy level and how big is its potential to create harmful disturbance?
- *Time:* Is the problem continuous (by the mean periodic signals) or does it exists only at some cycles of the operation (e.g., disk drive write operation)?
- *Impedance:* What is the impedance of both the receptor and the source, the impedance of the whole transmission mechanism (related to separation distance, which affects the impedance of the wave) and the real impedance between the two?
- *Dimensions:* How big or small is the emitting device that causes emissions to be observed? What is its total dimension? For example, diverted trail lengths on a PCB have a relationship as transmission ways for RF currents.

When designing a PCB for use within a product, we are concerned with RF current flow. Current is preferable to voltage for a simple reason, 'Current always travels around a closed loop circuit following one or more paths'. To control the path in which the current flows, we must provide low impedance, RF return path back to the source of the energy.

1.3.1 Continuous Interference (http: en.wikipedia.org/wiki/Electromagnetic-compatibility)

Continuous Interference arises where the source regularly emits a given range of frequencies. This type is naturally divided into subcategories according to frequency range.

- Audio Frequency, from very low frequencies up to around 20 kHz. Frequencies up to 100 kHz may sometimes be classified as Audio. Sources include mains hum from power supply units, nearby power supply wiring, transmission lines and substations.

- Radio Frequency Interference, RFI, from 20 kHz to a limit which constantly increases as technology pushes it higher. Sources include:
    - Wireless and Radio Frequency Transmissions
    - Television and Radio Receivers
    - Industrial, scientific and medical equipment
    - High Frequency Circuit Signals (For ex. microcontroller activity)

- Broadband noise may be spread across parts of either or both frequency ranges, with no particular frequency accentuated. Sources include:
    - Solar Activity.
    - Continuously operating spark gaps such as arc welders.

1.3.2 Pulse or Transient Interference (http: en.wikipedia.org/wiki/Electromagnetic-compatibility)

Electromagnetic Pulse, EMP, also sometimes called Transient disturbance, arises where the source emits a short duration pulse of energy. The energy is usually en.wikipedia.org/wiki/)

Sources divide broadly into isolated and repetitive events.

- Sources of isolated EMP events include:
  - Switching action of electrical circuitry.
  - Electrostatic Discharge (ESD), as a result of two charged objects coming into close proximity or even contact.
  - Lightning Electromagnetic Pulse (LEMP)
  - Nuclear Electromagnetic Pulse (NEMP), as a result of nuclear explosion.
  - Non-Nuclear Electromagnetic Pulse (NNEMP) weapons.
  - Power Line Surges/Pulses
- Sources of repetitive EMP events, sometimes as regular *pulse trains*, include:
  - Electric Motors
  - Gasoline engine ignition systems
  - Electric Fast Transient / Bursts (EFT)

1.4 Brief Description for Product Testing

The clearance of the concept, the beforehand analyzation of product testing makes engineers feel more comfortable during the design period. Understanding how EMC testing system works and which of the data measured are appropriate, valid and accurate. These powerful acknowledge will guide the engineer's design to defense the product from some serious cases of EMC aspect.

1.4.1 Testing Conditions

While we are trying to analyze an EMC event, the most significant role may be played with where the product is physically located, in either producing problem or preventing another problem from happening. Recognization techniques may sometimes be hard to execute. The first cycle of product testing or troubleshooting is to work out if undesired electromagnetic fields are caused by radiated or conducted systems.

The most difficult part in conducting tests in an industrial environment is that other products located in close proximity may be identical or similar in build. For example a big company office complex has many personal computers and networking equipment. If the main network hub installed in a wiring closet is having some functional or interference problems, it may be not useful to directly remove the hub and send it back to repair. The cause might not be about the hub but from a large number of personal computers working at similar frequencies causing a complex set of radiated emission events. The computers are the problem, but the hub could be damned about the problem.

For European Unions, the Parliament has made a law which legally interprets a rule that all electrical devices have to comply with both emission and immunity levels of protection. When the compliant finished with the corresponding test standards, the equipment is marked with CE (Conformity European) logo.

1.4.2 Self Compliance

Any system may also not have a perfect compliance in itself. This situation is generally thought as self jamming. As an example a PCB is functionally disrupted, is the problem caused by software, firmware, or hardware? All the responsible people may be called upon to have self check for their design, and each one asserting that their part of the design is in perfect condition and that another one is responsible for fixing the system. Electromagnetic disturbance is generally caused by “glitches.” Glitches are temporary peaks or spikes occurred in a digital component or connected transmission lines due to EM field coupling. Figure 12.1 shows various aspects of high speed digital signals and how errors can arise.

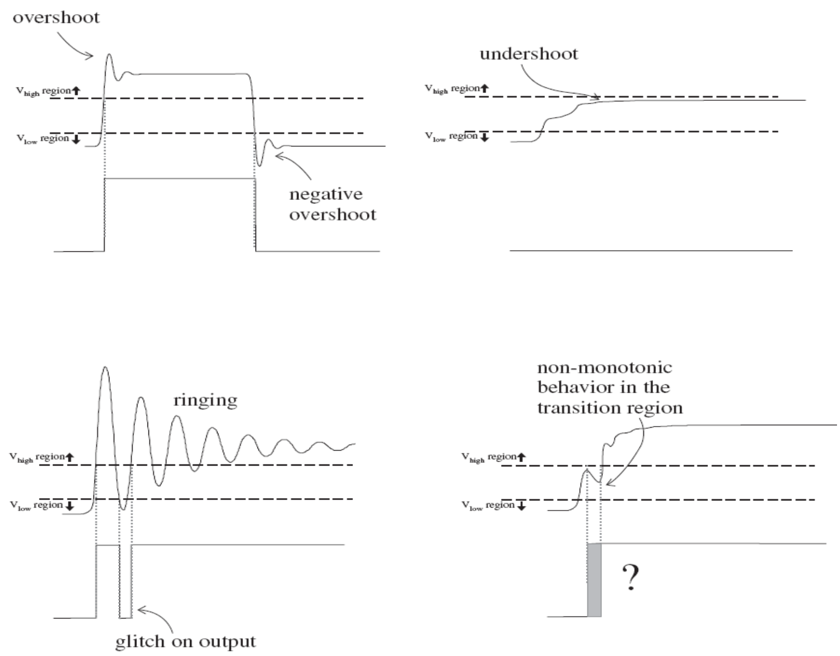


Figure 1.3 Examples of digital signal anomalies (Measurement techniques, (May 2009). http://www.radioradar.net/en/)

Digital devices have three distinct input voltage regions: low, high, and transition. The output is undefined while the input is in the transition region. Any no monotonic behavior in the transition region can cause output glitches.

Radiated fields that is transmitting between functional sections in a product or between digital components, cables and interconnections also regarded to self compatibility. A firm decision must be made in advance if circuitry or subsections are responsible for both emissions of and susceptibility to internal radiated RF energy. With respect to the placement of components, associated with related circuits or input - output connectors, a potential linking of inner radiated energy must be expected before finalizing the design of a PCB or guiding cables in the proximity of the large bandwidth switching components.

CHAPTER TWO
STATIC, ELECTRIC AND MAGNETIC FIELD THEORY

In this section, instead of touching on detailed electromagnetic concepts, basic types of fields that exist are mentioned, the manner how they propagate and the types of coupling that affect overall system operation. Electromagnetic interference studied through free space radiation, conducted within interconnects or by propagating EM fields. And coupling is a significant aspect of EMC design.

The concept of radiation from, and coupling to, interface cables, PCB tracks, wiring, etc. is generally foreign to engineers despite involvement with equipment containing digital, analogue, RF and control circuits. The reason may be that it is difficult to envisage interconnections as antennas, or circuit elements, or see the potential for crosstalk between conductors. This is particularly true when equipment exhibits EMI or fails an EMC requirement and the engineer is under the pressure of schedule to find the quick fix usually demanded by management. In order to make simple EMC predictions or solve an EMI problem efficiently an understanding of the principles of radiation and coupling, including frequency dependency and resonance effects, is essential.

2.1 Static Fields

All electronic and electrical devices and relevant circuitry must combine protection against strong static fields. These field types used for EMC are commonly classified as ESD, fast transient surge, electromagnetic pulse (EMP), or lightning, although there exist other forms of high energy potentials. Most of the static occurrences enter through I/O interconnections and open enclosures. In addition, direct handling of components on a PCB or chassis assembly can cause permanent damage to electrical devices. Once a component is assembled into a unit, devices are generally protected from static damage unless the design and grounding methodology was not implemented in an optimal manner.

2.1.1 Electrostatic Discharge Waveforms

A detailed discussion of waveforms and equivalent ESD circuits of humans, furniture, and other materials is complex and depends on many variables. At lower voltage levels, a "precursor" spike due to the local area of the source (test finger) is produced that has a very fast rise time on the order of a few hundred picoseconds. Although this spike contains a small amount of energy, damaging effects happen, especially with fast digital equipment.

An ESD event is normally separated through two primary types of discharge: direct (means human) and air (means furniture). Direct discharge is characterized as a quick slope of current, time approximately 1 ns, up to a peak of 10 A following with a damped decay back to zero. By this waveform, significant RF energy is come out up to 300 MHz. Air discharge is a slower rise of current to a peak of 100 A following with damped oscillations. The RF energy for this waveform is observed up to 30 MHz (Figure 2.1). Furniture discharge is a more severe event, as the area under the curve is significantly greater than the human discharge model because the real concern is the magnitude.

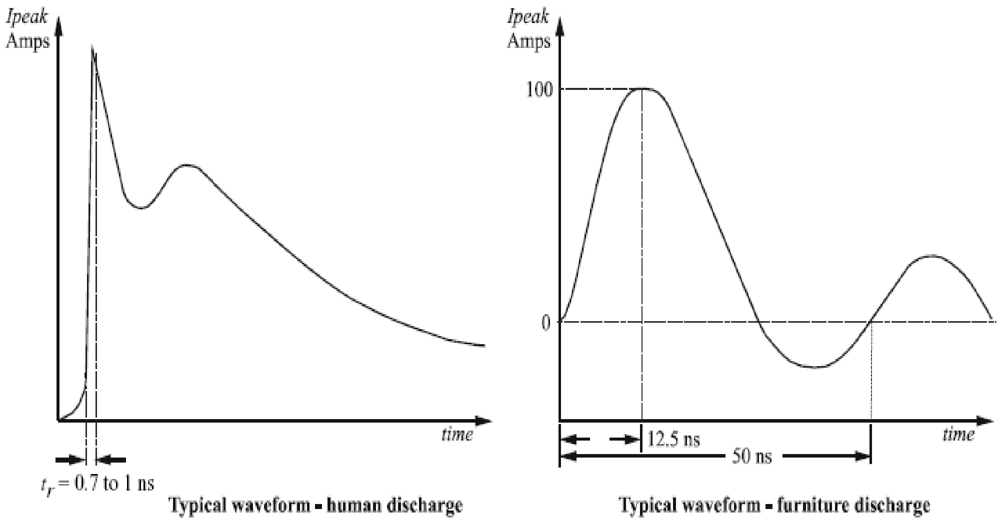


Figure 2.1 Electrostatic waveform (Mardiguian, M. (1992). *Electrostatic Disch arge Understand, Simulate and Fix ESD Problems,* Interference Control Technologies)

2.1.2 Failure Modes from a Static Event

Component Damage can occur whether the component is installed in a circuit or not. A semiconductor influenced by an electrostatic cause fails because of junction hole burning or fusing. This type of damage is permanent and easy to detect.

Operational Disruption is caused by direct or indirect touch of energy. Direct discharge occurs when electrostatic current finds its way to circuits through ports: power, ground, input, or output.

Direct discharge is the discharge directly executed to the EUT. It may be by direct galvanic contact between source and circuit or it may be by a discharge through air to metallic items on the PCB.

Indirect discharge is applied to a nearby metallic surface by electromagnetic radiation. The radiated fields couple to the circuit.

Most devices are susceptible to damage at relatively low voltage levels, such as 100 V. Many disk drive components are sensitive to discharges above 10 V.

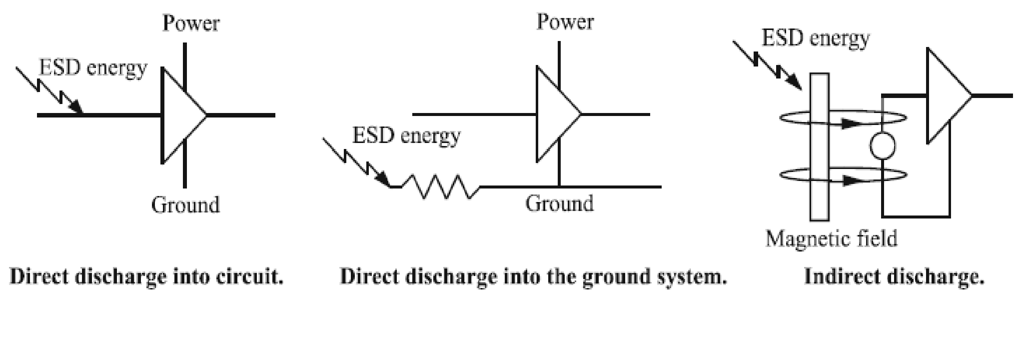


Figure 2.2 Failure modes caused by an ESD event

2.2 Relationship between Electric and Magnetic Fields

Understanding field theory is a must before making tests for EMC. In this part, basics of electromagnetic are introduced but this time in terms of EMC design. There are two basic types of field, electric and magnetic. The word electromagnetic comes from these two words; electric and magnetic.

According to Maxwell's equations "a time variant current produces a time variant magnetic field, which also rises up the electric field, whereas these two fields are related to each other mathematically". In addition the strength of field decreases while the distance between source and observation point increases. The close part is called near field and, it is determined as $\lambda/6$ in general EMC topic. λ is the wavelength which equals 1/f. Any distance greater than this value called as far field.

The effects and propagations of near field and far field are demonstrated in figure 2.3. The change in RF energy can be easily observed while it comes from near field to far field by this figure.

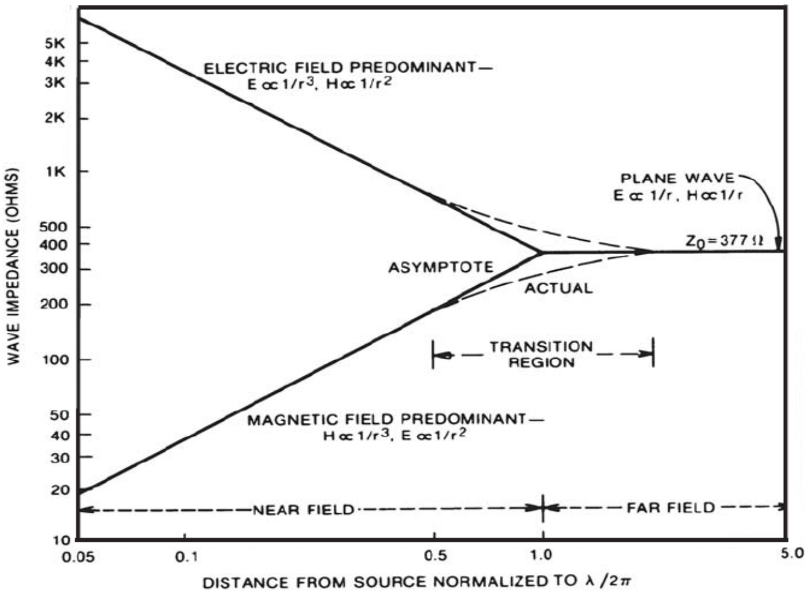


Figure 2.3 Wave impedance vs. distance from electric or magnetic sources

All electromagnetic signals, waves, are combination of electric and magnetic components. This is outlined by Poynting vector or plane wave. Actually Poynting vector is a method of expressing the direction and power of EM wave in units of W/m^2. In far field, electric field and magnetic field are right angles to each other and perpendicular, 90°, to the direction of propagation. Both fields propagate radial from the source with the velocity of light ($c \sim 3x\ 10^8$ m/s where $\mu_o=4\pi \times 10^{-7}$ H/m and $\varepsilon_o=$

8.85 x 10^{-12} F/m). Electric field component is in terms of volts/meter and magnetic field component is in terms of amperes/meter. The ration of these two components is identified as characteristic impedance of EM wave and expressed in terms of ohms (Petre P., Sarkar T.K., (August 2002). *Antennas and Propagation* , ieeexplore.ieee.org). For a plane wave in free space, wave impedance known as;

$$Z_0 = \frac{E}{H} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \cong \sqrt{\frac{4\pi \times 10^{-7}\ \text{H/m}}{(1/36\pi)(10^{-9})\ \text{F/m}}} = 120\pi \qquad \text{approximately } 377\ \Omega$$

2.2.1 Magnetic Sources

Let's think about a circuit containing a local oscillator and a load. Current is flowing in this circuit around a closed loop (as signal transmission and return current, shown in Figure 2.4). We can easily calculate the generated radiated field or the emission from this circuitry.

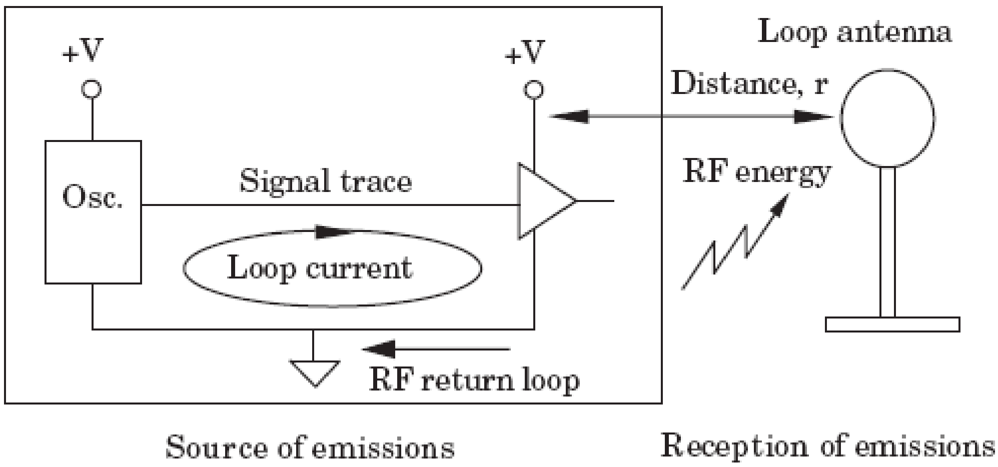


Figure 2.4 Magnetic field transmitted by RF energy (Montrose, M. I. (1999). *Design, Theory and Layout Made Simple*, Piscataway, NJ: IEEE)

2.2.2 Electric Sources

As mentioned before we can call electric sources as a dipole antenna carrying a time varying change in electric charge. This change provides a current flow through the dipole length. We can also analyze caused EMI within the same four topics.

• Generated field is directly proportional to the amount of current flowing.

• Orientation of Source Relative to Measuring Device is also same as defined for magnetic source.

• Field created is directly proportional to the length of the dipole or the current source. For a specific physical dimension, it should be in resonant frequency.

• Electric and magnetic fields behave in the same form with respect to the parameter distance. Both field strengths decrease with increasing distance.

The RF energy propagation can be described as the form given in Figure 2.5 to simulate how electric or magnetic fields influence the measurements in theory. A time varying electric field between two conductors can be represented as a capacitor and a time varying magnetic field between these conductors can be represented as mutual inductance.

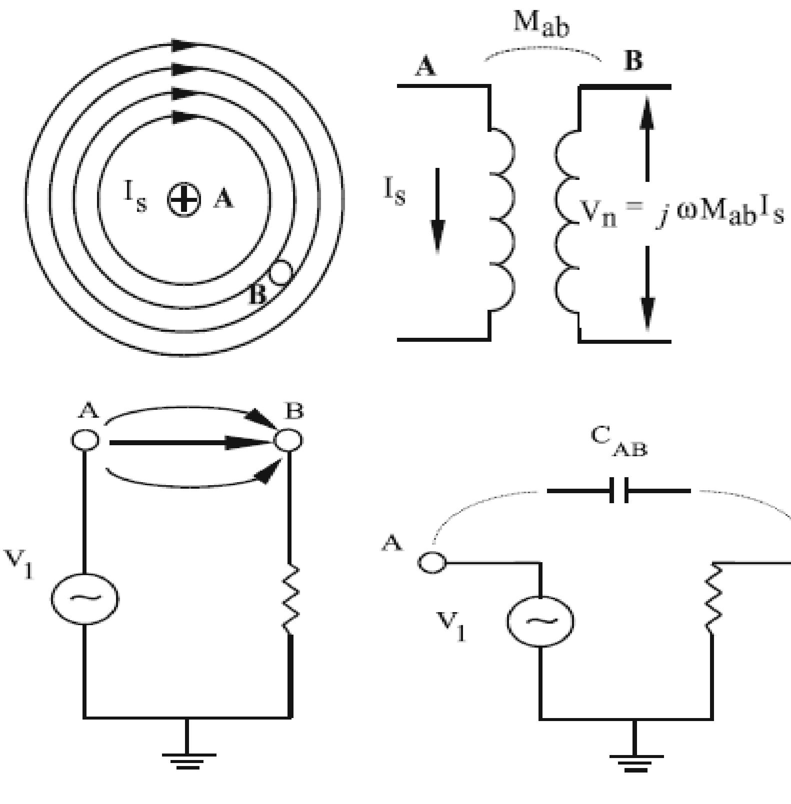


Figure 2.5 Electric and magnetic noise coupling analysis (Paul, C. R. (1992). *Introduction to Electromagnetic Compatibility*. New York: Wiley)

2.3 Noise Coupling Methods

In reduction of the EM interference for product design, there are two generally accepted ways. One is to decrease RF energy discharged from the source and the other one is to prevent emission by getting rid of coupling paths.

In an EMC situation, there are always a source and a victim. The connection between them is a coupling path. If both source and victim are within the same electrical part, the system is named as ‘intrasystem’ and if they are in separate functional groups, it is called as ‘intersystem’.

Propagation of RF energy should occur not only in one direct path from source to victim but in different path configurations such as given in Figure 2.6

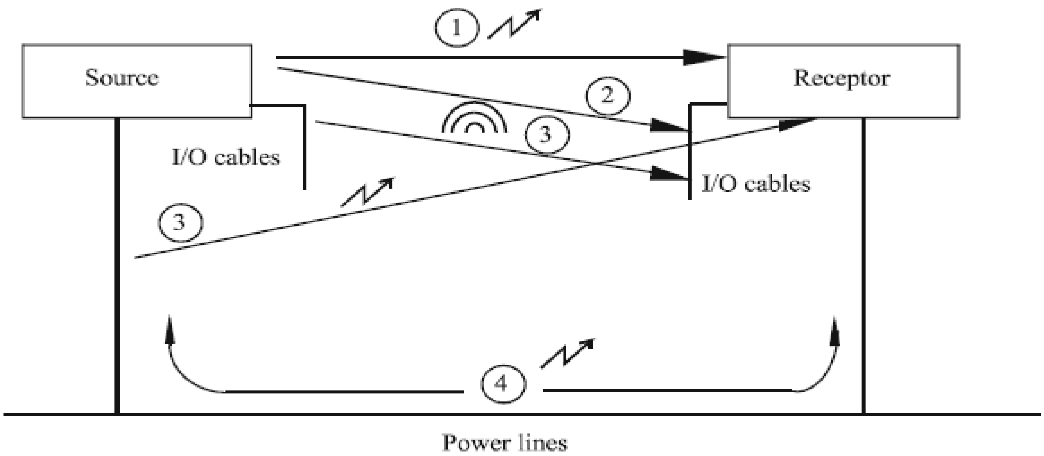


Figure 2.6 Different types of coupling path mechanisms (Paul, C. R. (1992). *Introduction t o Electromagnetic Compatibility*, New York: Wiley)

1) Direct radiation from source to victim or receptor (1st path)
2) Coupling from source to receptor’s AC mains cable mechanism (2nd path).
3) RF energy coupling radiated by AC or signal control cables from source to receptor (3rd path).
4) RF energy coupling radiated by the used power line (4th path).

The process of coupling can be prevented if the knowledge of field propagation and the manner of coupling types is used logically. For this purpose, the following modules are introduced to reduce EMI by coupling.

2.3.1 Electric Field Coupling

Electric field coupling consists when potential difference between two transmission lines or wires is provided. This comes from the basic idea "If there is a potential difference between two conductors, electric field is developed."

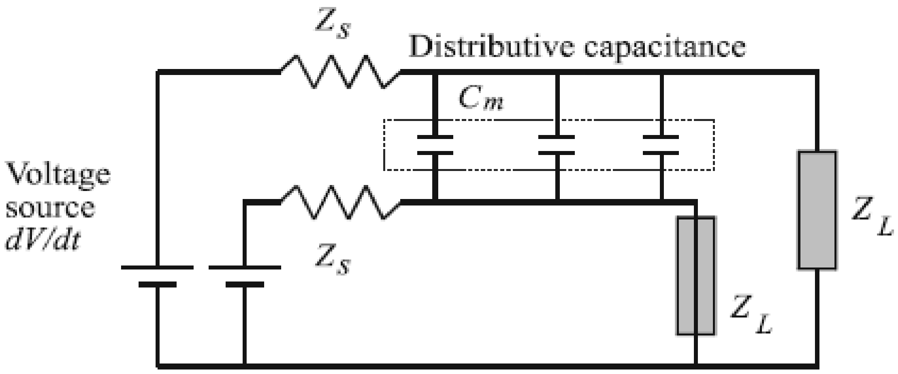


Figure 2.7 Electric field coupling (Montrose, M. I. (2000). *Printed Circuit Board Design Techniques for EMC Compliance*, Piscataway, NJ: IEEE.)

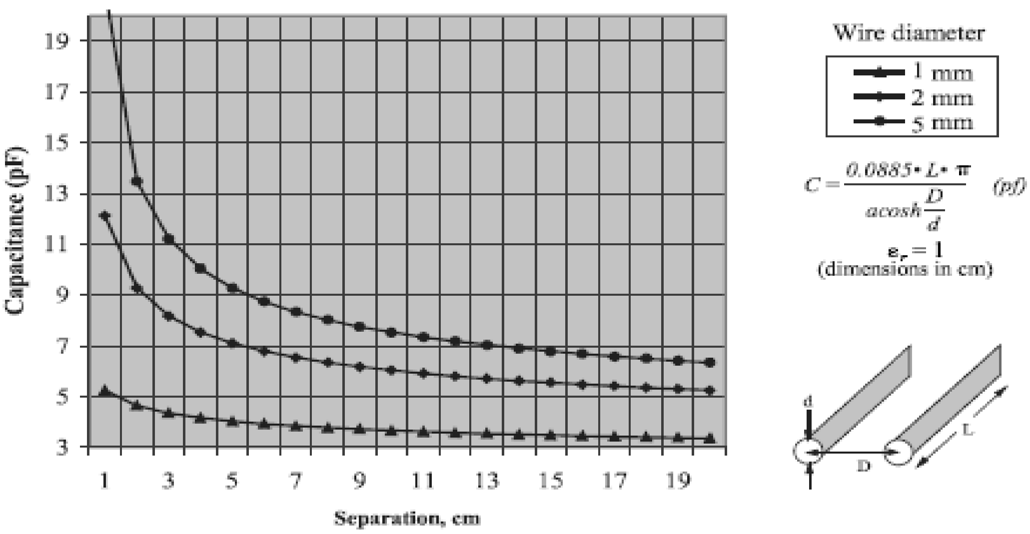


Figure 2.8 Mutual capacitance between two transmission lines (Montrose, M. I. (2000). *Printed Circuit Board Design - A Handbook for Designers*, Piscataway, NJ: IEEE.)

Mutual capacitance is affected by separation of distance, especially with the overlap area on two wires. In addition, the dielectric material between two lines should also affect the magnitude of capacitive coupling. In Figure 2.8, the concern of electric field is presented.

2.3.2 Magnetic Field Coupling

Magnetic coupling occurs if a magnetic flux created by a current loop transfers through magnetic flux pattern of another current loop. Induced voltage does not depend on subject's circuit impedance. It depends on the separating of conductors and the length of it which forms also mutual inductance. This information is necessary at product design to distinct magnetic coupling when it occurs on a PCB.

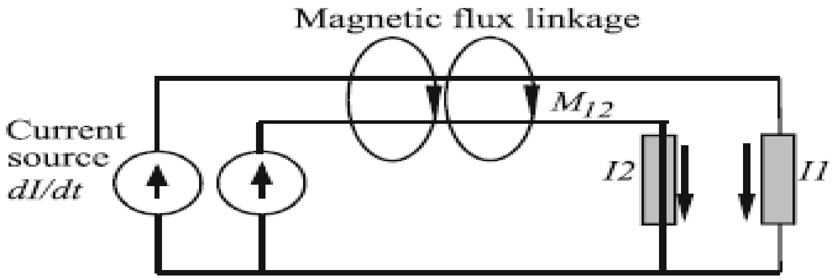


Figure 2.9 Magnetic field coupling (Montrose, M. I. (2000). *Printed Circuit Board Design Techniques for EMC Compliance*, Piscataway, NJ: IEEE.)

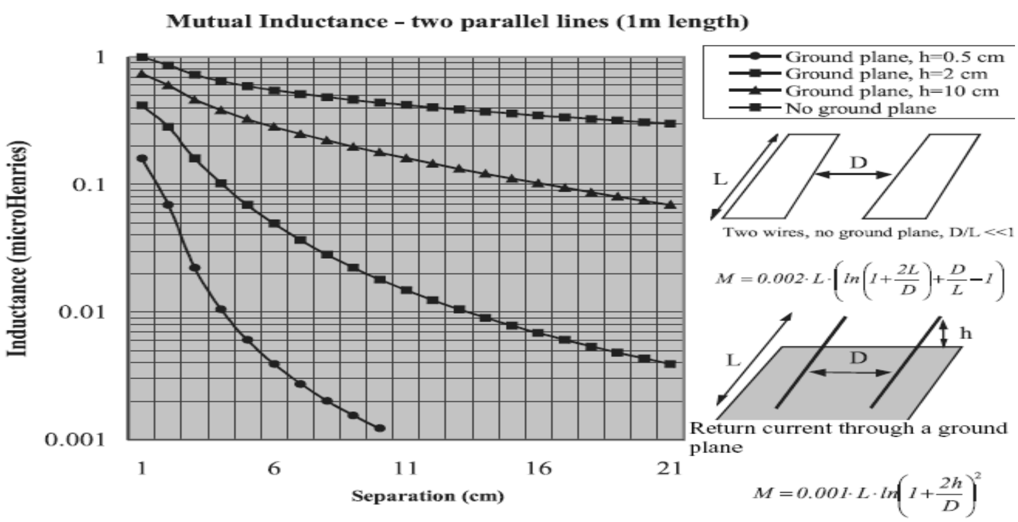


Figure 2.10 Mutual inductance between two transmissions lines (Montrose, M. I. (1999). *EMC and the Printed Circuit Board Design, Theory and Layout Made Simple*, Piscataway, NJ: IEEE)

2.3.3 The combination of Radiated and Conducted Coupling

For most cases, a combination of radiated and conducted disturbances can exist. Radiating field energy can produce coupling to a cable assembly which cause interference. Actually this effect of the radiated field appears as a conducted situation. Vice versa, radiating common mode energy from an unshielded cable which is transferring high speed and energy data can involve a field that has a potential propagation to sensitive electronic circuitry, causing disturbance. Here are some examples of these combinations:

1. Radiated coupling formations from power, signal and control transmission lines into any cable or chassis collaborated with any other electrical device.
2. Conductive coupling formations of both magnetic and electric fields from transmission lines to assemblies which means component radiation or etc.
3. Unwanted EM field signals improved in a system which is propagating to other electrical equipment. The interference can couple a receptor by either radiated or conducted ways.

For a transmission line between a source and load, terminated in fixed arbitrary impedance, three types of energy transference may be observed:

1. The transmission line with line losses,
2. A radiating EM wave showing losses in the ambient space,
3. An axial propagating field between source and load.

2.4 Common and Differential Mode EMI Current Sources

In all circuits, both differential and common mode currents can exist. Both types decide the total RF energy propagated between circuits or transmission lines. But there is a significant difference between two current types. Differential mode (DM) holds information or signal data on the transmission which is a wanted condition. But common mode (CM) is an undesired side effect of DM transmission which troubles EMC. Common mode is a primary concern of EMI. When in real life, parasitic, noise coupling or any other reason of common mode show up and unexpected EMI graph is obtained which differs from software simulation.

2.4.1 Differential Mode Current

DM signals carries desired information and also have the opportunity of low or none EMI with its return current path. In DM signals generated current is received by a load and same amount of return current should be transferred back to source. The difference between forward and return current due to cross talks, noise coupling etc. should provide a common mode EMI. In this manner, EMI of DM signaling can be reduced if ground impedance of return path is adjusted as low as possible, short return current paths provided or etc... All these methods have the same manner of controlling the excess energy fields through source and back to source.

2.4.2 Common Mode Current

Common mode (CM) current is the component of RF energy when both signal and return path have the same direction of RF energy transmission. The measured EMI is the sum of generated RF fields by both forward and return path current. CM current is generated if there is an imbalance in the circuit. Radiated emission is the result of these imbalances. Flux cancellation is poor when DM signal is not exactly opposite and in phase with its return path. The portion of RF current that is not cancelled exists as common mode current. Common mode (CM) signals are the major concern of EMI and do not carry useful information. The most important thing to prevent CM energy and EMI is to understand and manage RF return current paths.

2.4.3 Brief Instruction to Understand the Difference btw. DM and CM Currents

Common mode signal can be simulated as a pair of parallel wires carrying DM signal. Along these wires, DM signals flow in the opposite direction. These parallel wires act as a balanced transmission line which delivers a differential signal to load. But when CM voltage is placed on this wire no useful information is carried to the load. This wire pair behaves as a dipole antenna with respect to the ground. This antenna radiates unwanted CM energy which is also same as EMI. Common mode currents are generally observed in I/O cables in a television. This is why I/O cables radiate RF energy. To illustrate these phenomena, consider the figure given below;

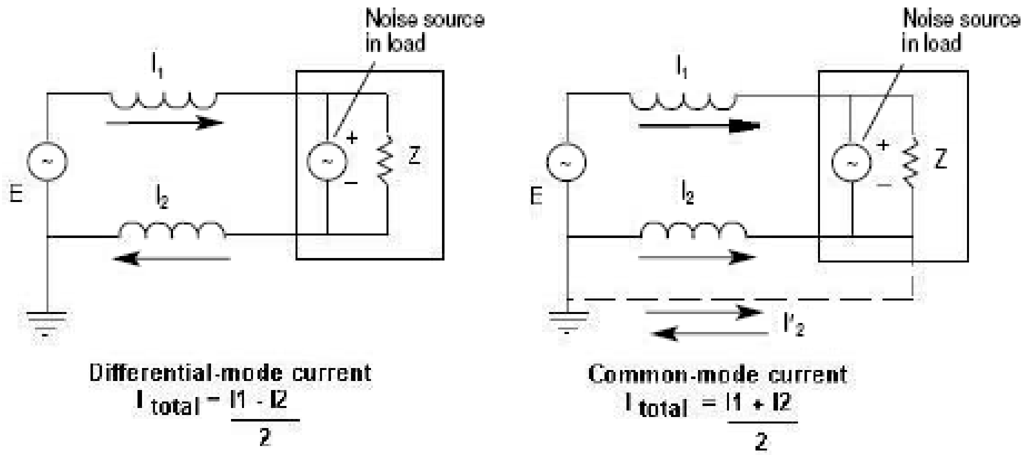


Figure 2.11 Current configurations of DM and CM (Montrose, M. I. (1999). *EMC and the Printed Circuit Board Design, Theory and Layout Made Simple*, Piscataway, NJ: IEEE.)

The flow current from source E to load Z is represented as I_1. Return current flows back to source is I_2 and this current provides I'_2 returns in a different path defined as dotted line. And I'_2 produces CM energy. Applying simple Kirchhoff's law to the CM and DM circuitries gives us below solutions;

$$I_{\text{total}}\ (\text{dm}) = ½(I_1 – I_2) = 1–2(1\ \text{A} – 1\ \text{A}) = 0\ \text{A}$$
$$I_{\text{total}}\ (\text{cm}) = ½\ (I_1 + I_2) = 1–2(1\ \text{A} + 0.5\ \text{A}) = 0.75\ \text{A}$$

For DM transmission, electric field component is created by the difference of I_1 and I_2. If they are equal to each other that mean perfect balanced system, there will be no RF field radiation. If there is an imbalanced system that is caused by RF loss on a system, CM energy is produced that causes EMI.

2.4.4 Radiation Due to Differential and Common Mode Current

Differential mode radiation is generally caused by the flow of RF current loops in a system. Radiated RF energy due to DM current is approximately given as below;

$$E = 263 \times 10^{-16}(f^2 A I_s)\left(\frac{1}{r}\right) \qquad \text{V/m}$$

where A = loop area (m^2)
f = frequency (Hz)
I_s= source current (A)
r = distance (m) from radiating element to receiving antenna

Radiated emission can be modeled as a small loop antenna carrying RF currents. We can illustrate this condition to the following figure 2.12.

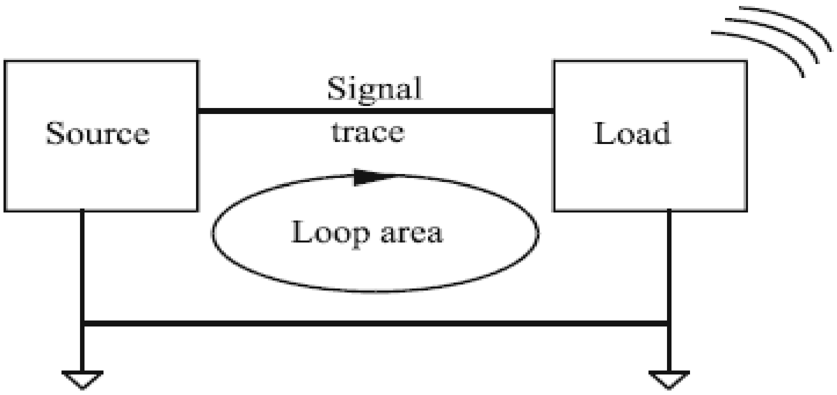


Figure 2.12 Loop areas btw. components (Gerke, D., and W. Kimmel (January 20, 1994) *The Designer's Guide to Electromagnetic Compatibility*, EDN.)

The area of the loop is critical for RF radiation. The maximum loop area that will not exceed a specific area given as below;

$$A = \frac{380rE}{f^2 I_s}$$

Conversely, radiated electric field can be calculated from the expression above as;

$$E = \frac{A f^2 I_s}{380r}$$

Where E= radiation limit (V/m)
r = distance between loop and measuring antenna (m)
f = frequency (MHz)
I_s = current (mA)
A= loop area (cm^2)

Note: In this chapter most of the fundamental titles derived from "Montrose, M. I. (1999). *EMC and the Printed Circuit Board Design - Design, Theory and Layout Made Simple*. Piscataway, NJ: IEEE".

CHAPTER THREE
EMC TESTING INSTRUMENTATION AND RAPPROCHEMENTS

In this chapter I tried to explain all the basic necessities for making electromagnetism compatible. We start with instrumentation and go through test sites, equipments etc… I wanted to explain all the questions about the idea of EMC testing, how EMC testing is performed, what the limits are, where the tests are realized in order to get precautions for compliance. I make use of CISPR-16-1 Part 1 in most of the parts of this chapter.

3.1 EMC Testing Methodologies

Before discussing how to perform EMC testing, and troubleshooting if necessary, there are considerations that one must be aware of. The most important aspect of EMC engineering lies in understanding fundamental EM theory and being able to apply this theory to product design.

3.1.1 Development Testing and Diagnostics

Performing tests well ahead of production will save a great deal of time and money throughout all stages of a product's development cycle. Standard test methods are not very useful in the early stages of development and evaluation when, for example, microprocessor or digital signal processing (DSP) chips are being specified or chosen.

Standard EMC laboratory test methods provide minimal value late in the stage of a project design when remedial work is required to solve an emissions problem. Standard test methods do not identify where the emissions are coming from, only that they exist. Therefore, it is necessary to use different techniques for development and diagnostic testing over that required for conformity compliance.

3.1.2 Compliance and Precompliance Testing

Many countries require compliance with international regulations before products may be imported. Other countries mandate only specific test laboratories within their jurisdiction. The EMC Directive in Europe requires manufacturers to issue a Declaration of Conformity listing the test standards they have "applied" when using the standards route to conformity. The term "applied" is not well defined. Customs officers in the EU have poorly defined legal rights to insist on seeing any EMC test report or certificate as a requirement for any goods supplied to member states. For most products, use of the CE mark is adequate on the packaging or product.

There are benefits to performing precompliance testing to discover whether there are EMC concerns before a mass-produced item is submitted for certification. Pre-compliance testing has the advantage that tests can be stopped at any time, the EUT modified, and the test redone. Full-compliance testing is more expensive per day and typically permits no disruption in the test sequence or involvement by the EUT's designers.

3.2 Instrumentation

While selecting the appropriate instrument, we can consider two approaches. Time domain analysis is helpful during debugging and troubleshooting and for investigating effects of signal integrity. Frequency domain analysis is used to measure RF energy, be it for certification testing or troubleshooting.

3.2.1 Time Domain Analyzer (Oscilloscope)

The most fundamental time domain signal is the sine wave. We can see the illustration of the sine waveform in Figure 3.1 where the vertical scale is at 1 V/div and the horizontal time base at 0.001 s/div. One cycle takes 0.004 s, the frequency can be defined as $1/T$ or 250 Hz with amplitude of 4 V peak.

The most useful instrument to view time domain waveforms is the "oscilloscope" or called in another way as "scope". A typical scope is shown in Figure 3.2.

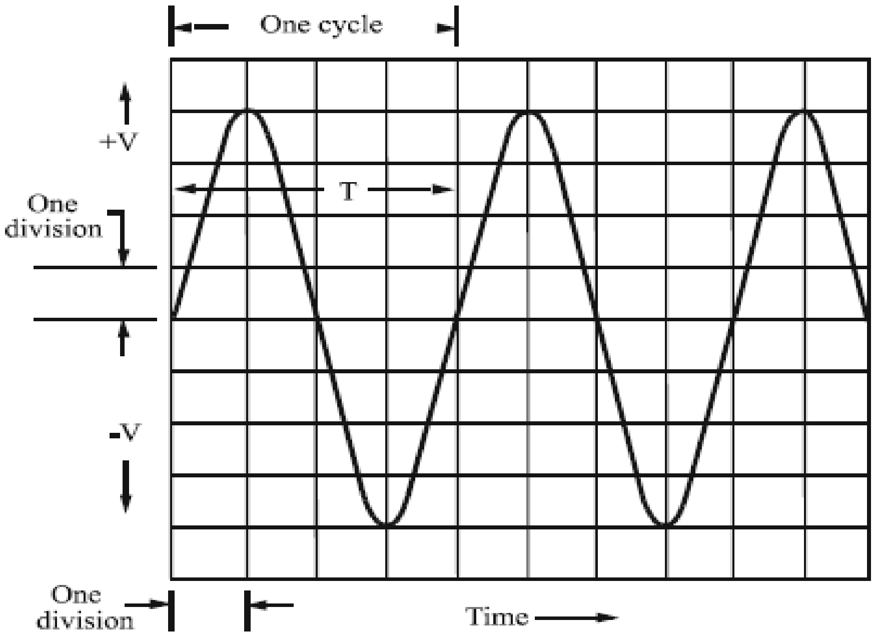


Figure 3.1 Time domain projection of a sine waveform (Prentiss, S. (1992). *The Complete Book of Oscilloscope*, 2nd ed. Blue Ridge Summit, PA: TAB Books.)

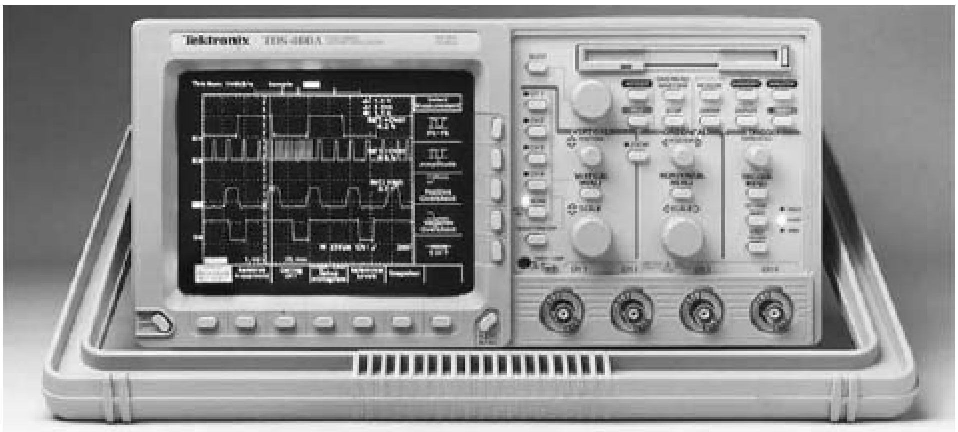


Figure 3.2 A typical oscilloscope for digital usage (the photograph is taken from Tektronix)

3.2.2 Frequency Domain Analysis

While working with oscilloscopes the problems occur on systems that have a large bandwidth. Using Fast Fourier transform functions for signal conversion from time to frequency give different results respect to the window chosen for the conversion. Oscilloscopes don't have quasipeak or average peak detectors which are required for suitable emissions testing. At this point another method and instrument appears; frequency domain analysis with "spectrum analyzer" or "receiver" which is another type. A typical digital pulse train and its frequency domain counterpart are shown in Figure 3.3.

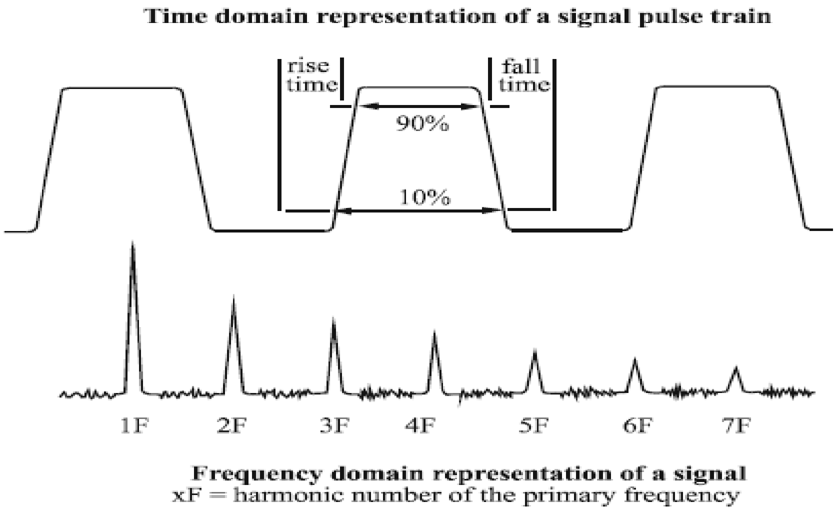


Figure 3.3 Digital pulse train representation (Prentiss, S. (1992). *The Complete Book of Oscilloscope*. 2nd ed. Blue Ridge Summit.)

3.2.2.1 Spectrum Analyzer

A spectrum analyzer or spectral analyzer is a device used to examine the spectral composition of some electrical, acoustic, or optical waveform. It may also measure the power spectrum. There are analogue and digital spectrum analyzers:

- An *analogue* spectrum analyzer uses either a variable band-pass filter whose mid-frequency is automatically tuned (shifted, swept) through the range of frequencies of which the spectrum is to be measured or a super heterodyne receiver where the local oscillator is swept through a range of frequencies.

- A *digital* spectrum analyzer computes the discrete Fourier transform (DFT), a mathematical process that transforms a waveform into the components of its frequency spectrum.

3.2.2.2 EMI Receiver

Receivers are becoming microprocessor based. This allows a great deal of flexibility for the receiver. Going from peak to AVG, peak to QP or QP to AVG is done by simply pushing a button, adding in correction factors for various accessories is an example of the flexibility associated with modern receivers.
Figure 3.4 shows basic type of receivers;

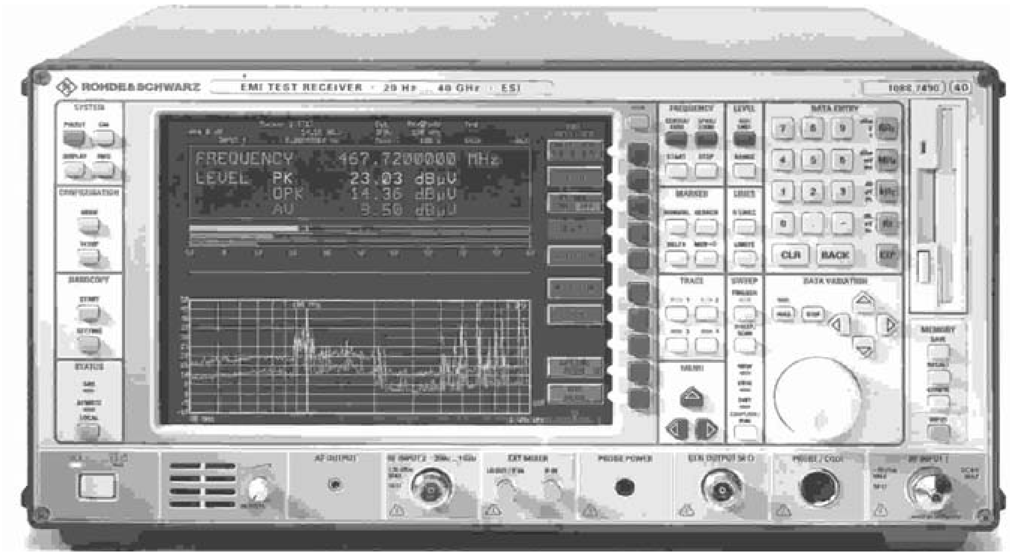


Figure 3.4 High end EMI receiver with preselector (Rohde & Schwarz GmbH)

Summarizing, a receiver has the following basic functions and characteristics:

- Variety of weighting functions (e.g., peak, average)
- Demodulation of audio frequency
- Measures modulation depth and frequency deviation
- Provides analogue output for recorders
- Low noise figure
- High overload capacity

The main difference lies in the capability of the receiver to handle overload or large input signal conditions over that of a spectrum analyzer.

3.3 EMC Testing Facilities

With this thesis only material is provided that allows one to understand the testing environment where products are placed and achievement for providing correlated test results. For both emissions and immunity, it is important to have a non reflected free space in addition to eliminate all external media from the test ambient. Included facilities are open area test sites (OATSs), screened rooms (anechoic or semi anechoic chambers), and special test cells e.g., Transverse Electromagnetic (TEM) / Gigahertz TEM (GTEM). (CISPR-16-1 Part 1: Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods)

3.3.1 Open Area Test Site

An OATS is the designed facility for performing radiated emission testing. It supplies direct and universally accepted method. Also you must locate it a significant distances from all metallic structures and high ambient electromagnetic fields such as broadcast towers and power lines. The main disadvantage of using an OATS for EMC testing is the need to search the entire frequency spectrum for any accidental emissions in an EM environment which may have ambient noise. For example, while we are trying to measure a weak 200 MHz clock harmonic in the presence of a television signal at 199.25 MHz clock source in the middle of the FM radio band, particularly if the radio station has a strong signal.

We can summarize requirement for an OATS as the matters below;

- *Reflecting ground plane*
- *EUT turntable*
- *Antenna Positioner*
- *Appropriate measuring distance*
- *Electromagnetic Scattering*

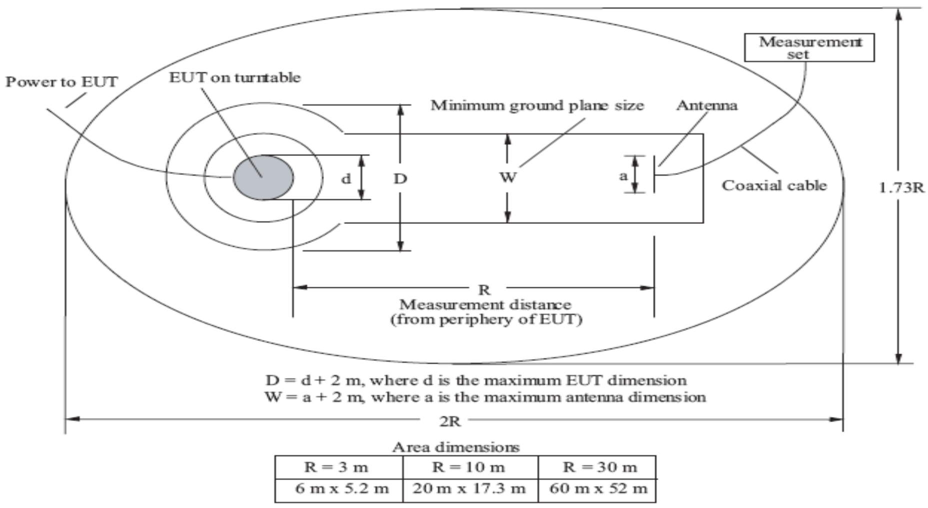


Figure 3.5 The site configuration of an OATS (CISPR-16-1. Part 1: Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods)

• *Site attenuation:* The process of calibrating an OATS range. The transmitted RF energy is measured by a receive antenna with proper instruments, shown in Figure 3.6. The measurements should be ± 4 dB of theoretical NSA curve.

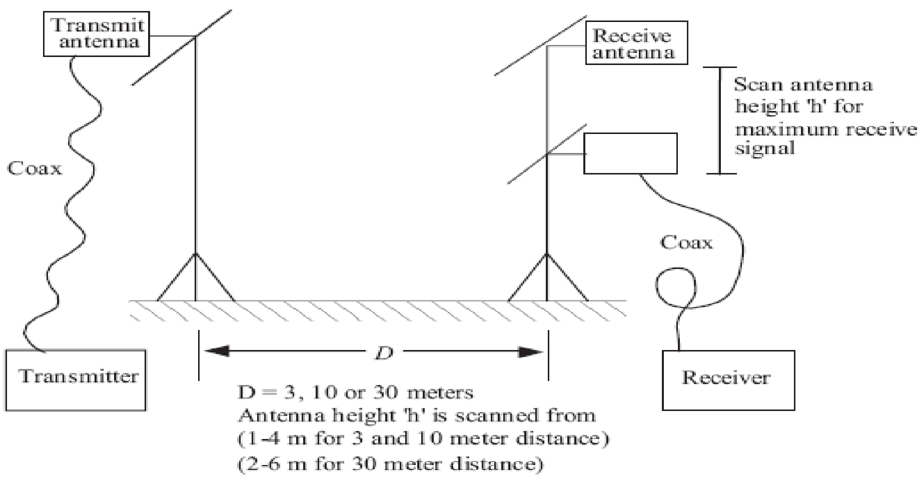


Figure 3.6 Standard site attenuation measurement schematic (CISPR-16-1, Part 1: Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods)

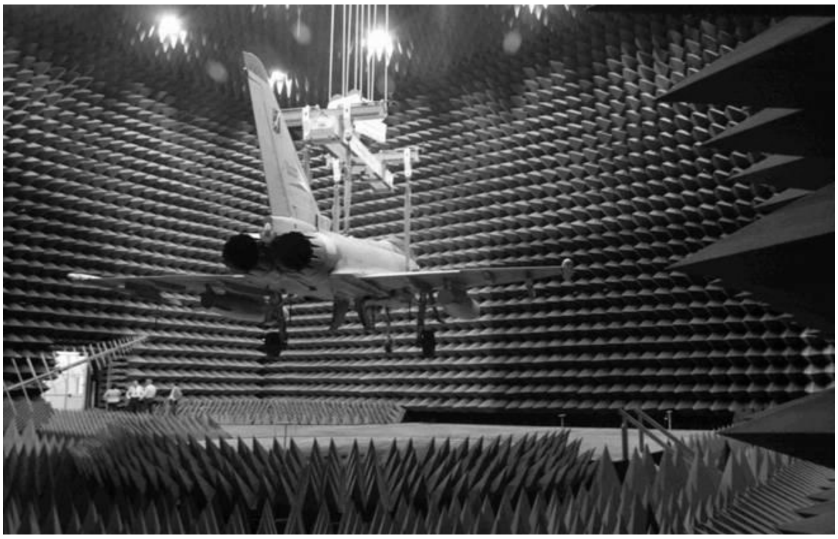
3.3.2 EMC Testing Chambers and Screened Rooms

Special rooms where OATs is not sufficient can be used for formal EMC testing. The most general used ones called anechoic chamber in EMC language. There are two types of anechoic chambers which are fully and semi anechoic. The difference between fully and semi anechoic chambers is the ground plane.

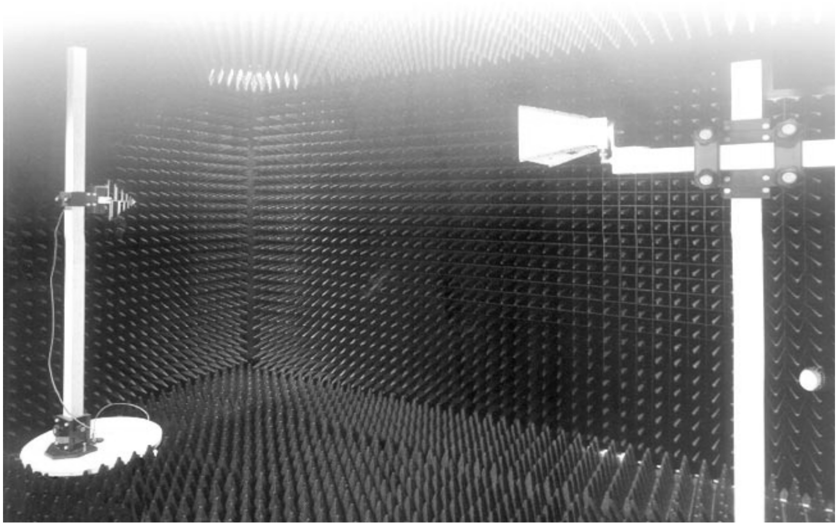
The main advantage of testing in a chamber environment is having a clean RF environment to work within. For radiated emission, this can save a huge time as no effort is wasted for attempting to eliminate ambient disturbance signals. Actually a screened room or chamber is nothing more than a full metal enclosure but complexity lies within special precautions for proper electrical and mechanical conditions.

3.3.2.1 Anechoic Chambers

Anechoic chambers are the most useful shielded rooms which have been preferred by most companies. This chamber includes carbon filled absorbers, ferrite tiles, or a combination of both. A full anechoic chamber has been also shielded from the floor while a semi anechoic one has a solid metal ground plane, which is useful for simulating the effects of an OATS.



a)



b)

Figure 3.7 a) 20 meters huge technology Semi Anechoic Chamber b) 3 meters Complex Full Anechoic Chamber

We must interest in the following items while using an anechoic chamber;

- *Field Uniformity*

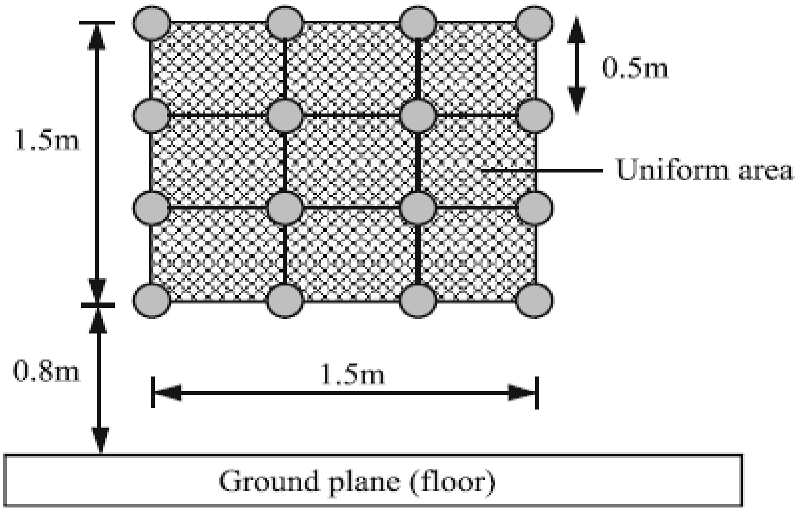


Figure 3.8 Field uniformity scheme based on 16 points calibration

- *Signal Source*
- *Power Amplifier and Field Strength*
- *Field Stren gth Levelin g and Monitoring:* The EM test fields are generally monitored with field strength sensors.
- *Transducers*
- *Sweep Rate*

3.3.2.2 Shielded and Screened Rooms

A screened or shielded room is an equipment that is used for problem identification tests or solving known EMI problems. This room can also be used to perform CE tests for controlling compliance. Use of this room for radiated emission compliance is not permitted because multiple reflections of RF waves can bounce around the chamber which is disturbing the real EM profile of the EUT.

Most of the screened and shielded rooms are made from steel and wood panels welded or clamped together. All electrical services, cables, cords, wires etc., which enter the room must be filtered, including AC mains, I/O signals and lightning protection. You can see two examples of those rooms in Figure 3.9.

a) b)

Figure 3.9 a) Screened room, b) Shielded room with mesh window

3.3.2.3 Reverberation Chambers

Reverberation chambers are generally used for military service testing such as Hazards of Electromagnetic Radiation to Ordnance, automotive applications, and large EUT compulsion testing at high field strengths. They are also used for commercial standards such as the volumetric uniformity requirements of IEC 61000-

4-3 and commercial avionics test standard RTCA/DO-160D. This type of chambers provide random, complex, real world conditions similar to the environments found in avionics chambers and automobile engine cells. A typical chamber is shown in Figure 3.10.

Figure 3.10 A typical reverberation chamber

3.3.2.4 TEM and GTEM Cells

Transverse electromagnetic (TEM) transmission line cells (Figure 3.11) are devices used to establish standard EM fields in a shielded environment. The cell consists of a section of rectangular coaxial transmission line tapered at each end to adapt to standard coaxial connectors. The wave travelling through the cell has a free space impedance (377 Ω), thus providing a close approximation of a far field plane propagating in free space.

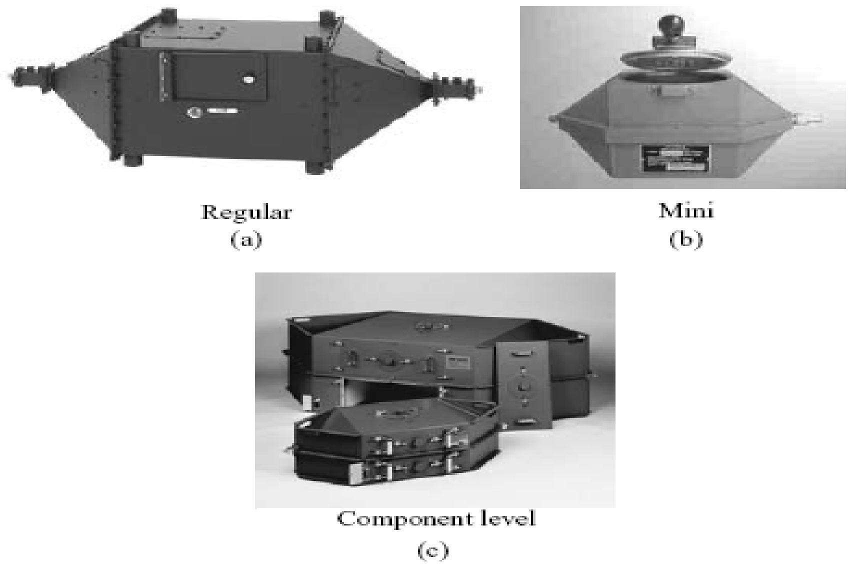


Figure 3.11 Different variations of TEM cells (Photographs courtesy of (a) Instrument for Industry, Inc., (b) CPR Technology, and (c) Amplifier Research)

The GTEM cell is a frequency extended variant of the traditional TEM (Transverse Electro-Magnetic) cell. When high-frequency signals are input, TEM waves will propagate along the septum. Field wave impedance is 377 Ω for the TEM wave propagation. GTEMs give excellent field uniformity and reproducibility over a given test volume. GTEMs are available in various sizes from 250 mm to 2000 mm septum heights. The size chosen will depend upon the EUT size that is to be tested.

3.4 Supporting Equipments (Antennas, Probes)

The used technique for input voltage, current, or EM fields is related through a device which is called a transducer. A transducer provides energy flows from transmission systems or media to another transmission system or medium. (Smith, D. (1993). *High Frequency Meas urements and Noise in E lectronic Circuits*, New York: Van Nostrand Reinhold)

There are two main types of transducers according to data which will be recorded:

1. *Active Transducer.* A device whose output and detection are dependent to the power source. The level of the power is checked by one or more of the input sources.
2. *Passive Transducer.* A device that has no power source except the input

signals and so on whose output signal power can't exceed that of the input. Most of the transducers used for EMC measurements are passive ones.

A concern in dealing with transducers has to do with gain and loss, where loss is negative gain. Called the *transfer function,* this can be defined as follows:

1. *Gain* is a measure of the ability of a circuit to increase the power or amplitude of a signal. It is also usually defined as the mean ratio of the signal output of a system to the signal input of the same system.
2. *Loss* is the decrease of signal power resulting from the insertion of a device in a transmission line. Generally expressed as a ratio in dB relative to the transmitted signal power, it can also be referred to as attenuation.

3.4.1 Antenna Types

Smith, D. (1993) described the antenna types as;

Dipole Antenna with tuner: The tunable dipole antenna is generally used in the frequency range of 25 MHz to 1 GHz.

Biconical Antenna: A biconical antenna is a broadband dipole consisting of two conical conductors having a common axis and vertex. The antenna emulates a very broadband dipole, which makes it convenient for most EMC tests compared to a dipole.

Log Periodic Antenna: A typical log periodic antenna usually works within the frequency range of 200MHz to 1 GHz and in a temperate manner directional when the source of the propagation signal is known.

Bilog Antenna. A bilog antenna is a single antenna which produced from combination of EM characteristics and properties of both biconical and log periodic antennas united in one instrument

Loop Antenna: A loop antenna is sensitive to magnetic fields and is shielded against electric fields. Electrically small loops are preferred to measure EMF in the frequency range of approximately 20 Hz to 30 MHz

Horn Antenna: These types of antennas are especially used to measure EMF strength in the frequency range upper than 1 GHz. Gains of horn antennas vary from approximately 10 to 30 dB over the frequency range of 1 GHz to 40 GHz.

In the figures below, you can see all the types of the antennas mentioned in this chapter;

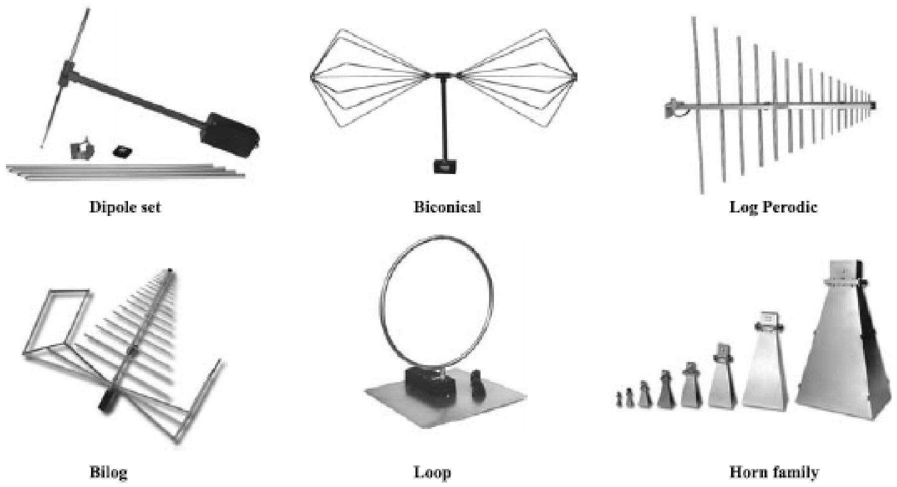


Figure 3.12 Typical EMI measurement antennas (Smith, D. (1993).)

3.4.2 Probes

Voltage Probes: Voltage probes are transducers which measures RF voltage level. The basic configuration of the voltage probe is shown in Figure 3.13. The resistor provides an insertion loss of approximately 25 dB, which must be corrected by using the calibration table provided by the manufacturer.

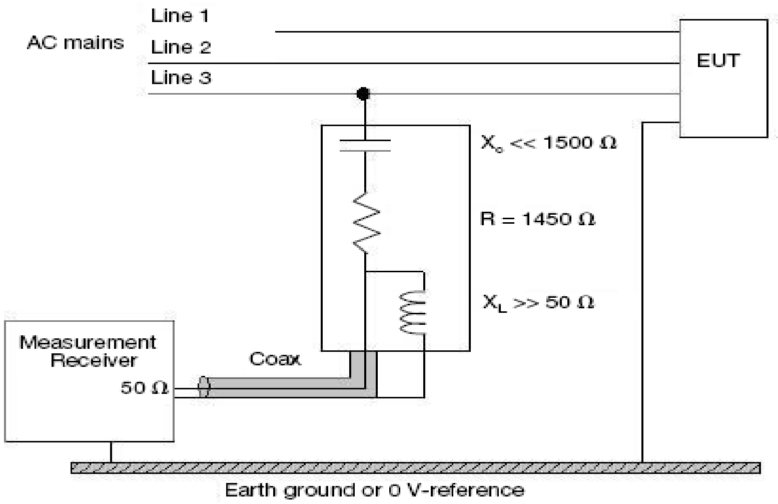


Figure 3.13 Configuration for voltage probes (Smith, D. 1993.)

Main disadvantage of using a voltage probe is stabilization of the RF impedance beyond a wide range of frequency. The reason of this situation is that the probe is inserted beyond the mains connection instead of connecting in series.

Current Probes: A current probe is a valuable type of transducer for measuring current levels in transmission lines. These probes contain a core material that observes the magnitude of magnetic flux and transfers this EMF measurement to a receiver. Examples of various types of probes are shown in Figure 3.14, which includes, clamp on, surface, donut, simple pick up, and flat cable types.

Figure 3.14 Most useful current probe types (Smith, D. 1993.)

Current probes can be used to measure CM currents from cable assemblies and individual wires. Close field loop probes can measure differential and common modes at the same time which makes them special.

A current probe is placed around a transmission line to measure various forms of conducted EMI. Some typical applications for current probe usage may be overviewed as:

1. to measure very small current instead of using microamperes.
2. To measure CM currents on cables for making prediction about radiated emissions for regulatory compliance.
3. to measure the balance between wire pairs to ensure optimal signal integrity.

Note: More details about measuring apparatus and methods about this chapter can be observed from the EMC standard "*CISPR-16-1. Part 1: Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods*".

CHAPTER FOUR
EMC EMISSION TESTING TECHNIQUES

There are so many modes of signal propagation. One mode of propagation is conduction within a physical connection such as wire, cable, transmission line, or PCB traces. The other mode of propagation is radiation through free space or a dielectric. A third mode is the coupling of energy by an electric or magnetic field. We can summarize the EMC testing methodology with the corresponding figure.

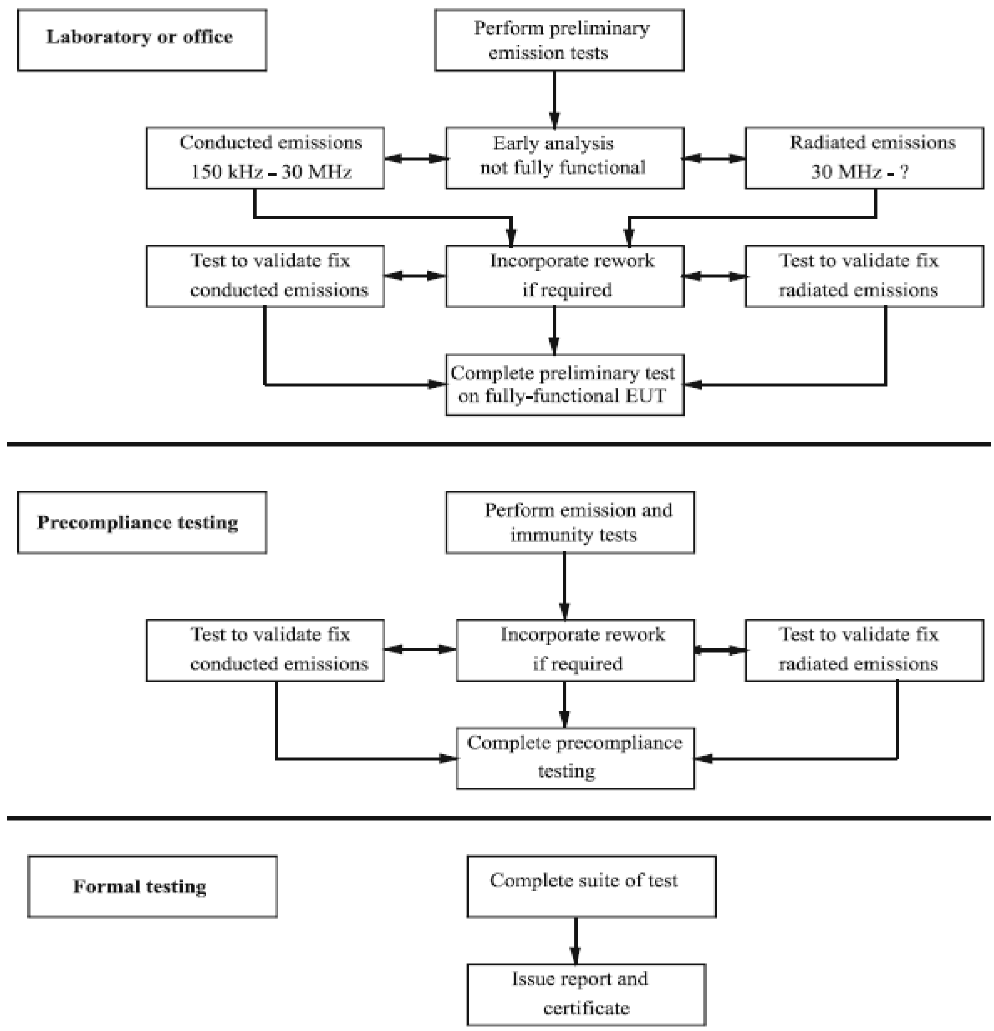


Figure 4.1 Standard processes while performing EMC task (Mark I. Montrose, Edward M. Nakauchi. (2004))

4.1 Radiated Emission

The main idea of this chapter is to provide information on fields that propagate from any transmission line, connection, or digital equipment. Undesired RF energy is usually mentioned within the 100 kHz–300 GHz frequency range, which is the most often used for telecommunication. Having the acknowledgement of different measurement techniques and using the right antennas, probes and instrumentation can make this task of recognizing radiated emissions easier.

4.1.1 Technical investigation for design

This part of analysis includes measurements with near field probes, simulation programs and applying design rules. Various subassemblies are tested for self investigation before final compliance test. This is the most important part and a necessity of EMC design to perform careful and perfect level of analysis during design stage. Analysis should include performance, manufacturability and compliance to regulatory standards. Theoretical and practical experiences take place in this part. These will affect the emission level of the product and cost of EMC troubleshooting techniques because if the design rules are not considered at this stage, additional EMI shielding components such as ferrites, gaskets and etc… should be used in order to get compliance. It will affect cost, producibility and quality of product.

4.1.2 Precompliance Testing

Precompliance testing usually means using the full compliance methods but cutting a few corners to save money and testing time. The important thing about precompliance testing is to know well enough about EMC testing, what errors are introduced by the cut sides. As I said before, saving time and money in EMC testing means being clever and precompliance is a good example. To depart from the precise test site and methods, or using low-cost instruments that is not compliant to CISPR16 itself, can mean unknown measurement errors, either causing wasted time and energy (late to market, over engineering, high cost of production) or to immoderate financial risk (weak reliability, high rate of customer returns and warranty costs).

There are two ways to solve the errors in a precompliance testing. One is to follow the same procedure as for a full compliance test, including measuring the normalized site attenuation (NSA) for the site, as mentioned in the previous chapter, obtaining calibration data for all the equipment, cables, and antennas, and working out the measurement uncertainty. And the second method is to use 'golden product' testing method. With 'golden product' testing there is no absolute need to know anything about your site or uncertainties. There are several ways to perform precompliance testing. Set-up by using current probes or clamps given in Figure 4.2

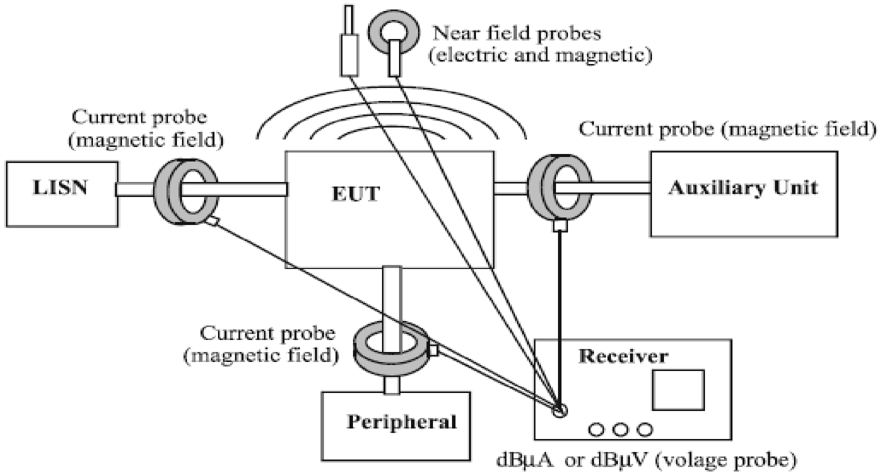


Figure 4.2 Alternate precompliance RE testing with using probes

4.1.3 Radiated EMC Testing for Certification (Full Compliance)

This level of investigation is for official certification and testing of televisions according to regulatory requirements. Tests are performed in accordance with published standards for electrical equipments such as EN55013 (Sound and Television broadcast receivers and associated equipments - Radio disturbance characteristics- Limits and methods of measurement) and EN55022 (Information technology equipment- Radio disturbance characteristics- Limits and methods of measurement). As it is stated above, test specifications are developed to get system

EMC in almost every anticipated location. Formal radiated emission test can be performed in any test site which satisfies requirements stated in the standards, for instance Normalized Site Attenuation (NSA) measurement. For full compliance testing three aspects are to be considered:

- Quality of the test site
- Quality of the test equipment
- Accuracy of procedures

OATS, chambers and cells are generally used for formal EMC testing. OATS is the most common one where it is not the easiest way to supply. To determine if the measured signal is from the EUT, or ambient, a simple procedure exists. First of all, turn off the EUT, if the signal disappears, then this is probably a valid emission. Certain products may still emit significant levels of energy while in standby mode (e.g., inverter drives for AC motors).

There are alternate methods of performing radiated emissions tests. Most EMC standards measure radiated emissions at a distance of 10 meters, although for precompliance purposes it is more common to use 3 meters instead and increase the limits by 10dB.

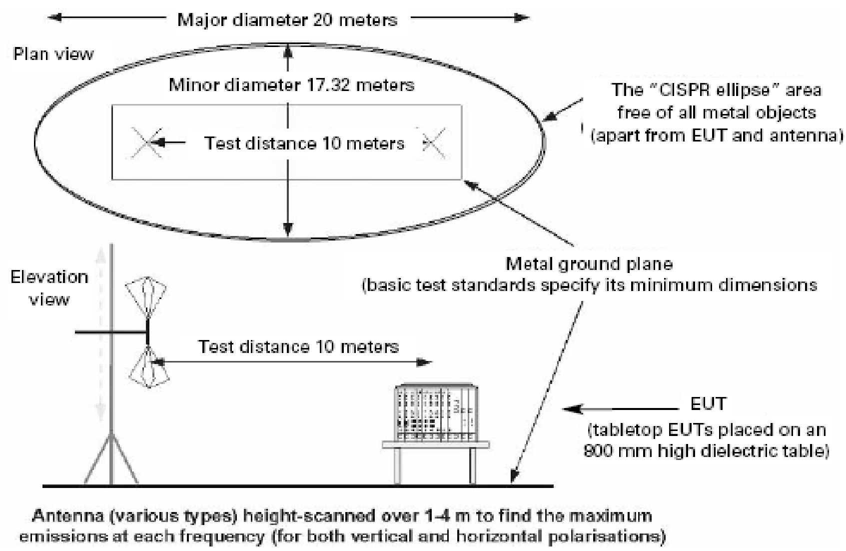


Figure 4.3 General OATS requirements (CISPR 22, (2006))

Let's give an example test procedure with respect to the EN55013 (Sound & Television Broadcast Receivers & Associated Equipment, Radio Disturbance Characteristics, Limits & Methods of Measurement) test standard;

- EUT is installed in the middle of turntable
- EUT is placed on a wooden table on the non metallic turntable of 0.8 m height at a distance of 3 m from the receive antenna.
- Prescan measurements of EUT are taken at 0, 90, 180 and 270 degrees of turntable at 1.00 m and 1.55 m horizontal, 2.00 m and 2.50 m vertical polarization.
- At the end of the prescan, final measurement for suspicious frequencies are examined.
- At each suspicious frequency, table is turned from 0 to 360 degree and antenna height is moved from 1 to 4m for horizontal and for vertical polarization.
- Highest Quasi-Peak value for each frequency is obtained and noted.

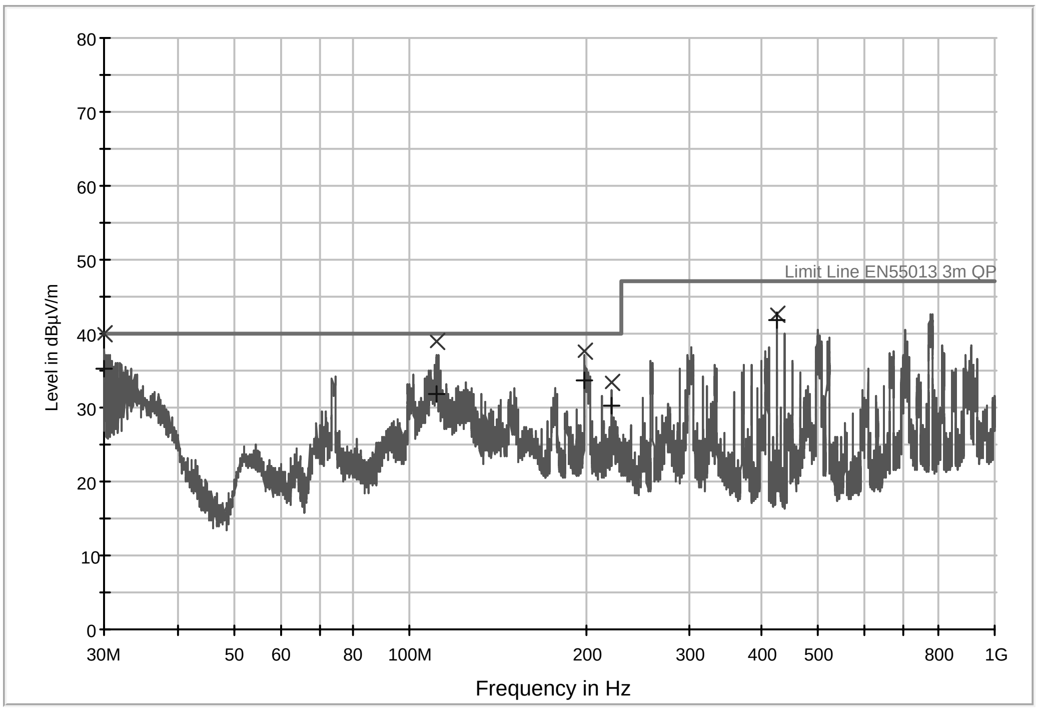


Figure 4.4 Test data taken from Rohde Schwarz EMI Receiver

4.1.4 Problems during Emissions Testing

While working on the aspects of EMC, the "Murphy's Golden Law" is useful to follow. Problems which will be faced always happen while testing and debugging. To minimize these problems, all the responsible must be aware of the following, perform the appropriate action as required.

Equipment Setup and Environment: Most products need usage of auxiliary systems to guarantee their functionality. Auxiliary equipment may be directly located near the EUT or be remote. If it is remote, guidance cables between whole systems play an important role in the setup. Cables should be routed under the floor or overhead.

The following procedure theme can be very useful to full, while working on the radiated emission aspect.

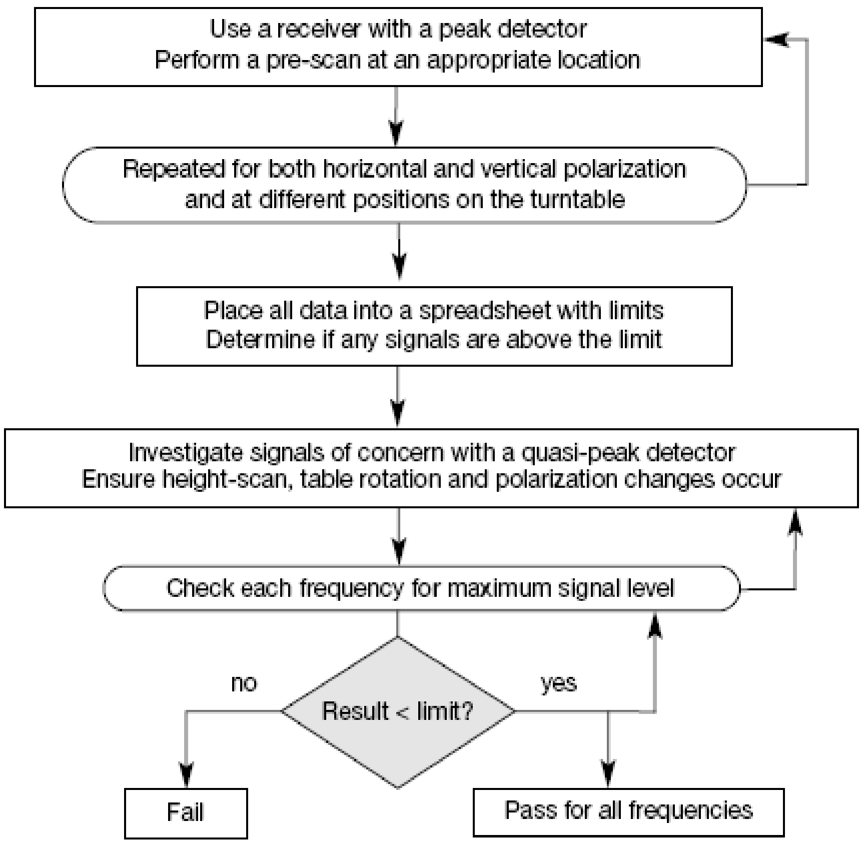


Figure 4.5 Full compliance measurement procedures

4.2 Conducted Emission

The term conducted emissions refers to the mechanism that enables electromagnetic energy to be created in an electronic device and coupled to its AC power cord. Similarly to radiated emissions, the allowable conducted emissions from electronic devices are controlled by regulatory agencies. If a product passes all radiated emissions regulations but fails a conducted emissions test, the product cannot be legally sold.

This section will investigate conducted emissions by studying its sources and methods to its reduction techniques. First the Line Impedance Stabilization Network (LISN) will be studied to give an overview on how conducted emissions are measured.

4.2.1 The Line Impedance Stabilization Network (LISN)

As an engineer in the EMC field, it is important to understand the measurement procedures that are used to measure conducted emissions. Conducted emissions are regulated by the FCC over the frequency range 450 kHz to 30 MHz, and the CISPR 22 conducted emissions limits extend from 150 kHz to 30 MHz.

As shown in the test setup diagram, the ac power cord of the product under test is plugged into the input of the LISN, and the output of the LISN is plugged into the commercial power system outlet. AC power is filtered through the LISN and the product is provided with “unpolluted” ac power. A spectrum analyzer is connected to the LISN and measures the conducted emissions from the equipment under test.

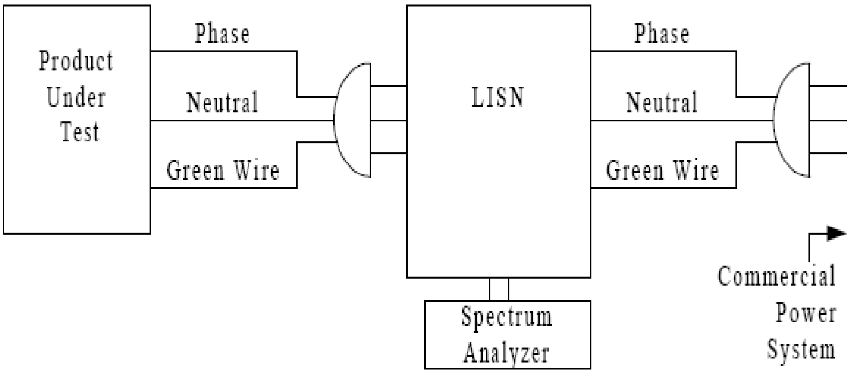


Figure 4.6 Block diagram of the CE test setup

The purpose of conducted emissions testing is to measure noise currents that exit the EUT's AC power cord and make sure that these currents are within the regulated limits. International regulations require that measured data be co relatable between measurement facilities.

Instead, the EUT is connected to a LISN, which stabilizes the impedance seen by the product looking from the AC power cord. This is one of the basic objectives of the LISN. The second one is stopping external noise, which exists on the power system, from entering the product's AC power cord. Any noise currents from the power system that will enter the product's ac power cord would add to the conducted emissions from the product.

4.2.2 Common and Differential Mode Currents

As I described in the previous section, the main purpose of the LISN is to satisfy standard impedances for the phase and neutral wires of a product so that the CE test can be accomplished by measuring the voltages across these impedances. A circuit diagram for the conducted emissions testing setup is shown in figure 4.8.

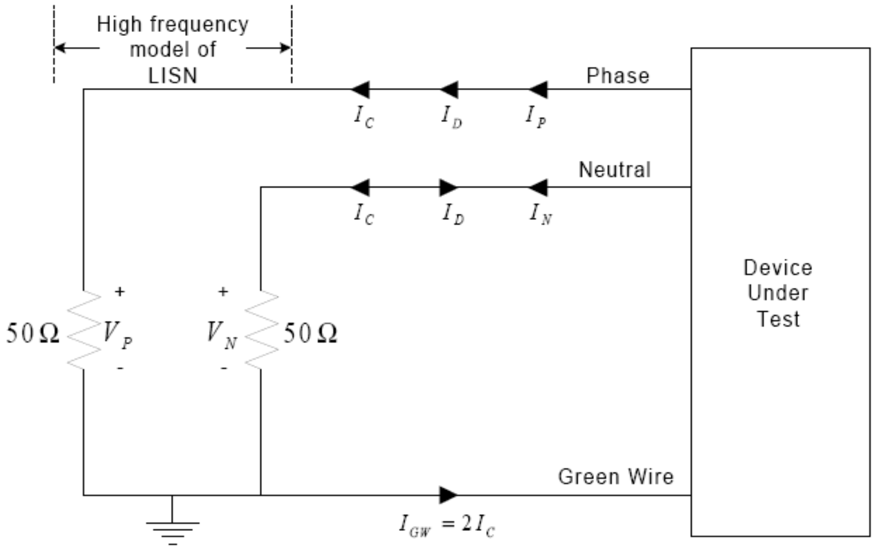


Figure 4.7 DM and CM currents on an AC power cord diagram

Within this figure the circuitry of the LISN has replaced by two 50 Ω loads to represent the LISN where the CE tests are measured. From the figure;

$$I_P = I_C + I_D$$

$$I_N = I_C - I_D$$

$$I_C = \frac{1}{2}(I_P + I_N)$$

$$I_D = \frac{1}{2}(I_P - I_N).$$

There are two main methods of suppressing the high frequency CM current returning on the ground wire. The first method is to simply wind the ground wire around a ferrite core after the ground wire has entered the product casing and before the wire is soldered to the case. The second method used to stop the CM current is to completely remove the ground wire and create a two wired device

4.2.3 Power Supply Filters

In real life no electronic products today can comply with conducted emissions regulations without the help of a power supply filter. Power supply filters are inserted through the PCB where the cord exits from device, thus they prevent conducted emissions currents before exiting the device. However, regarding to the high frequency range of CE testing, and the fact that both CM and DM currents must be reduced, electric filters are not appropriate to reduce conducted emissions. Instead, power supply filters are designed to reduce both CM and DM currents across the entire conducted emissions frequency spectrum.

4.2.4 Precompliance Testing

The same general conclusions can be drawn for conducted emissions testing as the radiated emissions part, follow the full test method as closely as you can, and calculate (or at least estimate) your measurement errors and take them into account.

4.2.5 Conducted EMC Testing for Certification (Full Compliance)

To appreciate the constraints on fully compliant conducted tests you have to be familiar with the test equivalent circuit (Figure 4.8). This shows that in the mains port test you are measuring a combination of DM and CM sources on each line (L or N) with respect to the ground reference plane, which is connected to the EUT's 'earth' connections if it has any.

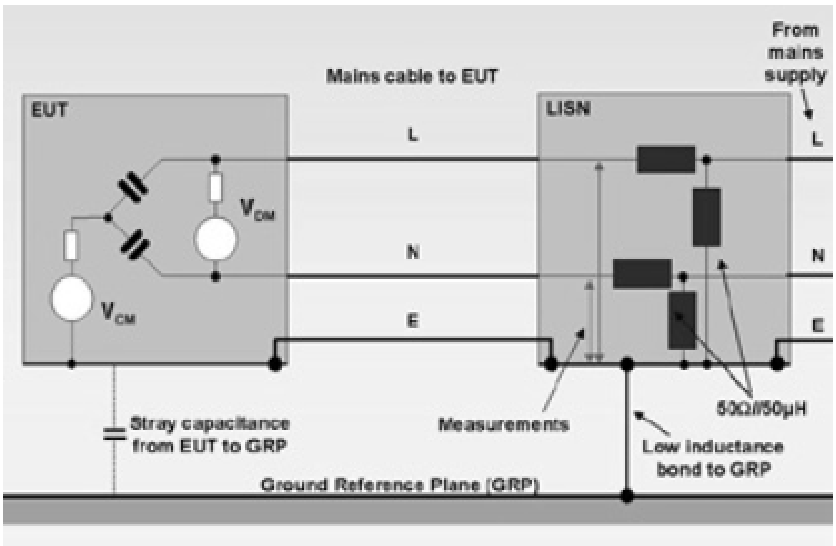
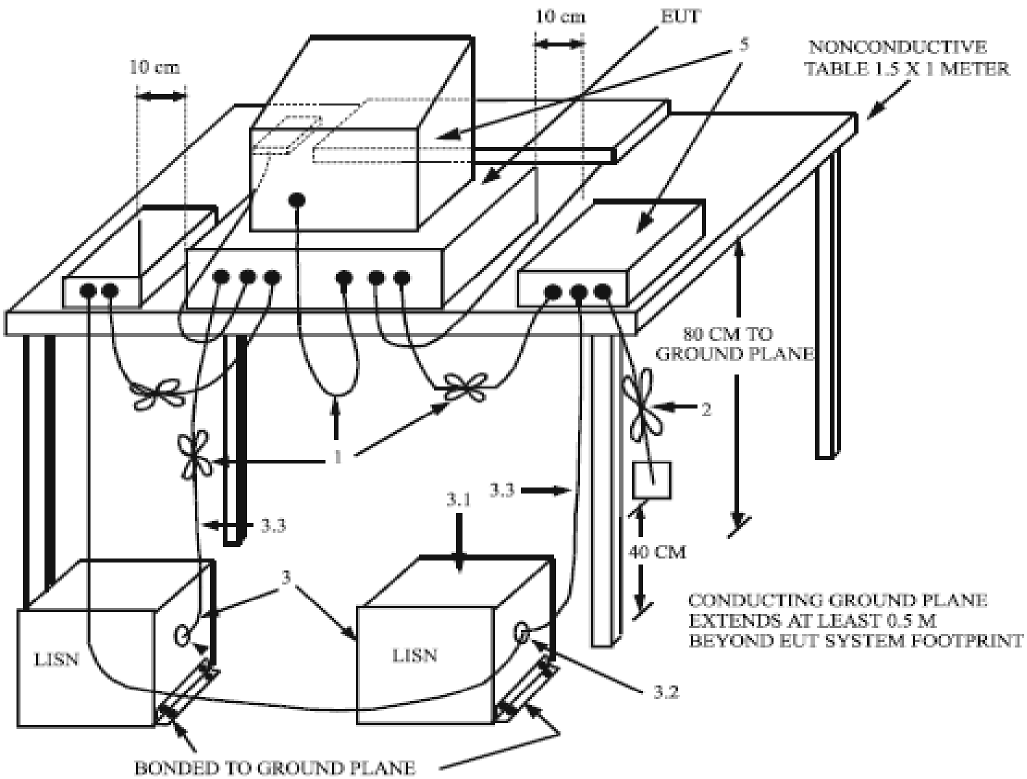


Figure 4.8 Conducted emissions test equivalent circuitry

The equivalent circuit shows that stray capacitance between the EUT and the GRP is an important part of the coupling path. The standard test set-up for table-top EUTs is shown by Figure 4.9 (similar figures based from EN 55022) and regularizes stray capacitance by insisting on a fixed separation distance between the two; 40 cm is the norm, with at least 80 cm clearance from all other conducting surfaces. For a fully compliant test you should be scrupulous in observing these distances. All test houses have an 80 cm wooden table on which the EUT can be sideways spaced by 40cm from a vertical GRP. An alternative that is allowed in some standards is a 40 cm separation from the bottom of the EUT to a horizontal GRP.



LEGEND:

1. Interconnecting cables that hang closer than 40 cm to the ground plane shall be folded back and forth forming a bundle 30 to 40 cm long.
2. I/O cables that are connected to a peripheral shall be bundled in the center. The end of the cable may be terminated, if required, using proper terminating impedance. The overall length shall not exceed 1 meter.
3. EUT connected to one LISN. Unused LISN measuring port connectors shall be terminated in 50 ohms. LISN can be placed on top of, or immediately beneath, reference ground plane.
   3.1 All other equipment powered from additionas LISN(s).
   3.2 Multiple outlet strip can be used for multiple power cords of non-EUT equipment.
   3.3 LISN at least 80 cm from the nearest part of EUT chassis.
4. Cables of hand-operated devices, such as keyboards, mouses, etc., shall be placed as for normal use.
5. Non-EUT component system being tested.
6. Rear of EUT, including peripherals, shall be aligned and flush with rear of tabletop.
7. Rear of the tabletop shall be 40 cm removed from a vertical conductive plane that is bonded to the ground plane.

Figure 4.9 Standard setup for conducted emissions test (EN 55022 Limits and Methods of Measurements of Radio Interference Characteristics of Information Technology Equipment)

4.2.6 Potentially Faced Problems During CE Tests

While performing CE tests, several types of protection methods must be implemented previously before energizing the system. This situation deals with the risk of electric shock and serious damage to test instrumentation.

Electrical Shock: If anyone deals with AC mains voltage, there is always a chance of electrical shock. Each device must be connected to a safety ground to prevent this problem. All LISNs must be connected securely to the ground plane and properly connected to the test facility's earth ground.

Damaging Instruments: I strongly recommend usage of a DC block for preventing DC voltage damage to instrumentation. A DC block prevents transient spikes or DC voltage on the coax, or transducer, from blowing out the front end of the instrument. The DC block does not change measurement results

Overloaded Analyzer: When performing CE testing, care must be taken to ensure that the front end of the spectrum analyzer, haven't become overloaded. This condition is possible when an analyzer is used without a front end RF preselector.

4.3 Harmonics & Flicker Tests

4.3.1 Harmonic Currents Test

The amount of reactive power drawn by given equipment for example a domestic television may be small. However within a typical street there may be 100 or more TVs drawing reactive power from the same supply phase resulting in a significant amount of reactive current flow. The generation of harmonics is a cost of the non linear behavior of the load. The major factor for this problem in electronic equipment is the mains rectifier. The situation is often seen in off line switch mode power supplies but it is not a consequence of the switching process but rather the mains rectification.

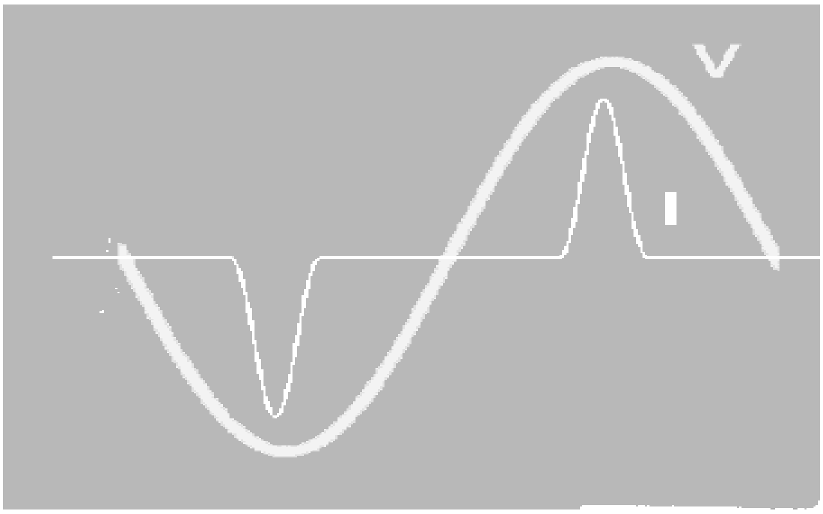


Figure 4.10 Current and voltage waveforms with single phase rectification

All equipment is classified as Class A with absolute harmonic current limits unless it is not. Portable tools become Class B, again with absolute harmonic current limits unchanged from EN 61000-3-2. Class C covers lighting equipment including dimmers and here relative limits are introduced for the first time. Dimmers for incandescent lamps whether integral or separate are required to meet Class A limits. If equipment has an input power between 75W and 600W and its input current wave shape falls within the "top hat" (95% of the time) it is categorized as Class D and new proportional limits apply.

Table 4.1 Harmonic limits specified by the EN61000-3-2 standard.

Harmonic order 'n'	Max current Class A	Max current Class B	Max current Class C (% of fundamental current)	Max current Class D (but no more than Class A)
2	1.08 Amps	1.62 A	2%	not specified
3	2.30 A	3.45 A	30 λ %	3.4 mA/Watt
4	0.43 A	0.645 A	not specified	not specified
5	1.14 A	1.71 A	10%	1.9 mA/Watt
6	0.30 A	0.45 A	not specified	not specified
7	0.77 A	1.155 A	7%	1.0 mA/Watt
8 ≤ n ≤ 40 (even)	0.23 (8/n) A	0.345 (8/n) A	not specified	not specified
9	0.40 A	0.6 A	5%	0.5 mA/Watt
11	0.33 A	0.495 A	3%	not specified
13	0.21 A	0.315 A	3%	0.35 mA/Watt
15 ≤ n ≤ 39 (odd)	0.15 (15/n) A	0.225 (15/n) A	3%	(3.85/n) mA/Watt

(λ is the circuit power factor)

4.3.2 Flicker Test

Flicker is concerned with the visual disturbance of filament lamps due to voltage fluctuations. It is caused by the finite source impedance of the mains supply and changing load impedance. EN 61000 defines it rather verbosely as: "Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time". The relative voltage change, d, is the change in relative voltage between periods of steady state of duration one second or more. Not all voltage fluctuations will produce a noticeable change in the illumination from a 60W filament lamp driven off the same supply. When such flicker occurs it is a serious nuisance to personnel.

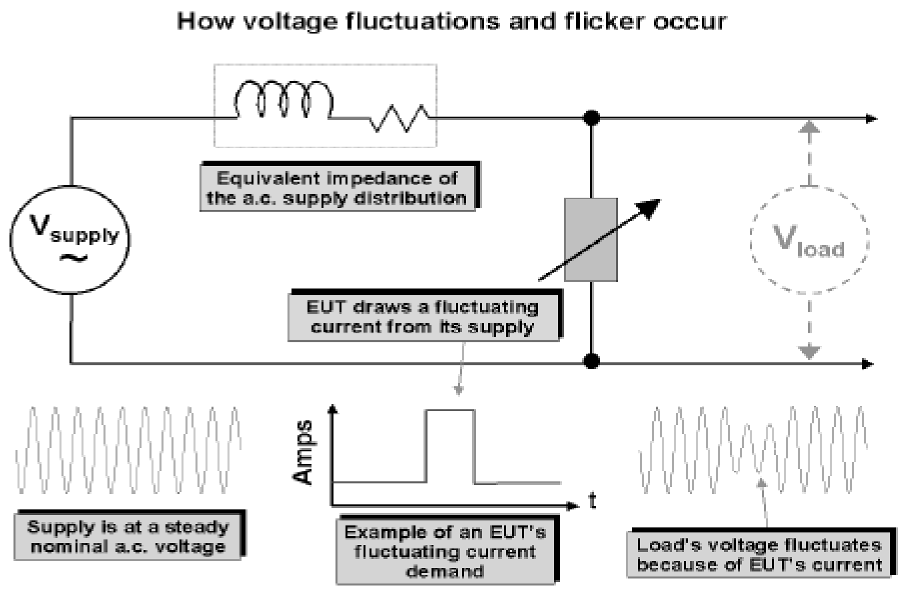


Figure 4.11 How voltage fluctuation and flicker occurs

The simplest case of flicker involves rectangular equidistant voltage changes. There are two flicker indicators defined in the Standard:

- **Short term Flicker Indicator** PST - The flicker severity evaluated over a short period (minutes).

- **Long term Flicker Indicator** PLT - The flicker severity evaluated over a long period (hours) of time using successive PST values.

CHAPTER FIVE
EMC IMMUNITY TESTING TECHNIQUES

Immunity (also called Susceptibility) is a measure of the ability of electronic products to tolerate the influence of electrical energy (radiated or conducted) from other electronic products and electromagnetic phenomena. "The financial rewards of producing reliable products can be very great indeed, as one UK manufacturer discovered when they spent £100,000 on redesigning their products to comply with just the ordinary EMC directive immunity Standards, and found that as a direct result, their warranty costs fell by £2.7 million a year" (Quoted from "EMC testing part 4 - Radiated Immunity" by Keith Armstrong and Tim Williams).To perform an immunity test, the manufacturer defines performance criteria against which a product will be assessed. These are commonly divided into three categories:

- The product continues to operate as intended.
- Degradation of the product performance occurs, but normal operation resumes at the end of the test with no data loss.
- The product either stops functioning or its performance degrades and does not recover after the test without intervention.

Whenever performing immunity testing, it is very important that the performance criteria and the monitoring method be clearly defined. The product should be operating in a fully exercised mode, allowing for the easy observance of failures. There are three common tests performed for all equipments to make sure about EMC with radiated fields. These are detailed as follows:

- Radiated Immunity Testing
- Electrostatic Discharge – ESD (both takes place in the conducted currents and radiated fields contents)
- Power Frequency Magnetic Fields

5.1 Radiated Immunity

With this EMC test method the simulation of the disturbances produced by radio transmitters such as cellular phones are tried to be realized. A standard test configuration for RF immunity test is shown in Figure 5.1.

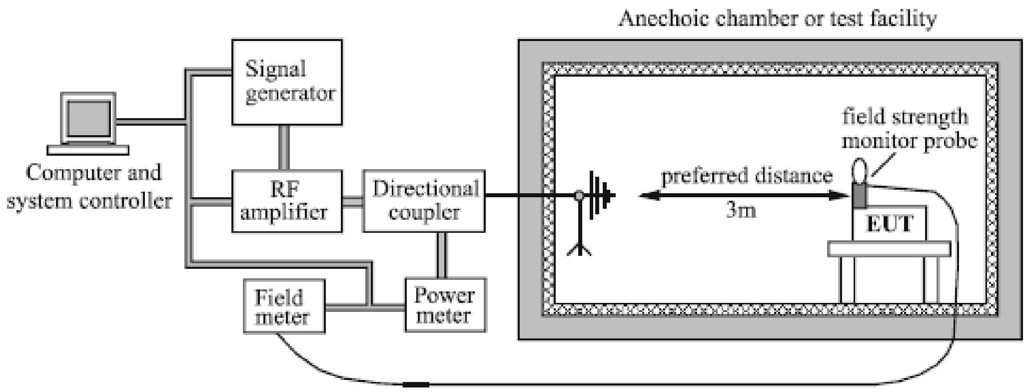


Figure 5.1 Standard test set up for RF immunity test (IEC/EN 61000-4-3. 1997. *Electromagnetic Compatibility Part 4 Testing and Measurement Techniques,* Section 3)

The main idea of radiated immunity testing is to create a constant uniform field over a specific volume in which the EUT is located. If a uniform field is developed across the device, it is assumed that the test will be repeatable when fully exercising all operational circuits of the EUT. The fundamental requirements contain RF signal source, broadband power amplifier, antenna and the test facility (chamber).

More detailed information about radiated immunity test can be obtained from the standard IEC/EN 61000-4-3. 1997 "Electromagnetic Compatibility Part 4 Testing and Measurement Techniques, Section 3 Radiated Radio Frequency Electromagnetic Field Immunity Test.

5.2 Electrostatic Discharge (ESD) Test

The causes of ESD events can be separated into two parts, one is static electricity. Static electricity is usually generated through tribocharging, the separation of electric charges that happens when two materials are getting into contact and then separated.

We can summarize examples of tribocharging as walking on a rug, rubbing plastic comb against dry hair, ascending from a fabric car seat, or removing some types of plastic packaging.

The second cause of ESD damage is electrostatic induction. This happens when an electrically charged object is placed near a conductive one which is isolated from ground. The existence of the charged object creates an electrostatic field that causes electrical charges on the surface of the other object to redeliver. There are two main discharging types, one is direct and the other one is air discharge. In the figure below, two waveforms of discharging presented.

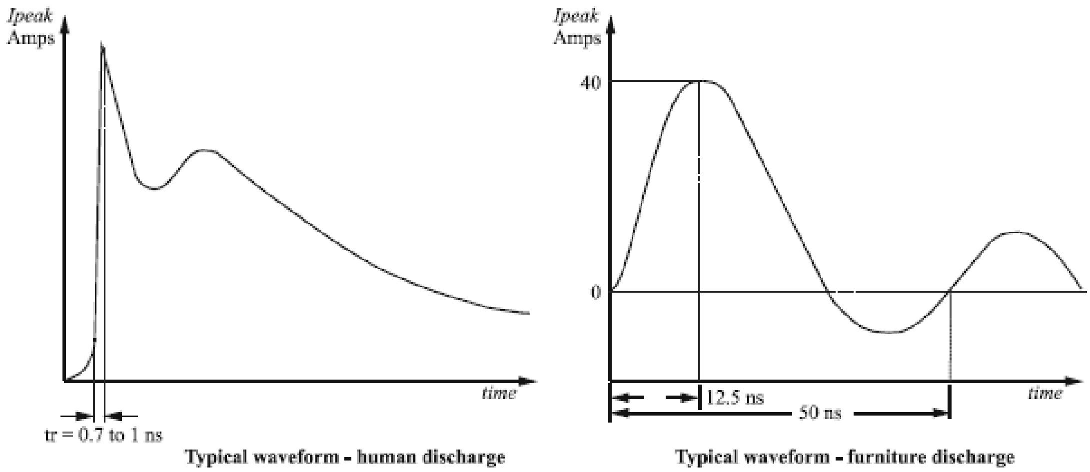


Figure 5.2 Waveforms of two main discharging types

A standard ESD test setup contains the following components.

- Ground reference plane (GRP)
- ESD simulator and appropriate test electrode (tip)

You must apply direct discharges through the points and surfaces accessible to operators during normal usage, including production staff. Areas that are accessible to maintenance personnel internal to the system need not be tested, as maintenance personnel should have already discharged themselves when approaching this section of the EUT.

For the air discharge test, the discharge switch is closed and the round tip of the simulator touches the EUT as fast as possible, coherent with not causing mechanical damage when the tip contacts the coupling plane or EUT. This test most closely achieves the real world environment because in a typical situation ESD results from a charged human body or furniture that usually approaches the receptor equipment gradually. For a reminder, atmospheric conditions such as humidity and air pressure may influence test results, in addition, the speed of approach can also change test results considerably.

5.3 Magnetic Field Disturbance Test

The written EMC Standard for power frequency magnetic fields, EN 61000-4-8, defines methods of generating consistently reproducible magnetic fields. To provide compliance to the generic immunity standard for residential and commercial products is 1 or 3 A/m until 30 A/m for industrial products.

Magnetic field disturbance test is designated for proving the susceptibility of equipment when vulnerable to magnetic fields with respect to specific location and installation conditions. It is strongly recommended that apply these test for all products, even if it is not legally wanted. The magnetic field is generated by power frequency current in conductors or, less frequently from other devices, in the nearness of equipment. The EUT can be evaluated in an open area, as ESD, without any need for a shielded room. In addition, placement of a staff next to the EUT must not affect results. Precautions shall be taken to guarantee that the radiating magnetic field does not interfere with the other instruments or sensitive equipments near the setup. The test setup comprises the following components:

- Ground reference plane
- Induction coil
- Test generator

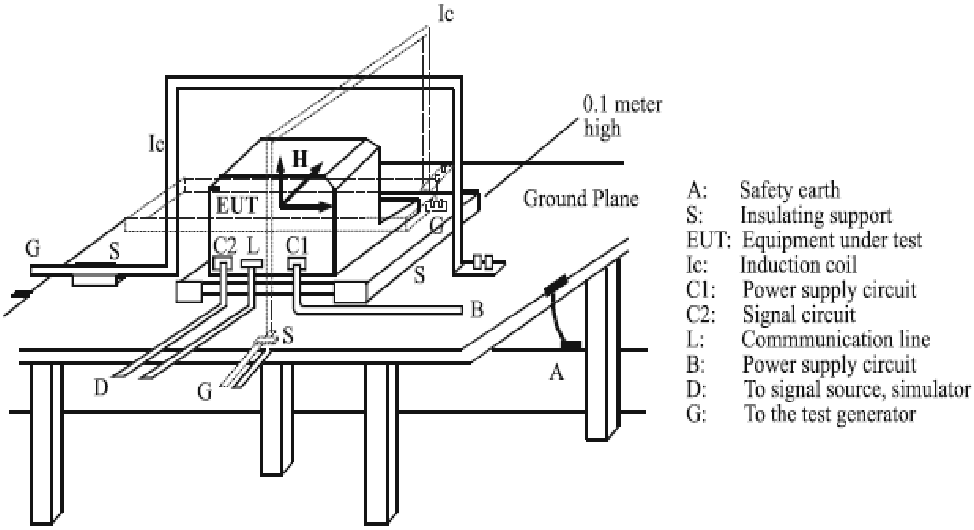


Figure 5.3 Table top equipment set up for magnetic field disturbance test

The test shall be performed with a test plan, the power supply, signal, and other functional electrical parts of the system shall be operated at nominal values. If actual operating signals are not available, they may be simulated. For table top equipment, all the dimension of EUT is submerged by the induction coil. For the floor standing equipment, the induction coil must be travelled around the unit by 360° in order to test all the volume of the EUT including each direction.

5.4 Electrical Fast Transient and Burst Tests

When a circuit is switched off, the current flowing through the switch is interrupted instantaneously. At the point of instantaneous switching, an infinite di/dt is generated. Some types of load, such as motors or solenoids, have considerably inductance. The voltage developed across an inductance L by a changing current I is $V = -L \cdot di/dt$.

The fast transient burst test aims to simulate the disturbances created by a ‘showering arc’ at the contacts of ordinary AC mains switches or relay contacts as they open, due to the fly back voltages caused by inductive energy storage in the current path. Figure 3C shows the standard waveform for the EN 61000-4-4 FTB test. It consists of a single unidirectional impulse repeated at a 5 kHz rate in bursts lasting 15 milliseconds each, with three bursts per second. Figure 3D shows the basic scheme of the waveform generator and Figure 3 shows the standard test set-up. These three figures are all developed from the EN 61000-4-4 standard.

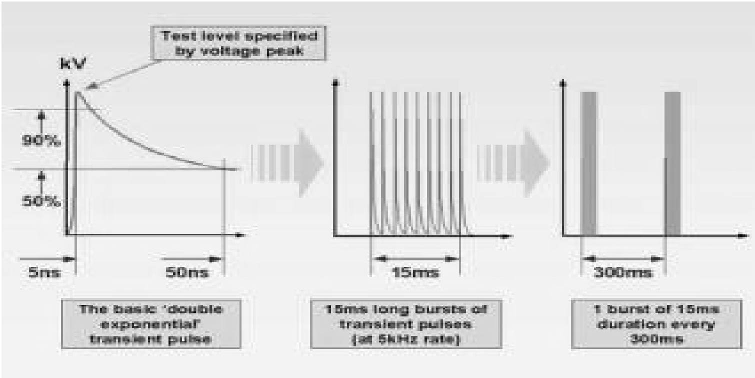


Figure 5.4 a) FTB test waveforms

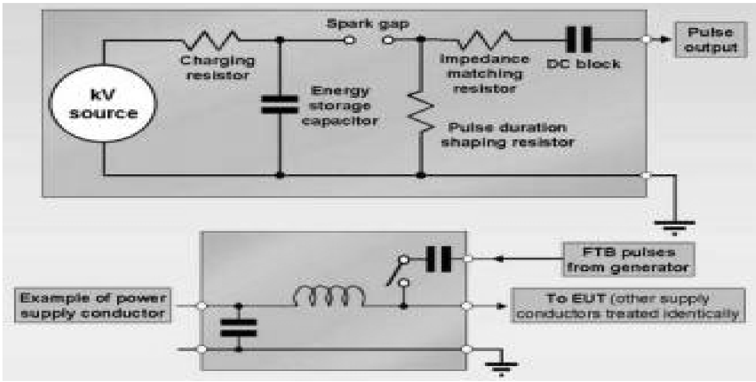


Figure 5.4 b) Generator and coupling network circuitry

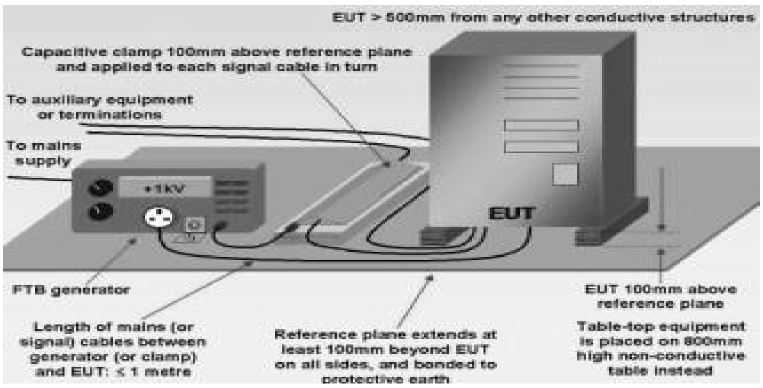


Figure 5.4 c) FTB test setup

In order to minimize the bad effect of EFT on electronics devices, the following steps should be sticked directly to:

a) Internal circuit design must be made bandwidth limited wherever possible, and the PCB layout prevents large interference voltages from appearing within the circuit,

b) Interfaces must be filtered or screened to a structural low impedance earth so that common mode pulses are prevented from entering the circuit.

5.5 Surge and/or Lightning Test

The surge test aims to simulate the effects of lightning on AC power supplies and any long cables. 'Long cables' is usually taken to mean metallic interconnections longer than 10m between different items of equipment which are themselves some meters apart, or outdoor cables. High energy transients appearing at the ports of electronic equipment are caused by nearby lightning strikes or power system disturbances such as fault clearance or capacitor bank switching. Lightning can produce surges with energies by the following mechanisms shown in the figure below.

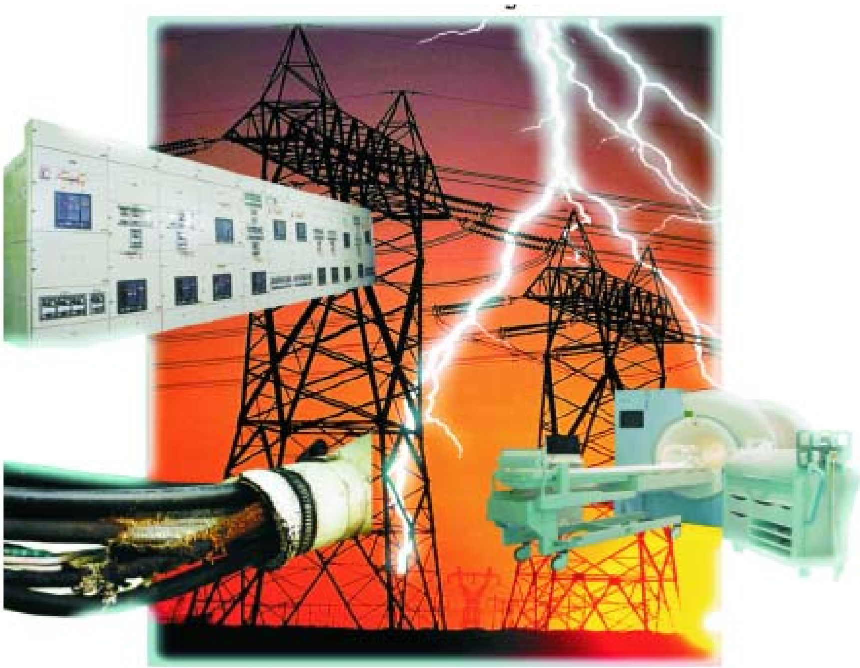


Figure 5.5 Some of the Surge – Lightning source examples

Fault clearance upstream in the mains supply distribution network produces transients with current that can go up to hundreds of amps in residential or commercial circuits, and higher for some industrial supplies. Power factor correction capacitor switching operations generate damped oscillations at very low frequency (typically kHz) lasting for several hundred microseconds.

Surges striking on electronic devices may cause hardware damage and complete failure. It may also cause the system to malfunction or hanged. Some electronics components may be damaged and need to be changed. The protections used against surge include adding parallel surge suppression devices such as clamping diodes, varistors or spark gaps. The purpose of these devices is to break down in a controlled manner at a voltage lower than can be sustained by the circuit, and dissipate the surge energy within them.

5.6 Conducted Immunity

EN/IEC 61000-4-6, the basic test method for "*Immunity to conducted disturbances, induced by radio frequency fields* ", is a complex standard which is very easy to misinterpret. This section offers a simplified stroll through the minefield to highlight the principal requirements. The basic requirement for the test system is to generate a modulated RF signal of sufficient amplitude, swept or stepped over the frequency range from 150 kHz to 80MHz. The system normally uses a standard GPIB controlled signal generator feeding a broadband linear power amplifier of the required power level, Table 5.1 gives the necessary power levels for a 10V (level 3) test, depending on transducer.

Table 5.1 Power levels required for 10 V of EMF (values taken from EN61000-4-6 standard)

Transducer Type	**Coupling Factor**	**Required power output from the amplifier**
CDN	0 dB	7 W
Current clamp	-14 dB	176 W
EM clamp	-6 dB	28 W

Because it is invasive, it may also have a significant effect on the signals carried in the cable, particularly if these are broadband. For some types of cable, particularly mains and DC power, low frequency signals, audio telecom, and the more common types of screened cable, it is reasonable to have a variety of CDNs on the shelf which you can select for particular tests. It requires no connection to the cable under test and is therefore popular for situations where many different types of cable must be tested, and it is also reasonably efficient, as Table 5.1 demonstrates.

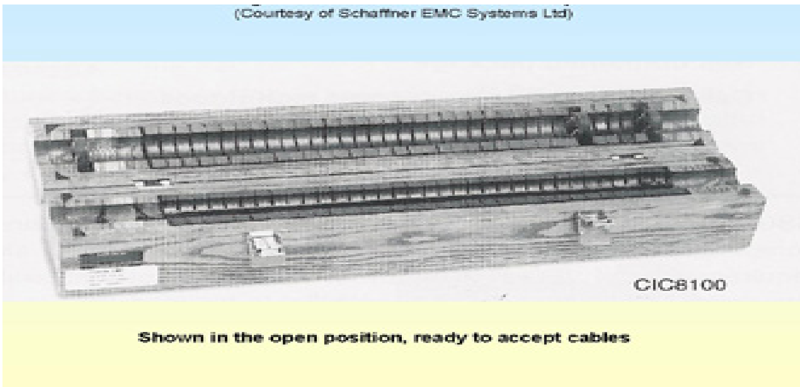


Figure 5.6 Picture of EM coupling clamp (Schaffner EMC systems)

Figure 5.7 shows an example test set-up for compliant conducted RF immunity tests to EN 61000-4-6. The important aspects of the test setup are to control the common mode impedance presented by the transducers, the EUT and its AE, and to ensure that cable resonances are avoided. The first of these is achieved by having an adequate ground plane for the whole test area, and placing the EUT a defined distance (10cm) above this ground plane.

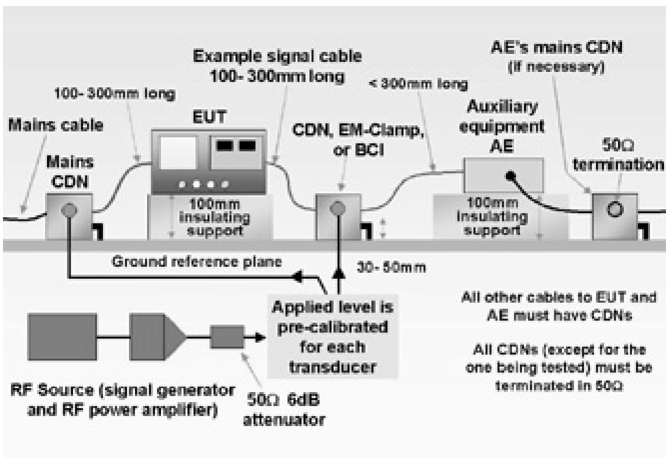


Figure 5.7 Conducted immunity test setup

Cable resonances are potentially serious. A distance of a quarter wavelength transforms a short-circuit impedance into an open circuit, completely altering the coupling properties of the setup. A quarter wave lengths at 80MHz is 94cm and therefore no cables included in the test environment should approach this length, even if they are not being tested. The standard insists that on the tested cables, the coupling/decoupling devices should be between 10 and 30cm from the EUT and the cables themselves should be maintained 3-5cm above the ground plane, as short as possible and un-bundled. When you are using the current injection probe, the cable length on the other side of the probe (the AE side) should also be less than 30cm.

5.7 Voltage Dips, Interruptions and Dropouts Test

According to some experts, the effects of poor AC supply quality on electronic equipment are one of the most significant world-wide causes of downtime and financial loss. Dips, sags, brownouts, swells, voltage variations, dropouts and interruptions are the main causes of poor supply quality. (In some areas waveform distortion is also becoming an important immunity issue, but that is not covered in this thesis.)

EN 61000-4-11 is the basic test standard for dips, sags, brownouts, swells, voltage variations, dropouts and short interruptions in the AC mains supply called up by the various generic or product-family harmonized EMC standards. When using the Technical Construction File route to conformity with the EMC directive it is possible to use directly.

Dips are short-term reductions in supply voltage caused by load switching and fault clearance in the AC supply network. They can also be caused by switching between the mains and alternative supplies in uninterruptible power supplies or emergency power back-up systems. Examples of dips: 30% dip for 10ms, 60% dip for 100ms. Figure 5.8 shows a 40% dip for 20ms (one mains cycle). A dip of 40% is equivalent to a reduction in supply voltage to 60% of its nominal value.

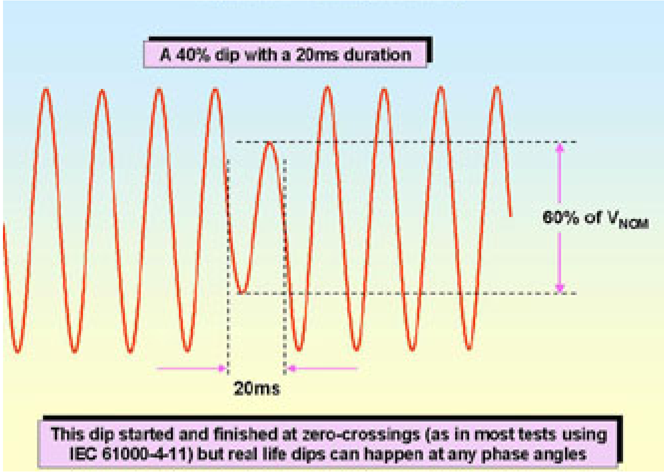


Figure 5.8 A typical example for voltage dips waveform

Short interruptions are 80 - 100% reductions in supply voltage (dips of 80% or more) lasting for up to 1 minute. The term 'dropout' is commonly understood to mean the same thing. Interruptions in the mains supply of more than one minute are simply called 'interruptions' and are not covered by EN 61000-4-11. Figure 5.9 shows a short interruption which is 60ms long (3 mains cycles). Like dips, they are caused by load switching and fault clearance.

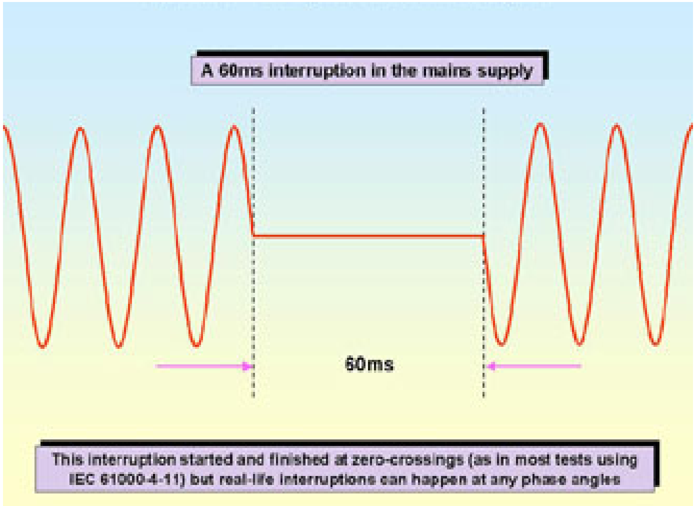


Figure 5.9 A typical example for short interruption waveform

The test set-up is very simple and is shown in Figure 5.10.

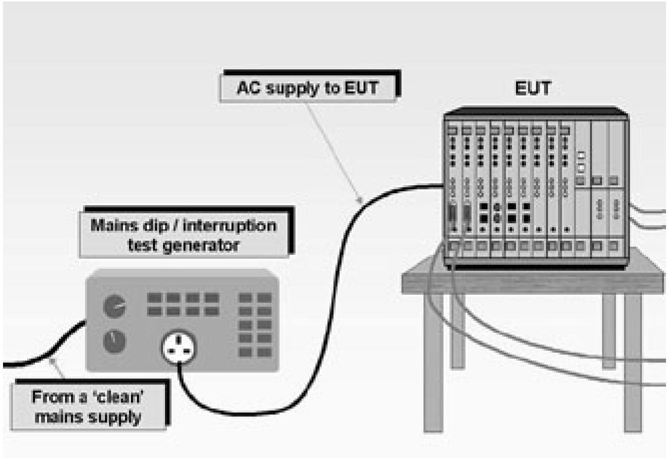


Figure 5.15 Voltage dips and interruptions test setup

There are no special requirements for the test environment, except that the electromagnetic environment should allow the correct operation of the EUT and the mains voltage must be monitored and be within 2% of the desired value. The temperature, humidity and air pressure requirements are also very loose (15-35^{O}C, 25-75%, 860-1060 mbar), allowing full compliance tests to be done on almost any test bench or floor in most places.

The functions of the EUT must be monitored adequately to identify any degradation during and after each test, and after each group of tests a full functional check shall be performed. In many cases a momentary dimming of displayed images or illumination is permitted during the test. Where the EUT's rated supply voltage range does not exceed 20% of its lowest voltage, any voltage within that range can be used for the test.

Alternative methods are unlikely to be necessary for most of the tests described in this section, because they are so easy to do in a wide variety of environments. However, when an alternative immunity test method is used for whatever purpose (e.g. design, development, troubleshooting, QA, variants) repeatability is very important, even though the correlation with the full compliance test method may not be. Hence all such tests should follow a written procedure which has been carefully worked out to ensure adequate repeatability. They should also incorporate as many of the specifications of the full compliance tests as are relevant.

CHAPTER SIX
ACHIVING FULLY ELECTROMAGNETIC COMPLIANCE

The costs of dealing with such issues, even if they only occur on one out of ten systems, can be so high as to compromise the financial viability of a company. There are actual examples where a single interference problem has made a company bankrupt, and this is of special concern where a contract includes penalty charges. The EMC compliance and reliability of a final apparatus, whether it is a product, system, or installation, is the legal responsibility of the final manufacturer or assembler. Many final apparatus contain complex electrical and/or electronic items that have been purchased from other suppliers, for example:

- Finished products may contain bought-in sub-assemblies such as computer boards, or complete units such as power supplies, PLCs, computers, motor drives, panel meters, instrumentation and control modules, etc. (some of which may be finished products in their own right).
- Finished systems and installations are usually constructed from bought-in finished products, and systems, such as computers, telecommunications gear, instrumentation and control equipment, machinery, etc.

The biggest problem faced while working the EMC phenomena on TFT and Plasma televisions are emission problems, especially radiated emissions (RE) and conducted emissions (CE). TFT and Plasma televisions have different working principles than cathode ray tubes (CRT). CRT TV has a working principle depends on interlacing. TFT and plasma TV uses de-interlacing method for converting the broadcast to progressive, while achieving this operation buffer circuits, rams and scalars are used. The usage of these components brings other high frequency EMI problems because their working principles depend on fast high frequency digital signals.

While working on the radiated emission side plasma TVs have a great advantage when compared with Liquid Crystal Displays (LCD) TVs. This advantage arises from the metal back cover of the plasma TVs. The source of the emission is caught in a trap between the display and the metal cover; this situation can be considered as the “Faraday Cage” rule applied on the interference source. On the side of the LCD TVs plastic back cover became a disadvantage, because there is no cage which is protecting the environment from the interference.

6.1 Troubleshooting by General System Checking

The personnel related in the area of EMC shall be convenient for understanding different approaches regarding to test and certification followed procedures detailed in regulatory standards, lets say it domestic, international, military, or customer specific. Many test laboratories and EMC staff perform the testing only to a product. If any failure is observed; like emissions over the limits or a system shutdown due to an immunity. The product is generally sent back to the customer without detailed investigation.

When EMC testing has been fully finished related to emissions and immunity testing and a failure is found, the next step is to analyze what to do next and where the problem area is. A radiated emission is due to current flow. Therefore, first solution to achieve in radiated emission problem is to decrease unwanted RF currents by using a conducted solution.

6.2 Troubleshooting on Emission Testing

Every EMI section has three parts: an energy source, a coupling path, and a receptor (we can call it as a victim) of the noise. Troubleshooting should be managed toward trying to discover where this energy is coming from and removing the element with the easiest way for achievement. While these investigations matters to consider include the following:

- What is the source and frequency of the noise,
- Is it continuous or periodic,
- Does the problem happen in relation with another problem,
- How is the noise getting to the victim or receptor,
- What is the error that is observed,
- Is disturbance temporary or any permanent damage occurred?

Answers to some of these questions will come out during identifying process of the event. Identification of the problem is the first step in troubleshooting. What is the failure mode and what do the symptoms indicate? Which part of the equipment is affected, and if it is an immunity problem, at which frequency does the product fails? The same procedure is valid for emissions that exceed the limits specified in the standards.

Most of the times a radiated emission problem may be due to several leak points, like a bucket with holes trying to hold water. Plugging only one hole will not save the bucket from draining water away; it will continue to drain until all the holes are plugged. We can think EMI working the same way. Therefore, when plugging one hole and then removing it in an attempt to plug another hole, the bucket will never stop leaking water. Only after all the interference has been stopped, it is suitable to determine which modification is necessary. (Mardiguian, M. (2000). *EMI Troubleshooting Techniques*, New York: McGraw-Hill)

6.2.1 Careful Attentions Related to Radiated Emission Testing

While performing radiated emission tests, the following procedures provide guidance on what must be evaluated. Consideration must be also made with respect to the environment and special properties of the EUT, which can differ with each product tested:

1. You must make an ambient scan at the chosen test point with the EUT turned off or in standby mode? If there is no possibility to assort the EUT from the ambient,

supposing the EUT can not be powered off in any condition, measured test data will generally be inaccurate.

2. A measurement with sweeping peak detector may be preferred with rationally fast scan speed, thinking about the EUT cycle timing. With this scan you can identify parts of the frequency spectrum in which the EUT emissions are more significant.

3. The steps explained above must be taken into account at all positions of antenna. It is strongly recommended to test all four sides of the EUT with the antenna measuring each side.

6.2.2 Careful Attentions Related to Conducted Emission Testing

While performing the conducted emission tests, most of the major concerns lay besides coupling of the interference to the ground reference plane, in other way stray capacitance between the EUT and earth, and layout of cable assemblies, especially AC mains.

When performing conducted emissions EMI testing and debugging, usage of a ground reference plane is highly necessary. EMC personnel must use what is available. Regarding ground reference planes, CISPR 16-2 suggests the following:

1. The existing ground system at the ambient of installation shall be used as the referenced ground. This reference system should consider the possibility of high-frequency (RF) noise. Usually, this is achieved by connecting the EUT, with wide and flat straps with a ratio of length over width not passing 3, to structural conductive parts of buildings which are connected to earth ground.

2. Generally, the safety conductors and neutrals of a test facility may not be appropriate as a reference ground, because these conductors may carry inessential disturbance voltages that can have undefined RF energy.

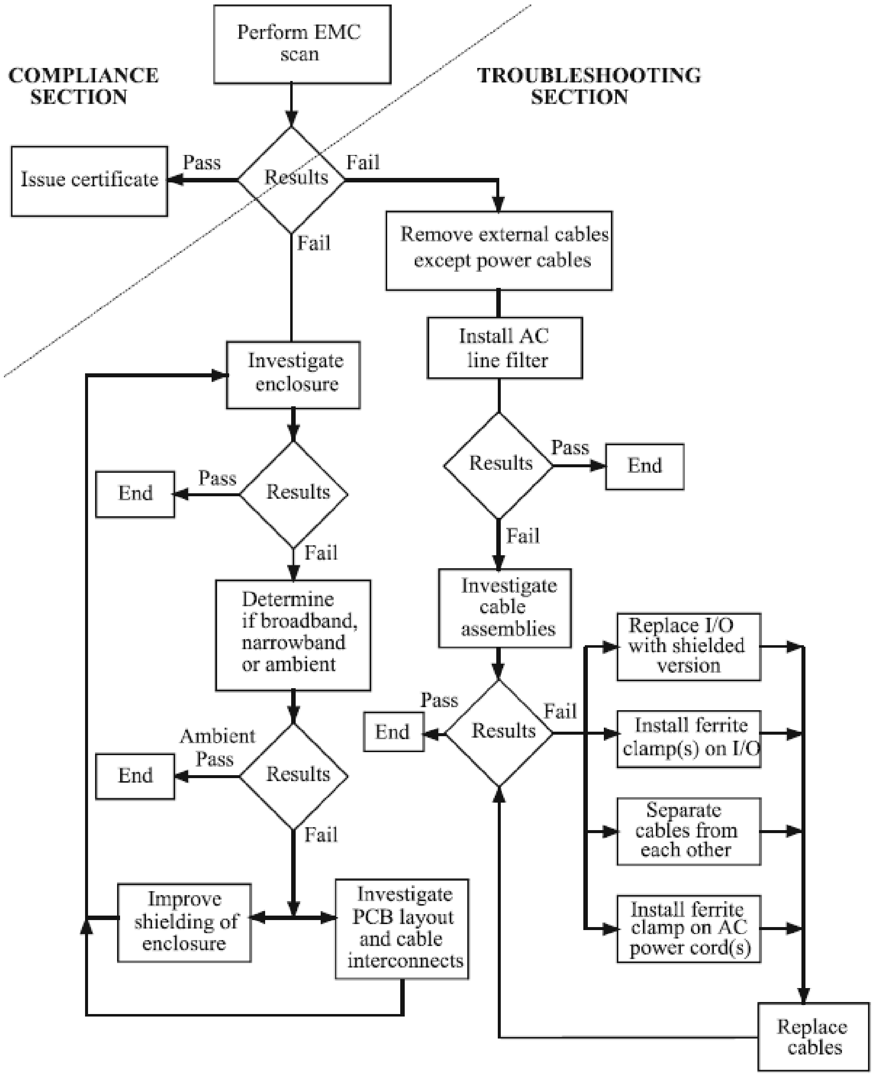


Figure 6.1 Simple and useful flowchart for Emission Troubleshooting

6.2.3 Emission Modification Tricks for Televisions

The main EMI reduction techniques in all TV designs are to increase conducting line isolations from each other and to decrease coupling impedances. Most of the couplings occur from high current and voltage changes, to decrease these couplings we must decrease the line impedances as possible. Line impedances can be decreased with; short line length, bigger line width, bigger line surface, small current loops and with no trespassing between these explained properties.

In the figure below the frequencies in common use in civilian daily life, from AC power lines through audio frequencies, long, medium, and short-wave radio, FM and TV broadcast, to 900MHz and 1.8GHz cell phones are listed.

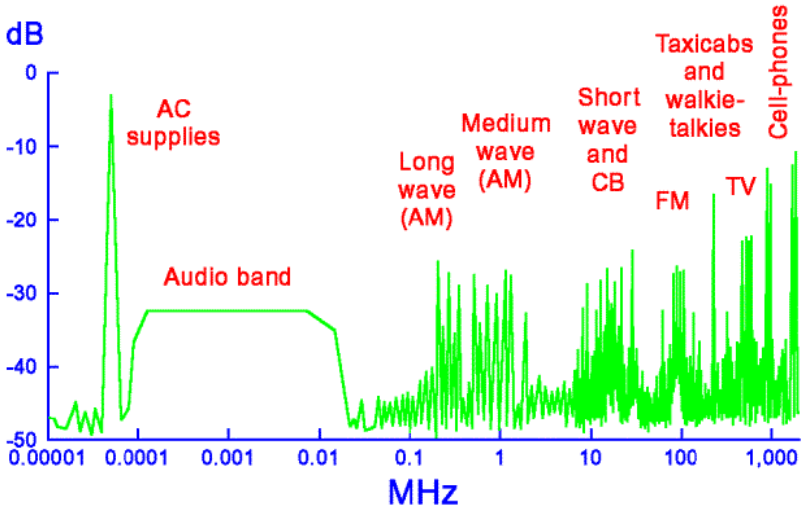


Figure 6.2 a) The frequencies we use in our daily life

The real spectrum is busier than this with all of the range above 9 kHz is used for something by someone. This figure will soon need extending to 10 (or even 100GHz) as microwave techniques become more commonplace in ordinary life. Figure 6.2 b overlays the usage spectrum of Figure 6.2 a with a less familiar spectrum showing the typical emissions from commonplace electrical and electronic equipment.

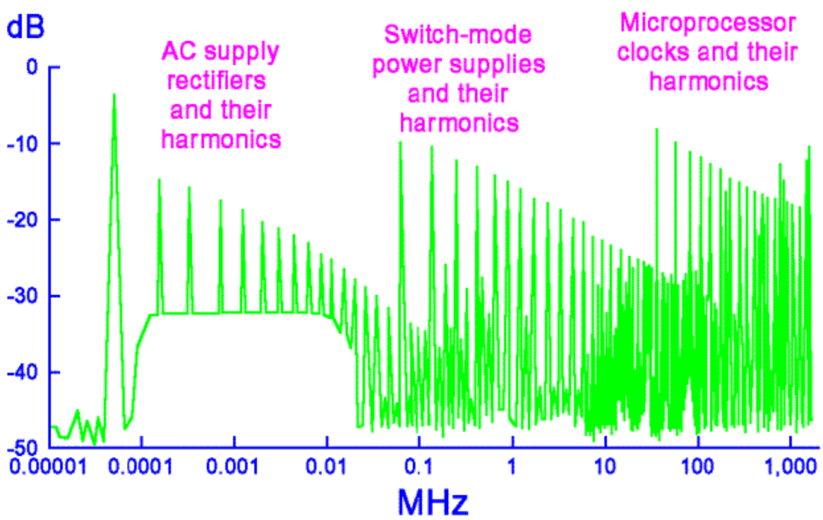


Figure 6.2 b) The frequencies plus the interference we create

6.2.3.1 PCB Layout

High frequency signals are the first to be careful while working on the ground distribution topic. Bigger emissions can occur, if high frequency signals develop large loops. This problem can be fixed with ground plains in multiple layered PCBs, but for double layer PCBs we need other methods for back current roads. Ground gridding may be the best choice among these methods. Ground gridding simulates ground plains and acts like them in double layered PCBs.

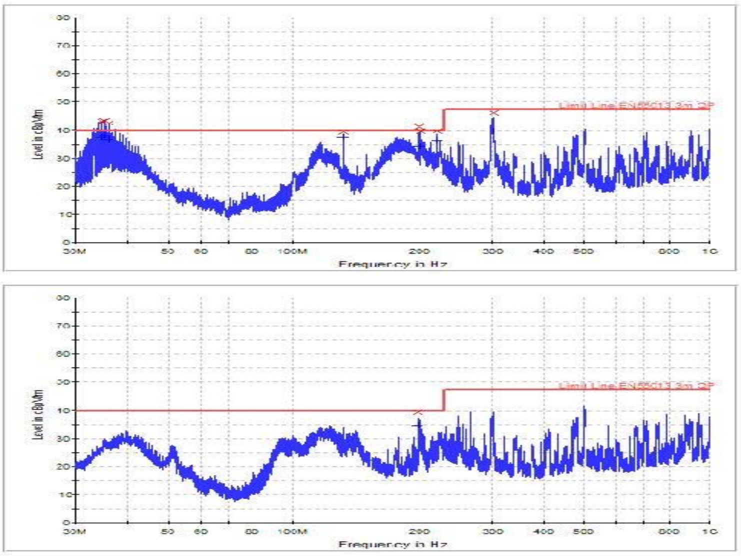


Figure 6.3 Ground gridding effect on PCB

An interference caused by a functional block in a TV between a frequency band of 30 to 300 MHz has been erased with ground gridding method. Ground gridding has an effect of shielding EMI as ground plains.

A ground plane is ideally a solid copper sheet in (or on) a PCB. It is definitely not a ‘copper fill’ or ‘ground mesh’. Planes must lie under all of their associated components and their traces and the 0V reference plane should extend beyond them on all sides of the PCB by as far as possible. It may even be worthwhile making a PCB larger simply to extend its 0V plane even further beyond the PCB’s devices and traces. One reason for this is that signal or power return RF currents flowing in the plane layer adjacent to the trace follow the path of the trace. The RF current also spreads out in the plane to either side of the trace's route, as shown by figure 6.4.

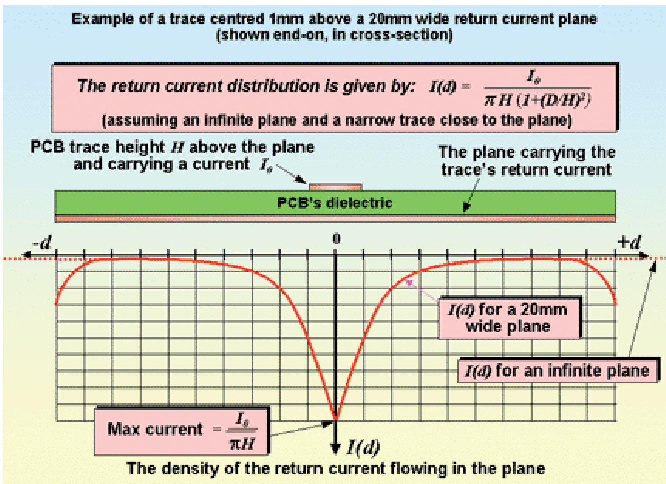


Figure 6.4 The distribution of a trace return current in a plane

About 95% of the return current is generally assumed to travel in a strip of plane as wide as 3 times the trace-plane spacing (H) or three times as wide as the trace width (W) whichever is the smaller centered along the trace's route. It is considered to be an important basic PCB layout technique not to have any holes, splits or edges in this region of the plane.

Figure 6.5 shows some of the common mistakes when traces are routed too close to antipads, plane splits or edges, thereby adding impedance to the return currents and worsening EMC. Note that adding impedance in a return current path has the same bad effect on wave shape as adding impedance in the send path.

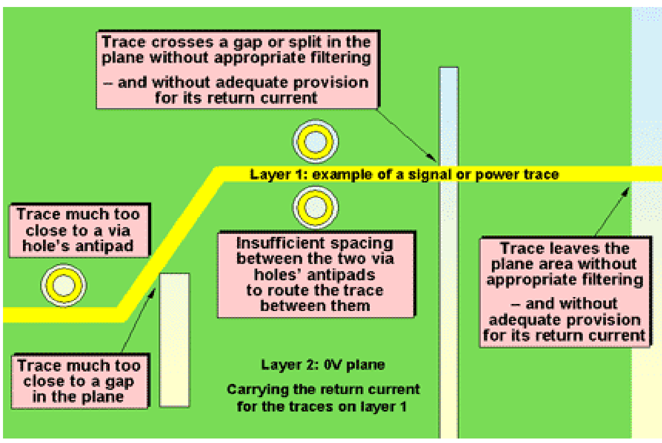


Figure 6.5 Some examples of common trace routing errors

The EMC phenomena start with the layout production and goes until the manufacturing stops. Practiced modification suggestions can be given as follows;

- Clock signals must transferred close as possible to groundings.

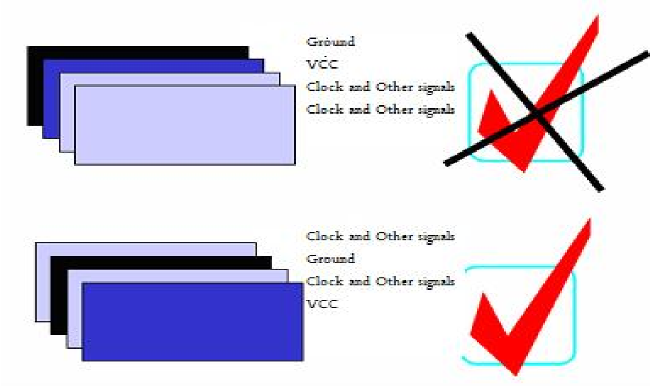


Figure 6.6 Suggested orientations of signals

- High frequency signal lines must be terminated.

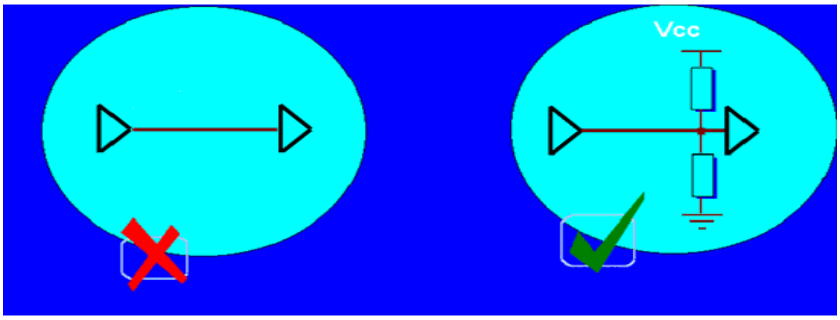


Figure 6.7 Correct terminations for high frequency lines

- Some of the termination techniques.

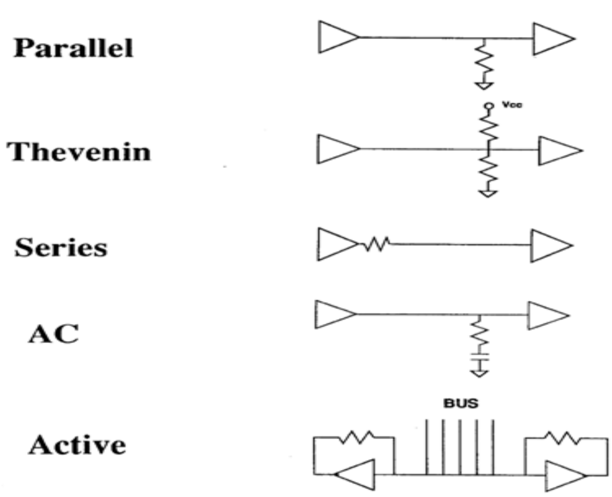


Figure 6.8Termination examples.

- High frequency signal lines shall be short as possible (LVDS, RAM etc...)

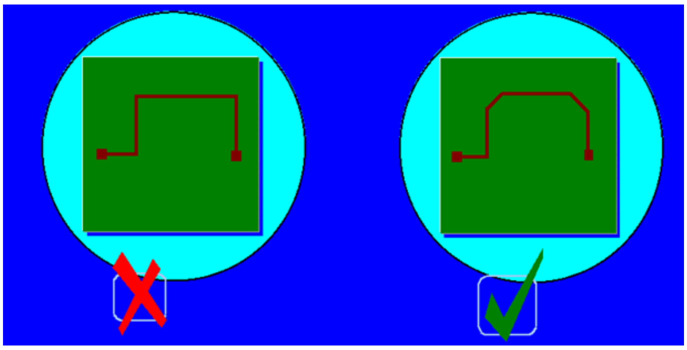


Figure 6.9 Smooth edges cause increased EMI.

- High frequency signal lines shall not form closed loops.

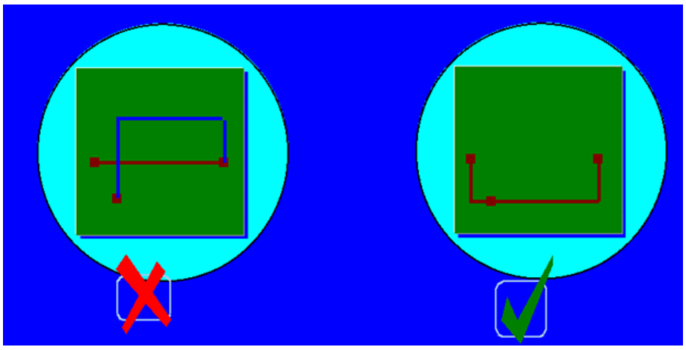


Figure 6.10 Closed loops increases interference

- Appropriate decoupling decreases the interference on the IC and power supply parasites.

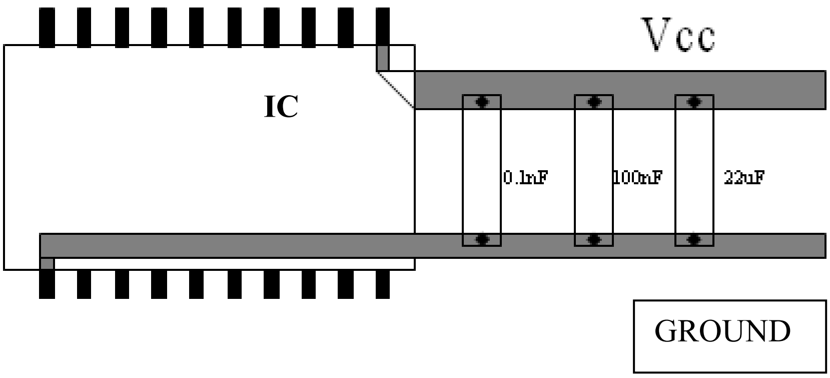


Figure 6.11 Decoupling to decrease EMI

6.2.3.2 Connecting components

Having gone to the trouble of creating planes with very low impedances (over the frequency ranges where we want to control EMC), the benefits of the planes can be compromised by the impedance of the connections between the devices and the planes. We need to minimize the inductance of the component to plane connections.

- Reducing the length of any trace. This applies to any trace used to connect the component's solder pad to the through / via hole that connects it to the plane layer.
- Increasing the width of any trace. As a general guide, the inductance per millimeter length reduces as the square root of the increase in trace width. So halving the inductance requires the width to be increased fourfold.
- Using multiple through-holes or via holes in parallel. The reduction in inductance is greater, the further they are apart. But if traces have to be used to increase the spacing, their extra inductance will reduce the benefit of paralleling.
- Increasing the diameter of a plated hole to decrease its partial inductance. As a general guide, the inductance per millimeter length reduces as the square root of the increase in diameter.

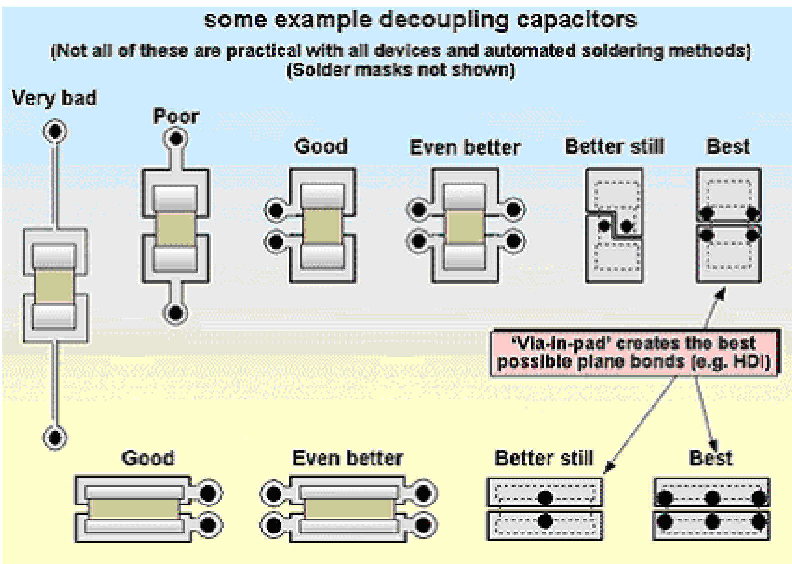


Figure 6.12 Plane connection method that minimize inductance

One of the TV projects' modification example with respect to the grounding can be given as follows. The TV was tested among the EN55022 standard and NOK test results observed. Test was made with cable terminations in VGA mode, so the cables act like antennas because of the bad grounding. After making some works we analyzed that the problem was based on the HDMI card emissions. The test graph before modification can be seen in figure 6.11.

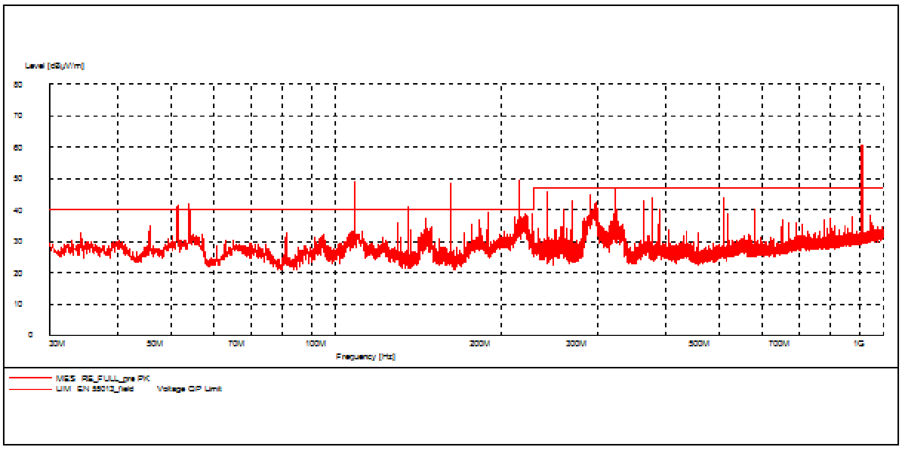


Figure 6.13 Test result obtained from EMI receiver before modification.

The modifications made for the decreased EMI are;

- Metal bracket used for powering up the ground of the HDMI connectors.
- Ground grids added to the HDMI card and it is connected to the metal bracket with metal screws.
- The six group resistances which were on the HDMI lines were exchanged with SMD ferrites on the main board.

Test result after modification can be seen as follows. It can be easily analyzed from the test graph that the modifications had a really good affect on the test result. In figure 6.15 all the modifications are specified.

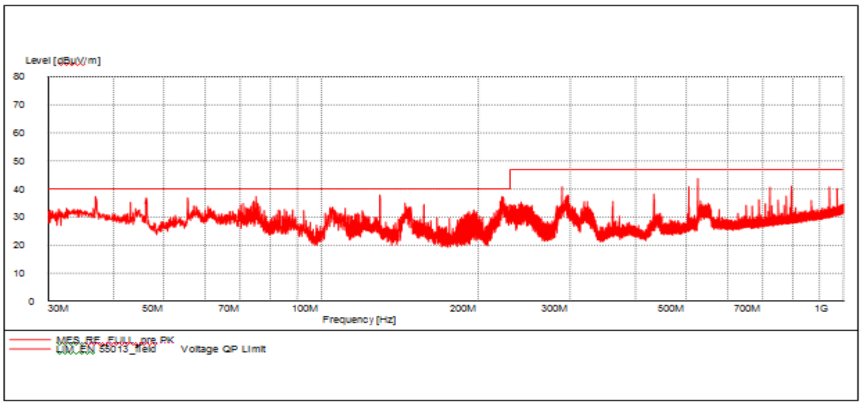


Figure 6.14 Test result obtained from EMI receiver after modification.

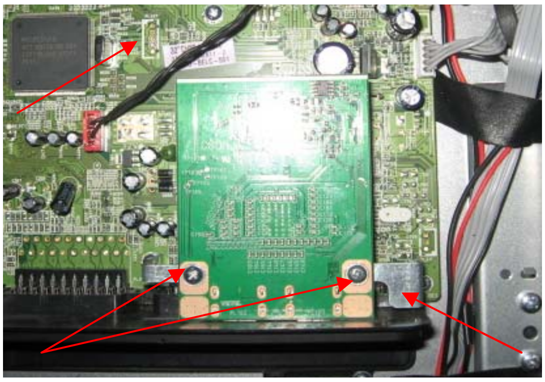


Figure 6.15 Modifications applied to the TV

6.2.4 Modification Studies for Cost down and Producibility

After this part I will give some workshop examples that we made about production and cost down in two months period. The works made within this concept was based on simplifying production and reducing the costs. I will give all the detailed explanations and test results before and after the study. The table below show the project list, changes applied to these projects and earnings from them.

Table 6.1 Workshop summary

	Project No.	Modifications made	Earnings
First Month	1 – 37” MBXX	Aluminum tape and fireproof black tape reduction	1,170 $
	2 – 15” MBXX	LVDS cable exchange	7,728 $
	3 – 19” MBXX	LVDS cable exchange	22,821 $
	4 – 19” MBXX WDVD	LVDS cable exchange	42,977 $
	5 – 32” MBXX	POP frame change	21,154 $
		Total savings 9	**5,850 $**

6.2.4.1 Project 1 - 37" Main board XX LCD TV

The related study was made for reducing the aluminum tapes and fireproof black tapes which is one of the difficulties faced in production and also to minimize the increasing labor costs. The study made in this project can be listed as below;

- 9 pieces of aluminum tapes and 18 pieces of fireproof black tapes were omitted for cost down purpose.

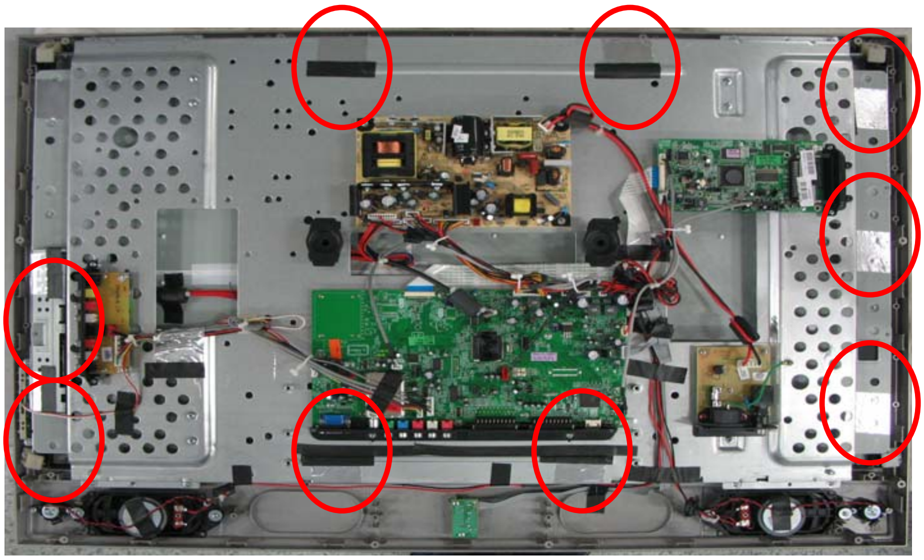


Figure 6.16 Modifications made (Vestel TFT TV)

The test result obtained after tape reduction is OK and as below.

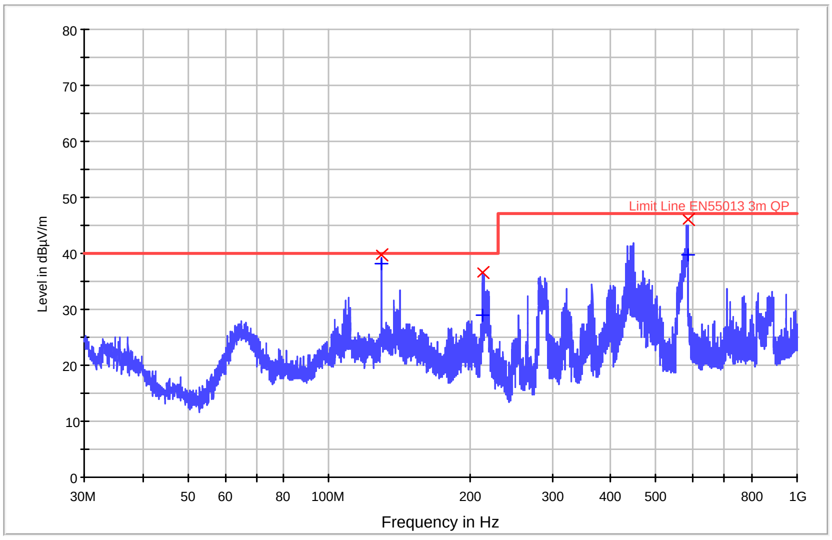


Figure 6.17 Radiated Emission test result graph of the first study

Table 6.3 Radiated Emission test result table of the first study

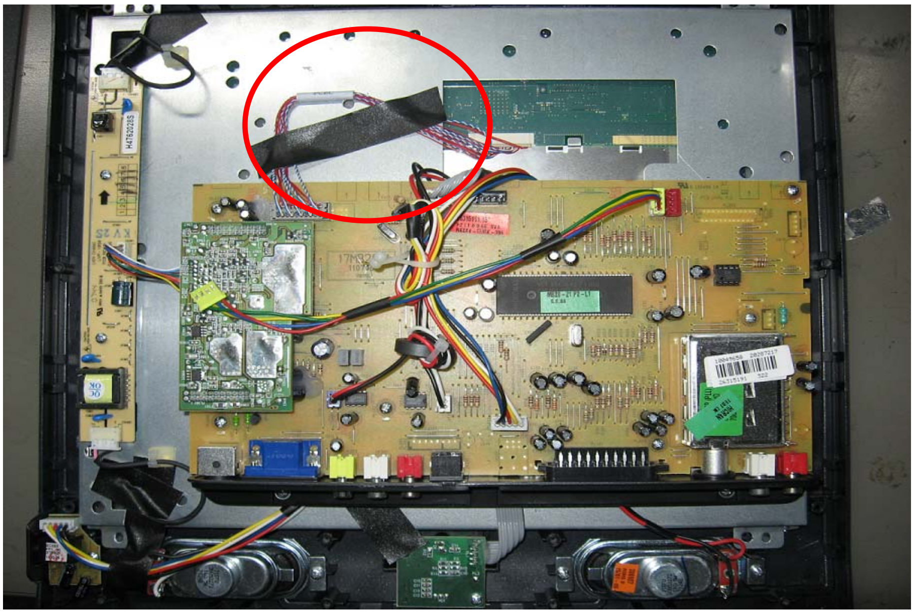
Frequency (MHz)	MaxPeak (dBµV/m)	QuasiPeak (dBµV/m)	Antenna height (cm)	Polarity	Turntable position (deg)	Limit (dB)	Margin (dB)
213.560000	36.6	29.1	200.0	V	90.0	40	10.9
129.600000	39.8	38.1	155.0	H	120.0	40	1.9
583.000000	46.1	39.7	155.0	H	180.0	47	7.3

Table 6.4 Earnings obtained from the study

Component	Number	Labor Cost (usd)	Component Cost (usd)	Earning/Product (usd)
Aluminum Tape	9	0.24	0.09	0.33
Black Fireproof Tape	18	0.15	0.3	0.45
			Total Earning / Product	0.78
			Monthly Production Quantity	1,500
			TOTAL EARNINGS	1,170

6.2.4.2 Project 1 - 15" Main board XX LCD TV

The related study was made for exchanging the high cost shielded LVDS cable with the unshielded one.



6.18 Photo of the LVDS cable exchange (Vestel TFT TV)

The test result obtained after tape reduction is OK and as below.

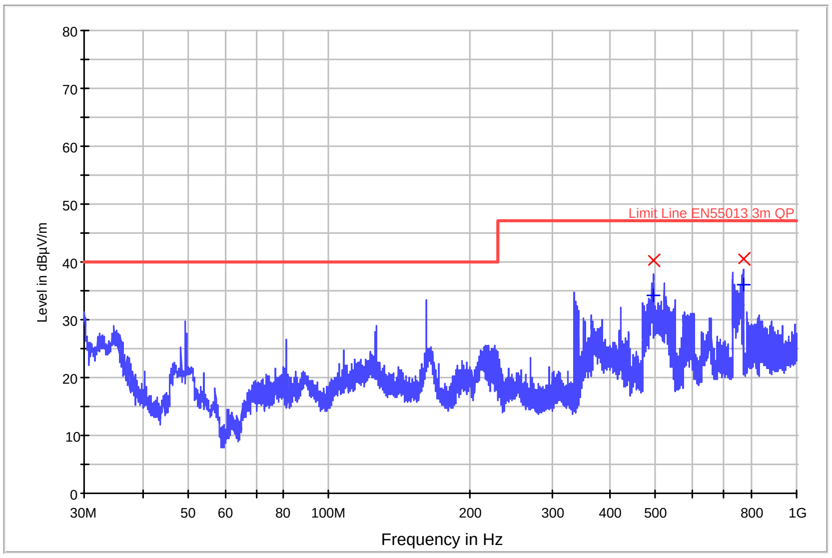


Figure 6.19 Radiated Emission test result graph of the second study

Table 6.5 Radiated Emission test result table of the second study

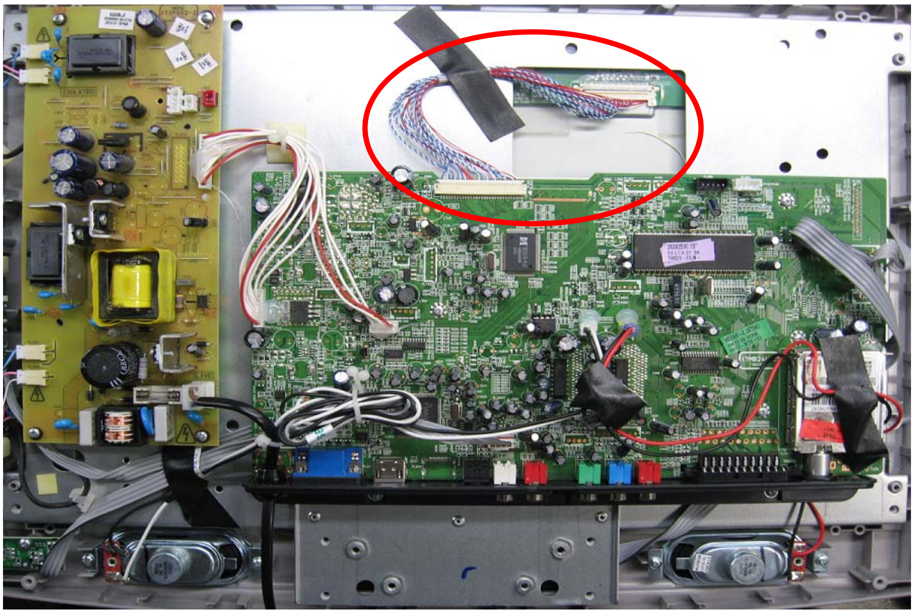
Frequency (MHz)	MaxPeak (dBµV/m)	QuasiPeak (dBµV/m)	Antenna height (cm)	Polarity	Turntable position (deg)	Limit (dB)	Margin (dB)
768.04000	40.4	36.1	100.0	H	64.0	47	10.9
493.68000	40.4	34.2	145.0	H	150.0	47	12.8

Table 6.6 Earnings obtained from the study

Component	**Number**	**Labor Cost (usd)**	**Component Cost (usd)**	**Earning/Product (usd)**
Unshielded LVDS cable	1	0.0	0.93-0.65=0.28	0.28
			Total Earning / Product	0.28
			Monthly Production Quantity	27,600
			TOTAL EARNINGS	7,728

6.2.4.3 Project 1 - 19” Main board XX LCD TV

The related study was made for exchanging the high cost shielded LVDS cable with the unshielded one.



6.20 Photo of the LVDS cable exchange (Vestel TFT TV)

The test result obtained after tape reduction is OK and as below.

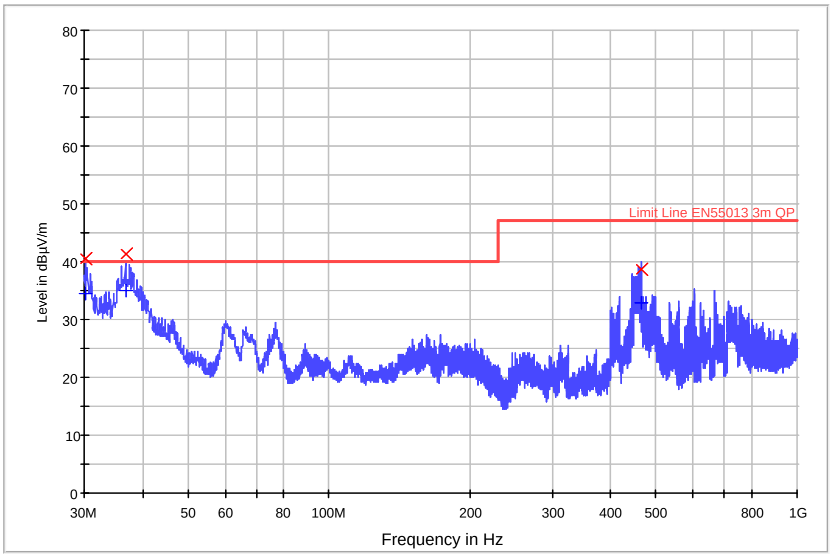


Figure 6.21 Radiated Emission test result graph of the third study

Table 6.7 Radiated Emission test result table of the third study

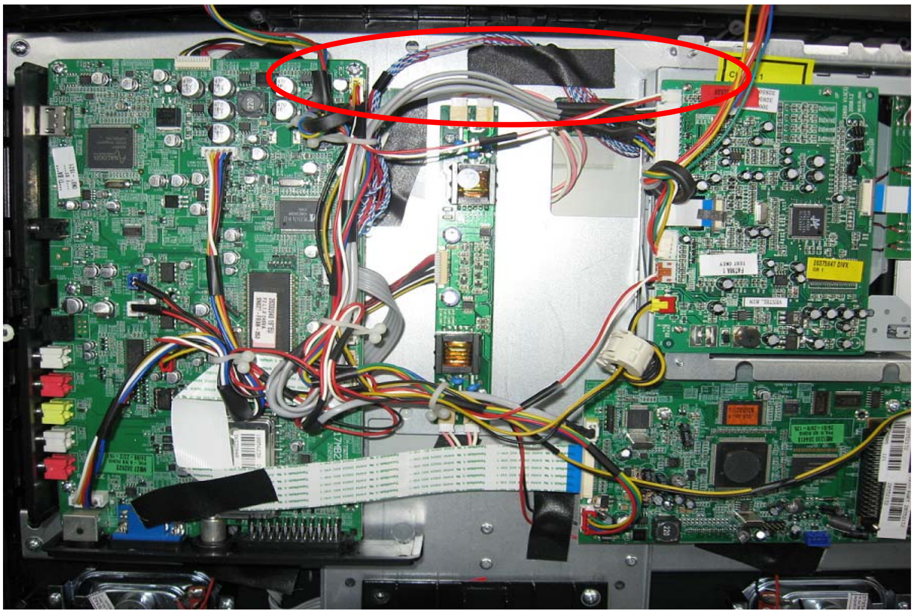
Frequency (MHz)	MaxPeak (dBµV/m)	QuasiPeak (dBµV/m)	Antenna height (cm)	Polarity	Turntable position (deg)	Limit (dB)	Margin (dB)
36.760000	41.4	34.9	100.0	H	64.0	40	5.1
30.200000	40.5	34.5	145.0	H	150.0	40	5.5
464.160000	38.6	32.9	155.0	H	0.0	47	7.1

Table 6.8 Earnings obtained from the study

Component	Number	Labor Cost (usd)	Component Cost (usd)	Earning/Product (usd)
Unshielded LVDS cable	1	0.0	1.75-1.25=0.52	0.52
			Total Earning / Product	0.52
			Monthly Production Quantity	43,888
			TOTAL EARNINGS	22,821

6.2.4.4 Project 1 - 19" Main board XX LCD TV DVD

The related study was made for exchanging the high cost shielded LVDS cable with the unshielded one.



6.22 Photo of the LVDS cable exchange (Vestel TFT TV)

The test result obtained after tape reduction is OK and as below.

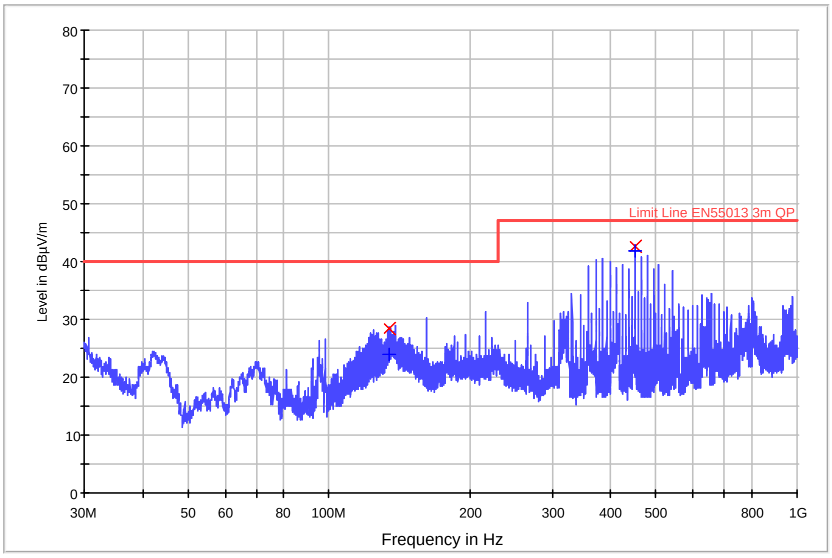


Figure 6.23 Radiated Emission test result graph of the fourth study

Table 6.9 Radiated Emission test result table of the third study

Frequency (MHz)	MaxPeak (dBµV/m)	QuasiPeak (dBµV/m)	Antenna height (cm)	Polarity	Turntable position (deg)	Limit (dB)	Margin (dB)
452.280000	42.6	41.8	155.0	H	240.0	47	5.2
134.920000	28.5	23.9	160.0	H	180.0	40	16.1

Table 6.10 Earnings obtained from the study

Component	**Number**	**Labor Cost (usd)**	**Component Cost (usd)**	**Earning/Product (usd)**
Unshielded LVDS cable	1	0.0	1.77-1.25=0.52	0.52
			Total Earning / Product	0.52
			Monthly Production Quantity	82,647
			TOTAL EARNINGS	42,977

6.2.4.5 Project 1 - 32" Main board XX LCD TV

The biggest goal of this related study was to omit EMC materials like aluminum tape, gasket, and ferrite and to decrease cost and simplify producibility. The display and frame was connected to each other with plastic component as shown in figure 6.24, but this design caused EMC problems because of bad grounding. To eliminate this problem our hardware group used gaskets between the frame and display. They also used aluminum tapes and black tapes to connect them to each other. This design reduced the EMI, but these modifications cost great money.

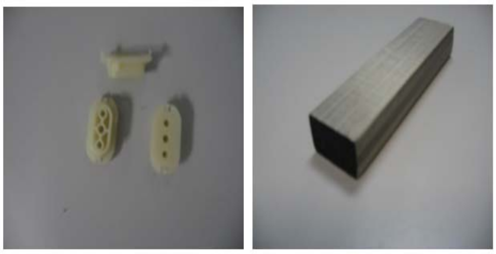


Figure 6.24 Plastic connection component and gasket used for design

Instead of using plastic component we decided to use a new frame connection type POP frame. You can see in the left side of the figure 6.25.

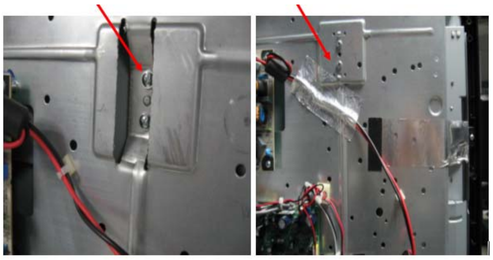


Figure 6.25 After and before (Vestel TFT TV)

The test result obtained after tape reduction is OK and as below.

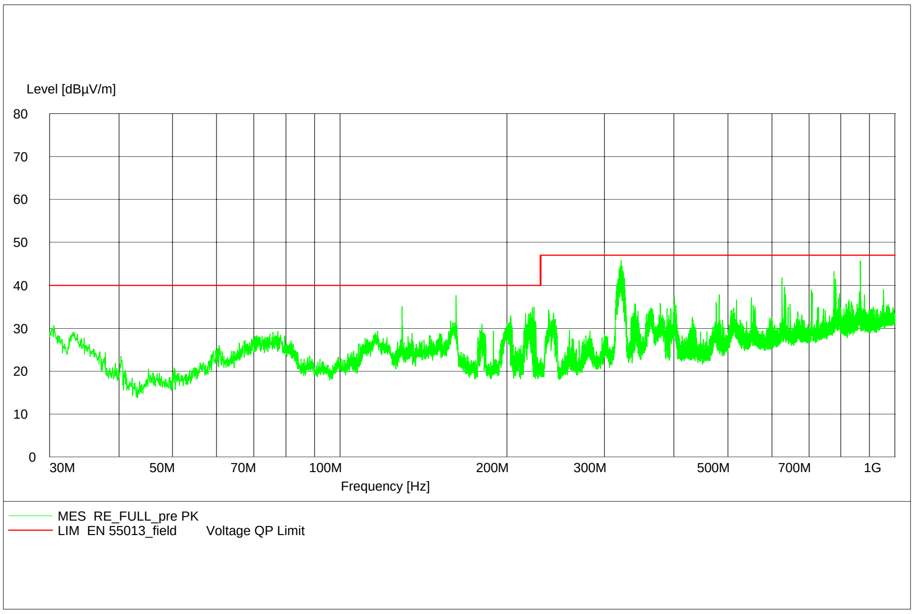


Figure 6.26 Radiated Emission test result graph of the fifth study

Table 6.11 Radiated Emission test result table of the third study

Frequency (MHz)	MaxPeak (dBµV/m)	QuasiPeak (dBµV/m)	Antenna height (cm)	Polarity	Turntable position (deg)	Limit (dB)	Margin (dB)
322.140000	43.8	42.7	200.0	H	145.0	47	4.3
626.220000	44.0	42.6	155.0	H	130.0	47	4.4

Table 6.12 Earnings obtained from the study

Component	**Number**	**Labor Cost (usd)**	**Component Cost (usd)**	**Earning/Product (usd)**
EMI Gasket	3	0	1.05	1.05
Aluminum Tape	6	0.16	0.06	0.22
Pipe Ferrite	1	0	0.15	0.15
Clamp Ferrite	1	0	0.23	0.23
Ring Ferrite	4	0	0.1	0.1
Plastic Holder	4	0	0.92	0.92
			Total Earning / Product	2.67
			Monthly Production Quantity	7,923
			TOTAL EARNINGS	21,154

6.3 Immunity Testing

For immunity testing, anyone needs to understand what the system has and how it performs. If the system resets itself during an immunity test, then we may need to examine on the reset line of a PCB. For immunity purposes many times you must use force to push the system to a failure. The purpose is to find the main noise entry point and can be achieved by removing cables or loads and by shorting inputs. Using positioned noise sources with hand held probes is very useful to analyze entry points. Always keep in mind the basic facts regarding to testing and troubleshooting. Electric fields are caused by high impedance and changing voltages, however magnetic fields are caused by low impedance and changing currents.

6.3.1 Careful Attentions Related to Immunity Testing

While performing the immunity tests, the following topics can be used as concerns if the product will be tested in an unchecked environment:

1. What is the local environment in regard to transient or radiated noise based upon intended application of use?

2. What specific areas of the EUT need attention? Each host system may be different in configuration, and susceptibility levels may be totally passive.

3. Is the equipment chosen to do the test the right one? For example, which type of injection probe is to be used for conducted immunity testing?

4. Has proper calibration been performed on the injection probes and other test equipment, and what was the last date of calibration?

5. If it is not possible to perform the test due to environmental limits or setup, is there another test option which can be used for evaluation of immunity levels?

6. Do we make testing exactly with respect to the standard or testing shall be taken to a higher level to determine the exact place of system failure? How much margin must be put while designing into the product prior to testing?

7. Do you have to perform all the tests, or by only selecting appropriate ones based on functional design, application, and use will be enough?

Figure 6.27 is a very good flowchart to follow while working on the EMC troubleshooting aspect. By following these steps you can easily summarize knowledge about detection and localization of the EMC problem.

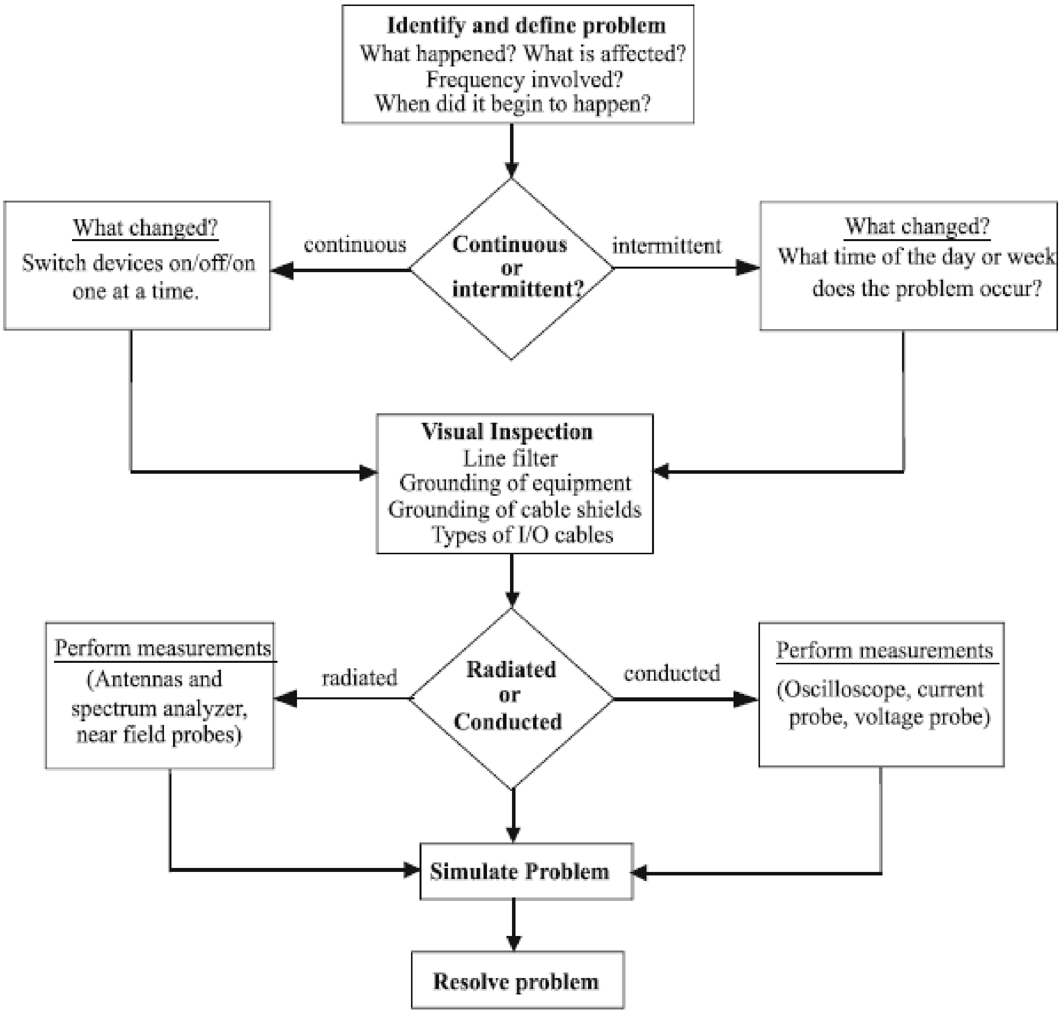


Figure 6.27 Systematic flowcharts for detecting EMC problems

6.3.2 Immunity Modification Tricks for Televisions

6.3.2.1 Input Immunity Test (S1)

The main idea of this test is to check the response of a TV when interference added radio frequency (RF) signal is given from the tuner ground. Important topics while reducing this interference are good grounding under the video integrated circuit (IC) and placing the saw filter between the video IC and tuner. Also the intermediate frequency (IF) lines shall be turned round with grounding.

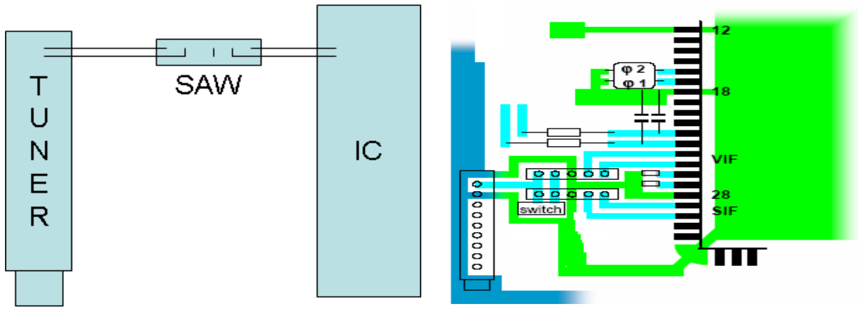


Figure 6.28 Saw filter and IF grounding configurations in TVs.

S1 test is a test based on the tuner performance, so the impedance value of the tuner IF exit lines is very important. One of the IF exit lines is taken through ground in the tuners which has an asymmetrical working principle as shown in figure 6.2.

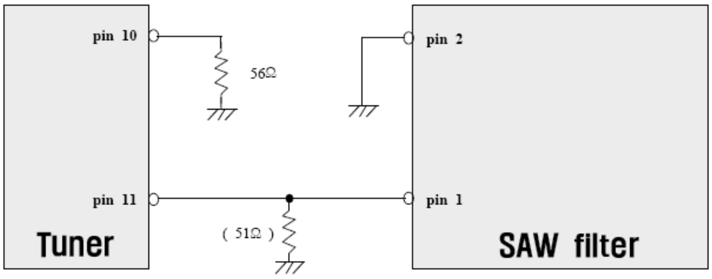
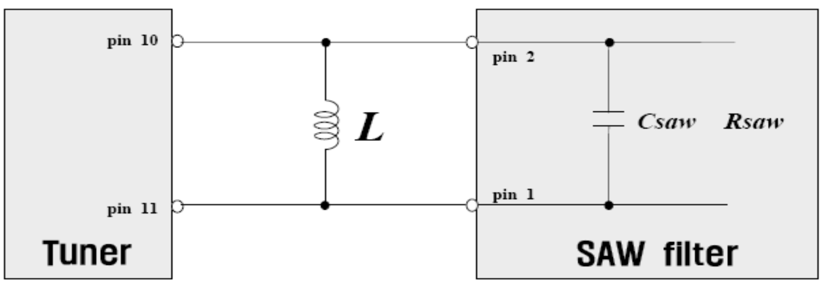


Figure 6.29 Asymmetrical tuner IF exit line impedances.

In symmetrical tuners the formula of the fixed coil inductance is calculated from the formula below. In the formula tuner IF exit line capacitance and line capacitances shall also be calculated with the saw filter capacitance. The tuner IF line and saw filter input line capacitances can be found from component specs. You can see the simple circuitry of the tuner and saw filter in the figure below.



$$L = \frac{1}{(2\pi)^2 \cdot f^2 \cdot Csaw}$$

Figure 6.30 Simple circuitry for inductive coil placement.

6.3.2.2 Immunity from Conducted Currents Test (S2c)

The interference signal is applied to tuner ground in S2c test. By the way the interference signals immunity of the PCB groundings can be tested with analyzing the sound and video effects.

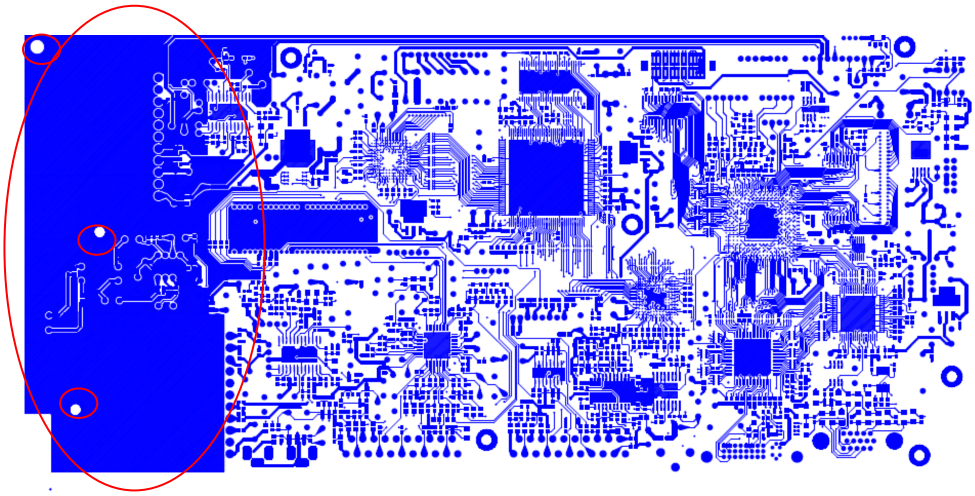


Figure 6.31 PCB ground layer layout of the TVs main board.

Any television which has a main board ground layout like above has no problems when checked with the s2c test. The main reasons of this issue are the homogenous ground distribution and the connection type of the board from the signed points to metal frame. But while working on any other project like four layered PCB without grounding layer and no connection to metal frame, some serious problems can occur in s2c test.

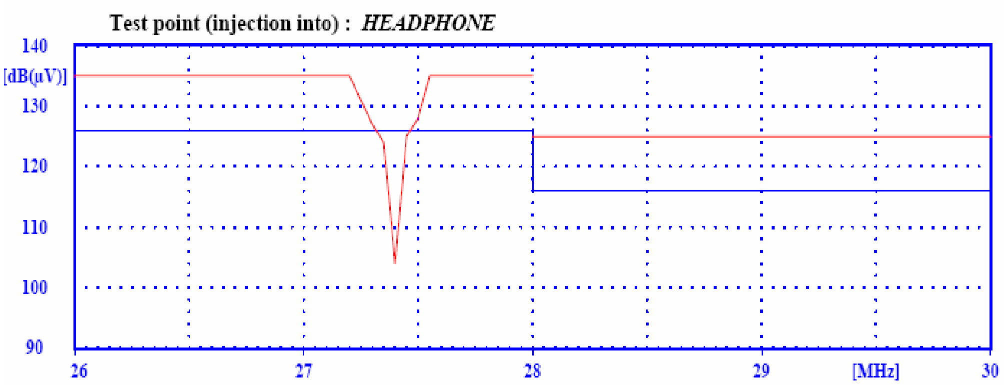


Figure 6.32 Response of the TV before modification.

In the figure below an example of this situation is given. The TV was failed from the s2c test and some modifications made to solve this problem. One was to connect the tuner ground and the metal frame with the copper blaster. The other modification method was to screw grounding cable of the power cord connection card to the nearest place of the tuner like shown in the figure below. Interference signal was sent directly to the system ground with this modification. As a result recruitment of 25 dBs was obtained from these two solutions.

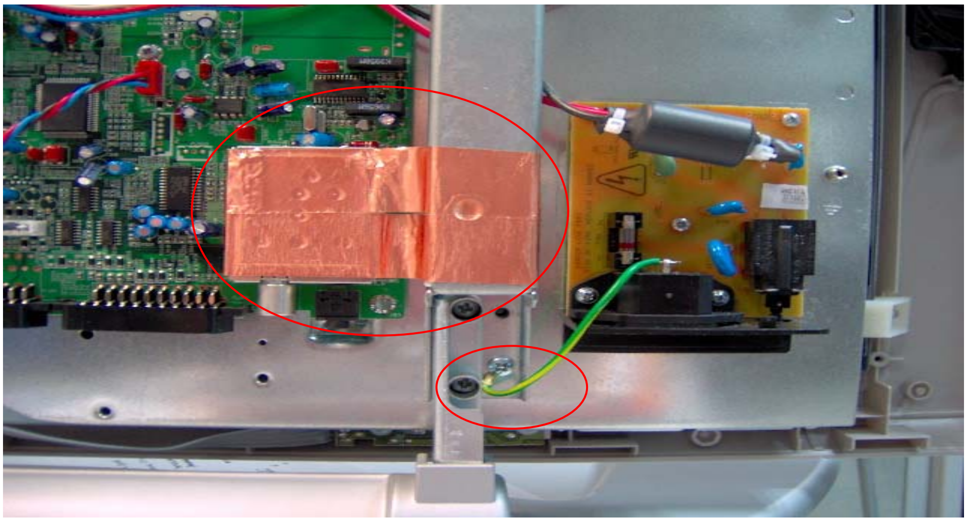


Figure 6.33 Photo of the modifications applied to the Vestel TV

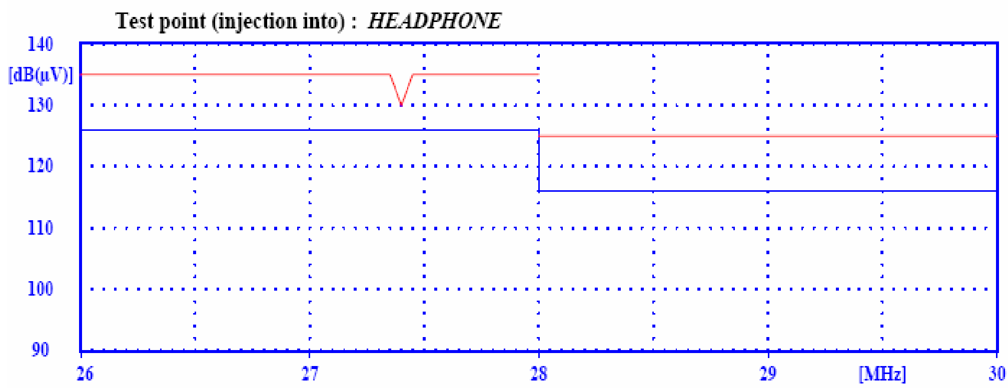


Figure 6.34 Response of the TV after the modification.

6.3.2.2 Immunity from Induced Voltages Test (S2a)

The interference signal is applied to each of the audio ports and the mains connection in this test. The signal to noise ratio of the EUT is checked for the evaluation of s2a test. The frequency of the interference signal is between 0.15 MHz and 150 MHz. Termination of the free audio ports with appropriate impedances is a must while making this test.

For the reduction of the EMI in s2a audio tests, surface mount device (SMD) ferrites can be used at all the audio pins and 10 nf capacitance can be attached after the ferrite at the dynamic tips. Also ring ferrites can be used on the headphone cable (prefer a closer place to the main board) which is connecting the headphone card and the speaker sockets.

If the headphone is on the same line with front audio video (FAV) inputs the interference signal can jump through the main board from this line. To solve this problem you can use 470 pF ferrites between video in dynamic tip and ground tip.

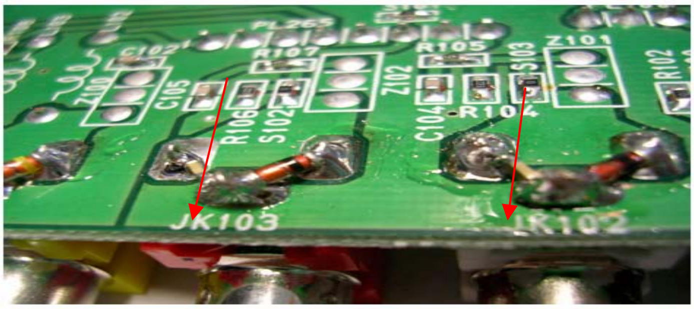


Figure 6.35 Ferrite modifications on board.

6.4 Managing the Subject EMC

As we know EMC is the ability of equipment to work satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. There are two points of view from an item of equipment as i described in the previous chapters:

- Emission: the system is considered as a source of disturbance
- Immunity: the system is considered as a potential victim of disturbance

These two aspects are not exclusive: an item of equipment can be the source of one type of disturbance and be the victim of another type of disturbance. EMC is a source – path – victim organized problem. The table below lists some examples of these three aspects.

Table 6.13 Some examples of source, path and victim aspects of EMC

Source (phenomenon)	Path	Victim
• Power frequency harmonics • Power frequency magnetic field • Lightning strike • HF harmonics • TV/Radio broadcast transmitters • Mobile phone / Base stations • Radar transmitter • Large energy plants etc...	• Conducted • Radiated • Earth • Capacitive • Inductive	• Electronic components • Displays • Telecommunication services • TV/Radio receivers • Alarm systems • Building management system

Interference occurs when it is possible to link a source or phenomenon to a victim via a path and the emission levels from the source exceed the maximum tolerable level of the victim. For example, as shown in the table above, high levels of power frequency magnetic field radiating close to displays may cause the displays to distort, causing visual fatigue to operators, who can even miss safety critical information displayed on their system.

6.5 Real Life EMC Failures

This section provides a few examples of failures or malfunction of equipment due to EMC problems. These examples show that the consequences can sometimes be very important, from a financial and/or safety point of view.

- A 1.5 MW induction furnace controlled in on/off time-proportioning mode (using large contactors to switch the current) interfered with the computers in a Marks and Spencer store half a mile away. *(From Laidler Associates Consulting Services, June 1998)*

- A large manufacturer of industrial fasteners, negotiating with a major customer, agreed to install a packaging cell containing an automatic weighing machine, which filled plastic packets with fasteners and an RF welding machine to seal the packets. For cost reasons the two machines were purchased separately. No assessment of the electromagnetic environment took place, and the machine contract specifications included no EMC requirements other than "shall meet all legal requirements". Both machines were supplied, installed, and tested successfully. Unfortunately when both were operated together the weighing machine suffered >25 % errors due to interference from the RF used by the welder (not an uncommon problem). In an 8 hour shift the cell should have packaged £20,000 of fasteners, but could have given away up to £4,000 of product in incorrect weights. The fastening manufacturer lost 6 weeks production, suffered additional costs, and lost credibility with their major customer. (*From the paper* "The real engineering need for EMC" *by John Whaley, General Manager of SGS International Electrical Approvals (UK)).*

- Silicon Film Technologies, the firm developing a digital 'film' that fits in a standard SLR camera body, has suspended operations because of failure to meet EMC standards. "The failure of certification tests in the summer delayed Silicon Film's anticipated revenues, but development expenses continued," said Robert Richards, president and CEO of Irvine Sensors, the firm's largest creditor. Last week Silicon Film said it had met the FCC emissions requirements but could not conform to the stricter European standards. "We believe at least some of those stricter standards must be met for a successful product launch," added Richards. If alternative finance is not found, the firm – 51 per cent owned by Irvine Sensors – will go onto liquidation. *(From Electronics Weekly, 19th September 2001.)*

- Offshore oil and gas production platforms present an extremely difficult electromagnetic environment due to the amount of electrical and electronic devices crammed into a small space. In this case, a platform was anchored to the sea bottom, but its exact position was adjusted by thrusters, i.e. large electric motors driving propellers. The position of the platform was controlled by a computer system. The power and control cables, all screened, were routed from the control room on the bridge at the top of the platform, all the way down to the engine rooms far below. However, the cable feed troughs were not protected against electromagnetic disturbances. Com radios were used both on board the platform and for communication with land. When a technician tried to use his com radio in the engine room, the connection was continually bad. By letting the radio antenna touch a cable harness, the connection became much better. By feeding its electromagnetic energy into the cable screens, the radio got a much improved “antenna”. Unfortunately, the energy in the cable screens also went elsewhere. It went via the cable screens to the thrusters control equipment, which interpreted the energy as a signal for adjusting the position of the platform. *(From Roxtec Ltd, page 22 of its booklet on ‘Cable and pipe transits for EMC’, December 2002,* www.roxtec.co.uk*)*

CHAPTER SEVEN
CONCLUSION

The aim of this thesis is to prepare a special guideline for an engineer to gather appropriate techniques and approaches on Electromagnetic Compatibility issue. The thesis starts with an introduction of the necessity of concerning EMC during each product investigation and design stage. The history of EMI consideration and harmful effects of EMI to other devices or systems had been presented. Depending on harmful effects of EMI to other systems, product testing regulations had been accomplished and nature of product testing in the side of EMC had been observed.

In product development, designing for EMC conformity is high on the list of priorities and for many years most high volume manufacturers have achieved compliance at minimal extra cost through careful design. At the large system and installation level, however the assembler often relies on assumptions made in the standards or technical requirements. Verification testing is a possibility for added confidence but is likely to be applied only when field experience indicates that there are any problems. The topics below will guide EMC based persons for their investigation, with the condition if the TV is previously verified with CE mark but have compatibility problem at site.

- All the components may not have been retested or truly certified for EMC, even though they may be signed with the CE mark. Conformity may have been issued for another directive or the wrong one.
- The EM compliance test results and the corresponding documentation may be suspicious, especially may be regarded to performance tolerances.
- Also requested in the actual test report, there may be significant problems about the test setup or the data have been taken from a different configuration which has no relation with the EUT.

- Even if the product was tested correctly, the test setup may not have been worst case or must be made for the environment the product is used in, in addition to having all cables connected to the system operating in a worst case mode.
- Components may have been declared compliant based on a certain environment which may be inappropriate for the end use product. For example using an assembly tested product for a heavy industrial application, but installing it in a prescript environment.
- After certification, changes made to the product may occur without retesting to supply continued conformity, assuming that the change has no effect on EMC. No quality control system may exist to verify that all products are copy exact. An example can be given for died shrinking of silicon components.
- Component purchasers may substitute copied components for legally ones without knowledge of a change in provider. Both good and weak ones may be mixed together in the storage facility.

The following questions will provide guidelines whether if the taken data are valid.

1. Is the measured signal the correct one or ambient? In this situation you must be suspicious whether if the signal is not related to any harmonic of the oscillator.
2. Is the EUT operating at fully functional or stand by modes?
3. Does the measured RF energy, seemed stable or several signals significantly asymmetric?
4. Is the ambient greater than 6 dB below the limits for electric and magnetic field measurements?
5. Are all instrumentation the best for wanted performance and are all instruments calibrated in a proper condition?
6. Are all cables maximized for the worst case during the test?

A new EMC Directive is on the horizon with a few changes proposed particularly in respect of Technical Files and treatment of installations. Technical Construction Files are often viewed with suspicion by some as being costly and dependent on opinion rather than fact, but for many manufacturers they offer great flexibility in dealing with variants and upgrades, and give the manufacturer added confidence in his product's conformity. In the new directive, the manufacturer has the option of preparing and assessing his own file or seeking the services of a Competent Body, which should provide a more flexible approach.

In this thesis I also try to accomplish a design procedure for electronics applications. Thus it becomes a useful guide for the design for ensuring the compliance for EMC with minimal cost. Thesis is prepared for general application of electronics, but the main property and specialty of this thesis is the clear procedure for a specific topic that is EMC which takes a big role in consumer electronics. An electronic product design and verification has lots of considerations such as electrical, safety, performance and etc... But this guideline should be both used in design and also in troubleshooting stages. If there is an EMI problem occurred after a product development, specific troubleshooting methods with minimal cost can be found as explained within this thesis, if the problem is localized.

As a final conclusion, I tried to give general but brief explanation about performing EMC tests and solving problems with appropriate knowledge. This is not a 100 % guide for product design and development, but will help anyone responsible with EMC during design and after the production. If I want to summarize my thesis, the recommendations made within this paper will generally require more work from designers before they may be used to, but they should be seen as part of a right-first-time approach to improve overall business efficiency and profitability. Also reduces financial risks. Adopting these approaches and techniques will generally result in:

- Cost and time savings for the overall project,
- Higher reliability for the user,
- A lower level of warranty claims,
- An improved market image and level of repeat sales,
- Very significantly reduced exposure to penalty clauses in contracts,
- Lower risks of banning from the EU market for non-compliance,
- Significantly reduced exposure to product liability claims.

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