DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

RADIATED EMISSION EMC TESTING USING FULL ANECHOIC CHAMBERS

by

Hülya DÖNER

September, 2006

İZMİR

RADIATED EMISSION EMC TESTING USING FULL ANECHOIC CHAMBERS

A thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillement of the Requirements for the Degree of Master of Science
in Electrical and Electronics Engineering, Electrical and Electronics
Engineering Program

by
Hülya DÖNER

September, 2006
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"RADIATED EMISSION EMC TESTING USING FULL ANECHOIC CHAMBERS"** completed by **HÜLYA DÖNER** under supervision of **Assist. Prof. Dr. YEŞİM YÜKSEL** 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.

Assist. Prof. Dr. YEŞİM YÜKSEL

Supervisor

Prof. Dr. Haldun KARACA

(Jury Member)

Asst. Prof. Dr. Aysun SOFUOĞLU

(Jury Member)

Prof.Dr. Cahit HELVACI
Director
Graduate School of Natural and Applied Sciences

ACKNOWLEDGMENTS

First and foremost, I wish to express my great dept of thanks and sincere gratitude to my supervisor, Assist. Prof. Dr. Yeşim YÜKSEL for her continuous encouragement, constructive suggestions, invaluable recomendations and patient supervision during my research. It would be difficult to complete this study without her endless support.

And I am greatful to VESTEL Elektronik A.Ş. EMC Laboratories for supporting my education and providing me the necessary facilities to complete my research.

I would like to express my heartfelt thanks to my husband, Mustafa Zafer BELİRGEN for his love, unwavering support and understanding.

My final words of thanks are reserved for my parents. I wish to present my sincere gratitude to my lovely mother and father, Hatice and İshak DÖNER for their loving care and continuous encouragement. I would also thank my sister Zehra, and my brother Fatih, and of course my nephew Nurşah for their love and endless support.

Hülya DÖNER

RADIATED EMISSION EMC TESTING USING FULL ANECHOIC CHAMBERS

ABSTRACT

Nowadays, many types of electronic equipments are operating together in the same electromagnetic (EM) environment. EMC means that a device is compatible with its EM environment, which means that no interference is caused by and it does not emit levels of EM energy that cause EMI in other devices in the vicinity.

The most important section of EMC is “emission”. All manufactured electronic devices that would be sold in USA and EU are restricted by government regulations to a very limited “radiated” field strength leaking out of the case. To market a device, it must be proved by measurement that the device emits fields that are smaller than the permitted values. Hence, radiated emission test is required by operating the equipment in a controlled environment. The test must be done in a “quiet” electromagnetic environment such as a shielded anechoic chamber or in a facility located well away from urban areas, where the ambient field strength is small. Worldwide regulatory requirements specify the use of Open Area Test Sites (OATSs) or Semi Anechoic Chambers (SACs) for the measurement of radiated emissions from unintentional radiators. SACs have very big sizes and their initial cost is very high. And OATSs are not effective choice if they used alone, because the ambient noise is very high.

In this thesis, using Full Anechoic Chambers – which have low initial cost and small size – instead of SACs is investigated. Two test sites are compared by relative tests and results are analyzed. Considering the comparison results, an alternative way is defined.

Key words: EMC, EM, EMI, immunity, emission, radiated emission, anechoic chamber, open area test site, European Norm, CE marking.

TAM YANKISIZ ODALAR KULLANILARAK HAVA YOLUYLA YAYILIM ELEKTROMANYETİK UYUMLULUK TESTİ

ÖZ

Günümüzde farklı tipteki elektronik cihazlar aynı ortamda çalışmaktadır. EMC, bir cihazın içinde bulunduğu elektromanyetik ortamıyla uyumlu olduğu anlamına gelir; cihazda ortam kaynaklı karışmalar oluşmaz ve cihaz, çevresinde bulunan diğer cihazlarda karışmalar yaratacak seviyede elektromanyetik enerji yaymaz.

EMC'nin en önemli kısmı "yayılım"dır. AB ve Amerika'da satılmak üzere üretilen tüm elektronik cihazların dışarıya "yayacak" oldukları alan gücü, hükümet yasaları tarafından belli değerlerle sınırlandırılmıştır. Bir cihazı pazara koyabilmek için, cihazın izin verilen değerlerden düşük seviyede yayılım yaptığı ölçümlerle kanıtlanmalıdır. Bu nedenle cihaz, kontrollü bir ortamda çalışıyor iken hava yolu ile yayılım testi gerçekleştirilir. Test, ekranlı yankısız oda yada ortam alan gücünün düşük olduğu şehirden uzak "gürültüsüz" bir elektromanyetik ortamda gerçekleştirilmelidir. Dünya çapındaki düzenleyici gereklilikler, kasıtsız yayıcıların hava yolu ile yaydığı enerjinin ölçülmesi için Açık Alan Test Sahalarının (AATS) yada Yarı Yankısız Odaların (YYO) kullanımını belirtmektedirler. YYO'lar büyük abatta olup kurulum maliyetleri oldukça yüksektir. AATS'lar ise, yanlız başlarına kullanıldıklarında etkili bir seçim değildirler, çünkü ortam gürültüleri çok yüksektir.

Bu tezde, hava yolu ile yayılım testinde YYO'lar yerine, kurulum maliyeti ucuz ve boyutları daha küçük olan Tam Yankısız Odaların kullanımı araştırılmıştır. Bu iki alan karşılaştırmalı testlerle kıyaslanmış ve sonuçlar analiz edilmiştir. Karşılaştırmada varılan sonuçlar sorgulanarak alternatif çözüm yolu tanımlanmıştır.

Anahtar Kelimeler: EMC (EMU), EM, EMI, bağışıklık, yayılım, hava yolu ile yayılım, yankısız oda, açık alan test sahası, Avrupa Normu, CE (avrupaya Uyumluluk) işareti.

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

1.1 Introduction

EMC (electromagnetic compatibility) is the ability of electrical or electronic equipment to operate without creating interference for other equipment in the vicinity, or to operate together with other electrical or electronic aparatus in an interference environment. EMC means that a device is compatible with (i.e., no interference is caused by) its electromagnetic (EM) environment and it does not emit levels of EM energy that cause electromagnetic interference (EMI) in other devices in the vicinity.

Electromagnetic disturbances are all around us and the electromagnetic spectrum comprises everything from gamma rays to long wave radio. This includes X rays, ultraviolet and visible light, infrared rays, microwaves and radio waves. In the case of EMC, it is mainly interested in radio waves or RFI (radio frequency interference). If electronic equipment is not designed and installed correctly, it can function in the same way as a radio transmitter, or receiver and send out or receive RFI.

EMC is transmitted in several ways as seen Figure 1.1.

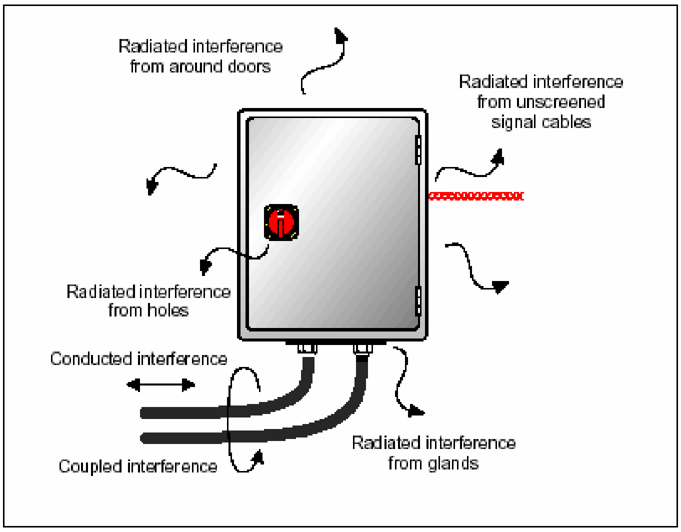

Figure 1.1 EMC transmission ways

To prevent EMI emission, we can apply below basic ways. Detailed information about preventing EMI will be given at the radiated emission part.

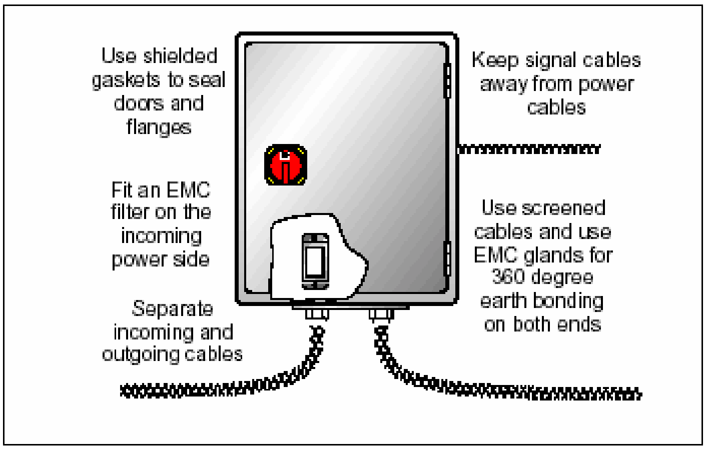

Figure 1.2 Ways of EMC preventing

1.2 EMC History

EMC first began to be an issue in the military environment particularly on board ships where many types of electronic equipment, had to successfully operate in close proximity to each other. In such an environment; communication, navigation and data processing electronics all need to function simultaneously in the presence of strong radio frequency (RF) fields. Such RF fields are produced by two-way communication equipments, radar transmitters and microprocessor controlled devices. Added to this "mix" on board, a military ship is the presence of ordinance or explosives and aircraft fuel. In such an environment it becomes transparently clear that each device needs to be electromagnetically compatible with its environment and not be rendered inoperative or unsafe by this environment. Also each device added to this milieu must not unnecessarily or unintentionally contribute spurious emissions that do not perform any particular function. From the preceding, the origin of the two major aspects of EMC, Emission and Immunity, can be seen.

Due to the global proliferation of electronic devices in non-military living, it is becoming increasingly important that EMC is maintained in civilian settings as well. Residential and commercial environments may contain dozens of appliances that are controlled by microprocessors, i.e., kitchen stoves, video cassette recorders, TVs, bread makers, personal computers, etc. All electronic devices utilizing microprocessor technology generate radio frequencies. For example a 100 MHz computer contains an electronic clock that steps the microprocessor through its program. In this case this clock frequency falls within the frequency spectrum allocated in the U.S. for FM radio broadcasting. If precautions were not taken by PC manufacturers, interference to nearby radio receivers would result. Harmonics or multiples of this frequency could, if not subdued, cause interference to other radio receivers; such as those used by emergency medical personnel and to television receivers. It is therefore incumbent upon manufacturers of digital electronic devices to guarantee their products will not be incompatible with or a nuisance to other electronic devices.

1.3 EMC Standards in the USA and in the European Union

Because of the proliferation of Information Technology Equipment (ITE) and other microprocessor controlled electronic equipment, in the 1970's the F.C.C. (as the authority having jurisdiction in the U.S.) implemented limits on RF emissions from digital devices. Digital devices that are intended to be used in residential environments are classified as Class "B" devices. All such class "B" devices must comply with limits set forth in part 15 of the F.C.C. rules for radiated and conducted emissions. Before a Class "B" digital device may be sold in the U.S., it must conform to the requirements of the F.C.C. rules. Currently there are no U.S. requirements for immunity testing. Products destined for use in the U.S. Industrial, Scientific and Medical fields are classified as Class "A" devices and may not be used in residential environments.

Products sold in the European Union must carry the "CE" mark that constitutes a declaration by the manufacturer of the products' compliance with all applicable harmonized Directives and Standards. Electronic devices are subjected to the EMC Directive, 89/336/EEC.

The apparatus (....) shall be so constructed that (a) the EMC disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended; (b) the apparatus has an adequate level of intrinsic immunity of EMC disturbance to enable it to operate as intended (EMC Directive, 89/336/EEC, Article 4).

Clearly, complying with the "essential requirements" of the European EMC Directive requires evaluation of a product's emission and immunity characteristics. The Intrinsic Immunity requirement dictates that an electronic apparatus be so constructed that it's performance will not be degraded by it's normal electromagnetic environment. For example a consumer in Europe has a right to expect that the digital security system monitoring in his home will not malfunction if a nearby ambulance crew talks to their local dispatcher via two-way radio communications equipment. The directive implies that manufacturers will design products to possess immunity not only to radiated RF fields, but to other Electromagnetic phenomena as well.

Specific immunity tests are itemized by generic and product-specific European Norms or Standards. Minimally, this means that a device's performance will not be adversely effected by: (1) RF fields such as radio and TV broadcast stations and licensed two-way radio equipment; (2) Electrostatic Discharge events (ESD); (3) and Electrical Fast Transients (EFT). Testing of products for immunity in simulation of real-world environments allows manufacturers to demonstrate compliance with Article 4, clause (b) of the EMC Directive. Additional immunity testing is required by certain product specific standards and the generic immunity standard. These additional tests include: Conducted RF Immunity; Surge Immunity; Power Frequency Magnetic Fields immunity; Voltage Dips and Interrupts Immunity; and Pulsed RF Fields Immunity.

1.4 CE Conformity

Conformity to the essential requirements of the EMC Directive 89/336/EEC must be declared by the manufacturer or his authorized representative. This is done by issuing a document called a "Declaration of Conformity" (DOC). It is the manufacturer’s responsibility to procure and maintain technical evidence supporting all claims of product "conformity". This supporting evidence is assembled in a Technical Construction File (TCF). A TCF will exist for each product sold in the European Union. Verification of compliance (testing) may be performed by the manufacturer or a third-party test house. In all cases though, tests must be performed in harmony with International IEC Test Standards. Results of EMC testing, such as the Test Report issued by a testing laboratory, shall be included in the TCF.

A product that meets the requirements of an appropriate "product specific standard", or in lieu of a "product specific standard" the generic standard, is presumed to meet the essential requirements of the EMC Directive. In addition to the EMC Directive, other directives may be applicable to an electronic device. Conformity with all applicable directives must be verified and documented. Having met all requirements, the "CE" mark may then be applied. For a period of ten years after being placed on the European Market, the supporting technical documentation (TCF) must be kept on file and be accessible by an authorized representative within the European Union.

Compliance with the European Union’s EMC directive leads to increasingly robust products, improvements in quality and increased customer satisfaction. For example; ESD (electrostatic discharge) immunity testing quickly reveals any latent vulnerability a product might have to such hazards and promotes corrective measures that render the product immune to such real world occurrences. The result is improved customer satisfaction realized from reliable, solid products that provide years of trouble free service (C.R.S., 1998).

1.5 Research Objective and Aim of Thesis

The key objective of this research may be defined as follows:

- First, to define what is EMC, who must comply with EMC and why;

- To explain radiated emission test for Sound and Television Broadcast Receivers and Associated Equipments, test setup, used equipments;
- To research the measurement test sites for radiated emission final testing accepted by the European Norm standards;
- Furthermore, to evaluate features, advantages and disadvantages of Semi Anechoic Chamber, Full Anechoic Chamber and Open Area Test Site as measurement site for radiated emission testing;
- To investigate using Full Anechoic Chamber instead of Semi Anechoic Chamber for radiated emision final testing, encourage the result by comparative tests.

1.6 Thesis Outline

Thesis is organized into five chapters. The topical organization of the thesis start with an introduction of EMC, the history of EMC and the necessity to care about EMC. EMC has two sectors, immunity and emission. These two faces of EMC is investigated in Chapter 2. Also EMC causes and relative EMC standards, EMC of Sound and Television Broadcast Receivers and Associated Equipments are investigated, relative standards and some requirements are listed in Chapter 2. In Chapter 3, radiated emission test for Sound and Television Broadcast Receivers and Associated Equipments is examined, measurement setup elements are explained. In Chapter 4, using Full Anechoic Chamber instead of Semi Anechoic Chamber for radiated emission final testing is investigated, two comparison test are performed. The result of the comparison tests are evaluated in Chapter 5.

CHAPTER TWO
THE EMC SECTORS AND BASIC EMC STANDARDS

2.1 The EMC Sectors

Emission is the ability of electrical or electronic equipment to operate without creating interference.

Immunity is the ability of electrical or electronic equipment to operate together with other electrical or electronic aparatus in an interference environment.

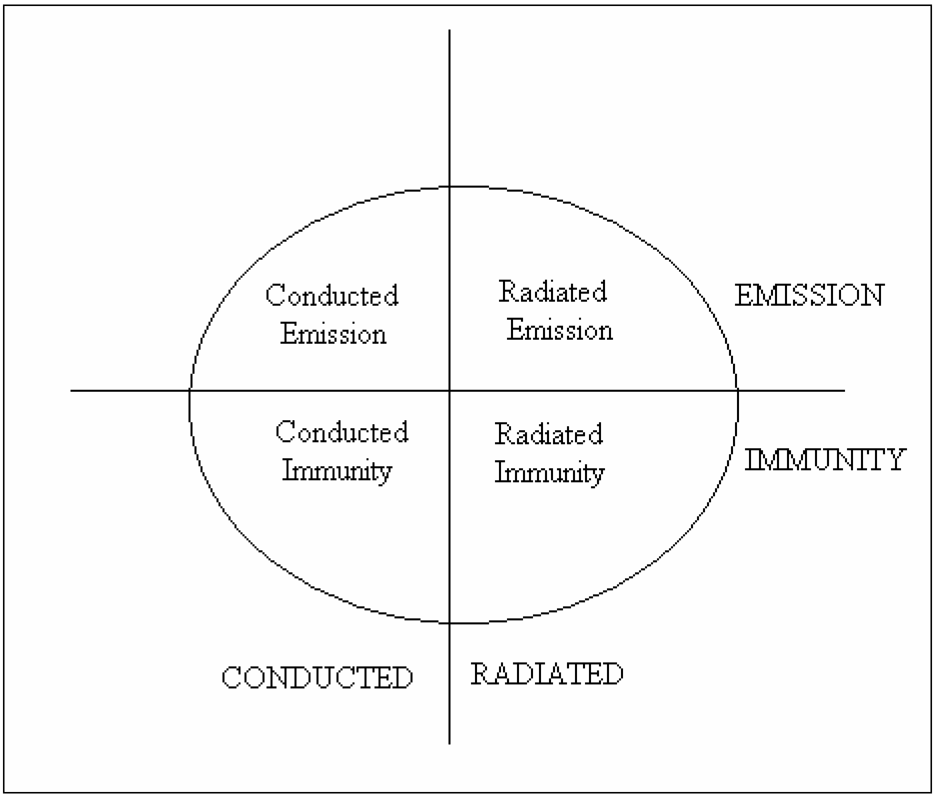

Figure 2.1 The EMC sectors

The importance of EMC can be explained as below:

- The quality of an eletrical/electronic equipment or system is influenced by it's electromagnetic compatibility;

- Electromagnetic pollution of the environment increases continuously (protecting electromagnetic environment and radio services like emergency services, commercial broadcast etc.);
- As speed increases in digital circuits, at integrated circuit level switching power is lower and lower;
- The necessity of preventing interference with other equipment intended to operate in the same environment;
- The necessity of ensuring adequate protection again interference annoyance (interference on radio and TV) and safety critical (lift electronics, vehicle ABS systems etc.).

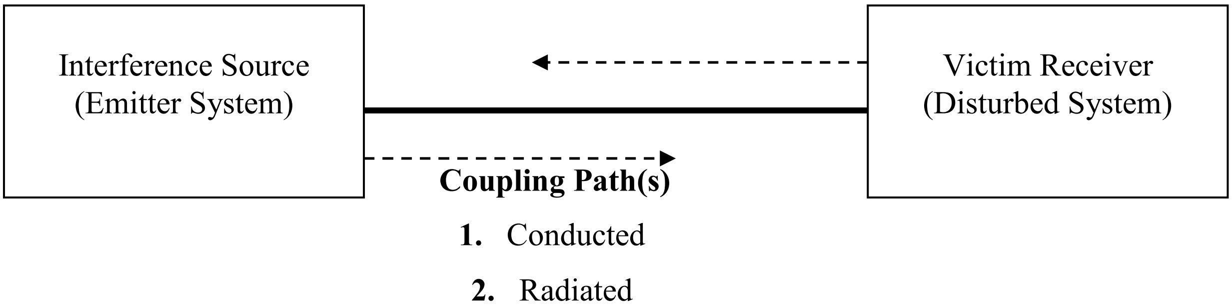

Figure 2.2 Basic EMC model

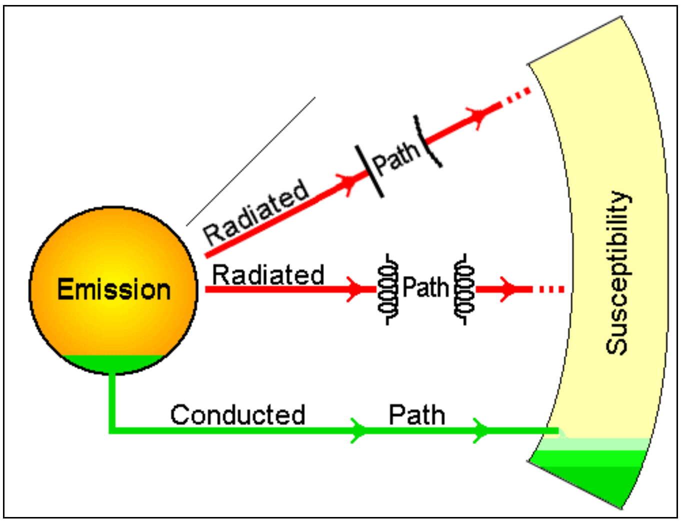

Figure 2.3 EMC paths

Path consists of Radiated and Conducted energy:

- Radiated (electromagnetic field);
- Inductively coupled (magnetic field);
- Capacitively coupled (electric field);
- Conducted (electric current).

Some EMC coupling paths are shown below figures.

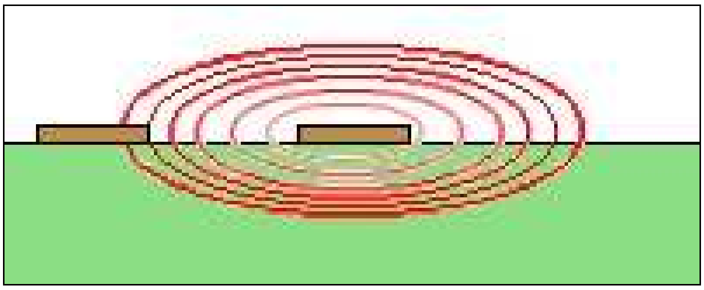

Figure 2.4 Inductively coupled (magnetic field)

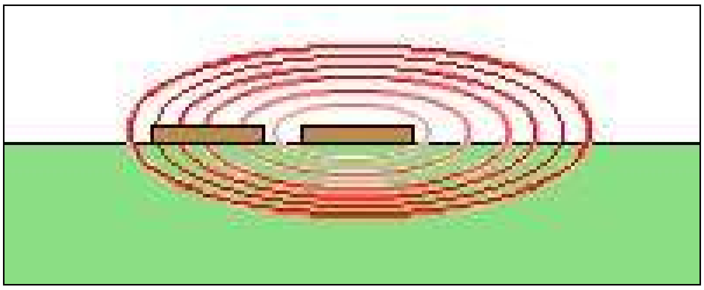

Figure 2.5 Inductively coupled (magnetic field), near

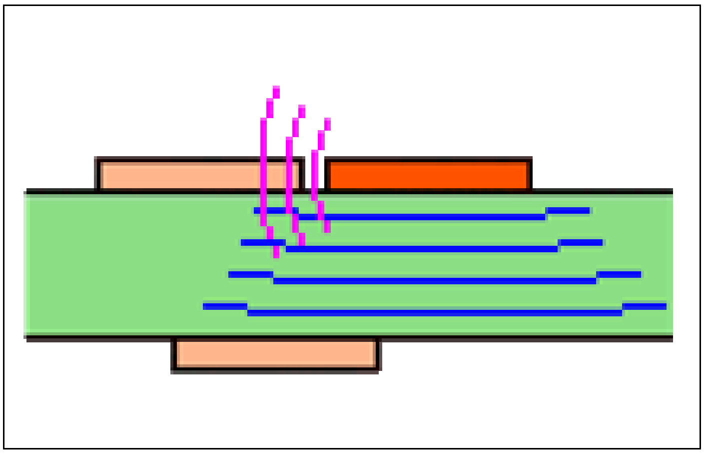

Figure 2.6 Capacitively coupled (electric field)

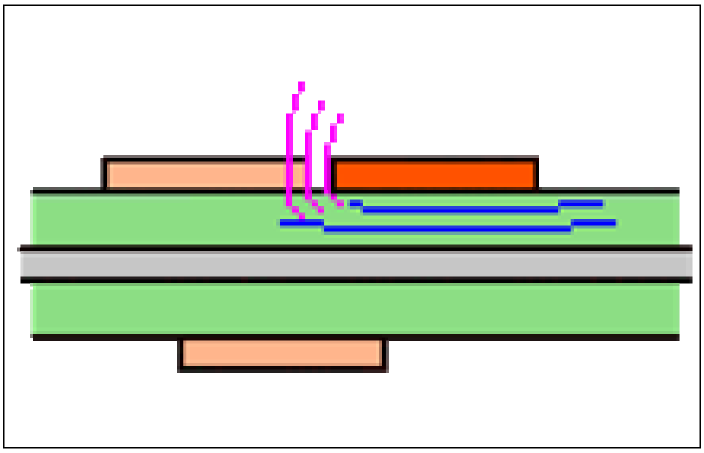

Figure 2.7 Capacitively coupled W/Shield (electric field)

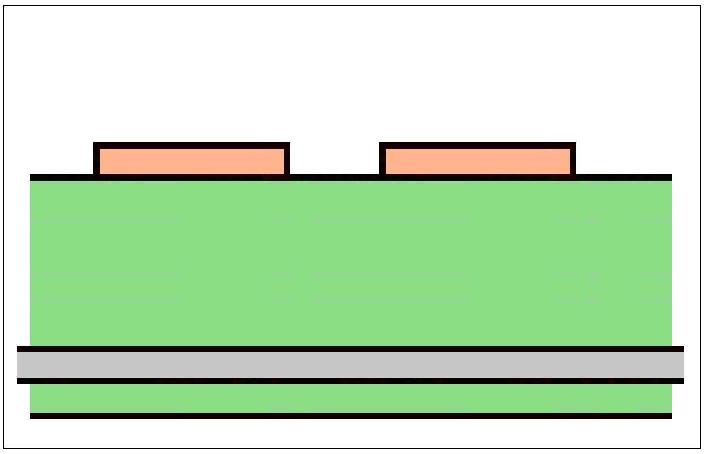

Figure 2.8 Microstrip Transmission Line Characteristic.

Impedance affected by Groundplane proximity: Z = High

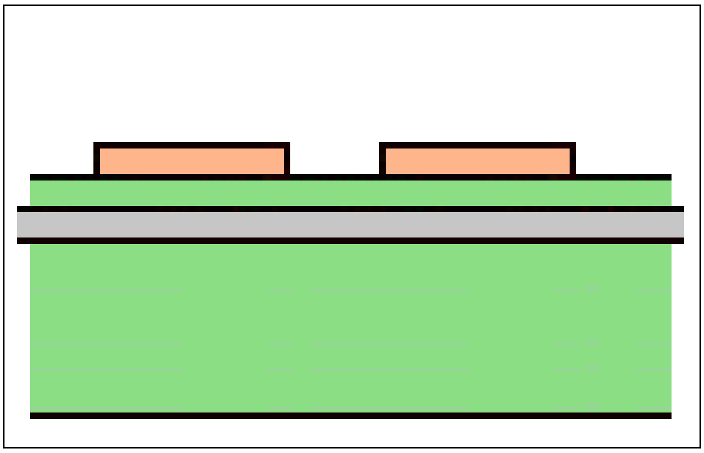

Figure 2.9 Microstrip Transmission Line Characteristic.

Impedance affected by Groundplane proximity: Z = Low

Possible counter measures:

- Reduce disturbance of the source or remove the source;
- Avoid coupling between: filtering, shielding, layouts;
- Increase the susceptibility of the electronic system.

2.2 Interference Sources

EMC phenomena that affect the electromagnetic environment can be divided into two characteristic groups :

- Transient Interference:
  - Power Line Switching;
  - Electrostatic Discharge (ESD);
  - Atmospheric Lightning;
  - H.E.M.P.

- Continuous Interference:
  - Radiated sinusiodal continuous waves from TV stations, radio stations, energy distribution system;
  - Repetitive impulse waves produced by thyristors and triacs used in mains swithcing, corona discharges from high voltage cables, RADAR equipment, preignitions in vehicles;
  - Fixed Transmitters;
  - H.E.M.P.;
  - Mobile Transmitters;
  - Power Distribution Systems;
  - Atmospheric & Stellar.

Manufacturers of electronic equipment for:

- Information Technology (ITE);
- Industrial, Scientific, Medical (ISM);

- Broadcast Receivers, TV;
- Household Appliances, Tools, similar;
- Fluorescent Lamp and Luminaries;
- Lift;
- PLC and UPS. ....

Or use in:

- Residential Environment;
- Commercial Environment;
- Industrial Environment;

must comply with EMC directive.

2.3 Structure of IEC Standards

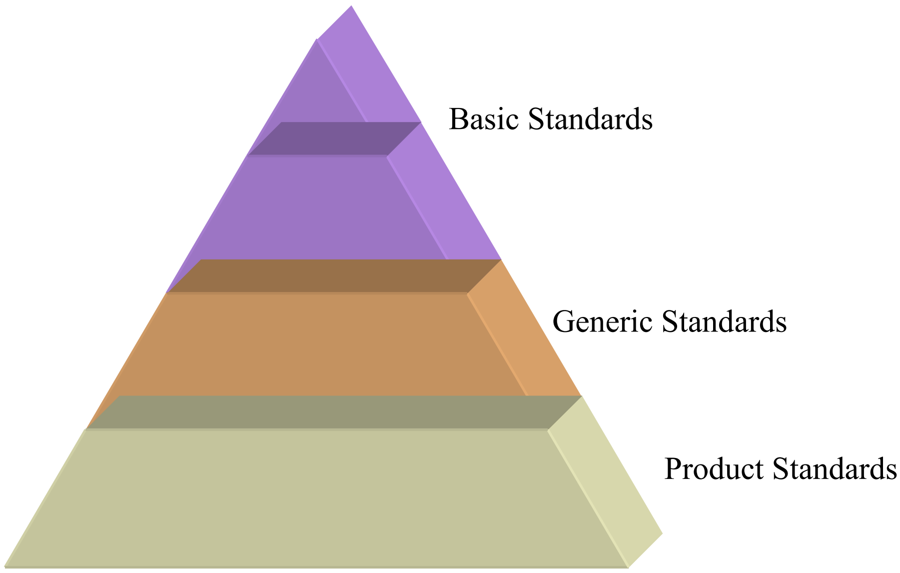

Figure 2.10 IEC Standards' structure

A "basic standard" can be described as phenomena translation standards.

- Included are:
  - Definition and description of one phenomnon;
  - Test and measurement methods specification;
  - Test instrumentation;

- Basic test set up;
- Range of test levels.

- Not included are:
  - Prescribed limits;
  - Performance criteria for a specific product;
  - Product specific test arrangements;
  - Test sequences.

A “generic standard” can be described as environment test standards.

- Included are:
  - Definition and description of an environment of household and industrial;
  - Collection of appropriate tests;
  - Range of test levels.

- Not included are:
  - Performance criteria for a specific product;
  - Product specific test arrangements;
  - Test sequences.

A “product standard” can be described as product specific standards.

- Included are:
  - Prescribed limits;
  - Perfromance criteria for a specific product;
  - Product specific test arrangements;
  - Test sequences;
  - All test required for a product (EMC, Safety, Mechanical, etc.).

European Standards (European Norms) are prepared by CEN, CENELC, ETSI. Aims of the Standardisation Process are:

- Drawing up harmonized standards;
- Defining technical specifications for manufacturers so they can comply;
- Taking into account the current state of technology;
- To transpose National standards into EN standards;
- Control whether products manufactured are in conformity with the harmonized standards.

2.4 Basic EMC Standards

Basic emission standards are listed below:

- EN 55011 – Industrial, scientific and medical;
- EN 55013 – Broadcast receivers;
- EN 55014 – Household appliances;
- EN 55015 – Lighting apparatus;
- EN 55022 – Information Technology Equipment.

Basic immunity standards are as listed below:

- EN 55020 – Broadcast receivers;
- EN 61000-4-2 – Immunity to ESD;
- EN 61000-4-3 – Radiated immunity;
- EN 61000-4-4 – Immunity to EFT/Burst;
- EN 61000-4-5 – Immunity to surge;
- EN 61000-4-6 – Conducted RF immunity;
- EN 61000-4-8 – Power frequency magnetic immunity;
- EN 61000-4-11 – Voltage dips and interruptions.

2.5 EMC of Sound and Television Broadcast Receivers and Associated Equipments

There are four basic EMC standards related with Sound and Television Broadcast Receivers and Associated Equipments approved by CENELEC.

They are:

- EN 55020;
- EN 55013;
- EN 61000-3-2;
- EN 61000-3-3.

2.5.1 EN 55020

EN 55020 standard explains the immunity characteristics of Sound and Television Broadcast Receivers and Associated Equipments and includes limits and methods of measurement.

Related tests are:

- Measurement of Input Immunity: The Input Immunity test measures the immunity of an EUT (Equipment Under Test) to specified interfering signals at the antenna input socket of a receiver.
- Mesurement of Immunity to RF Voltage (common mode) at Antenna Terminal: The main purpose of this test is to measure an EUT's ability to suppress AM modulated interference signals in the range 26 - 30 MHz induced onto the antenna port in common mode.
- Measurement of Screening Effectiveness: In this test, the screening effectiveness of the antenna terminal is measured, and is given by its immunity to the in-channel disturbance signal injected into the screen of the coaxial cable.

- Measurement of Electrical Transients (EFT): Electrical fast transient/burst test is a test in which burst signals, containing specified number of fast pulses, are applied to the power supplies, control and signal ports of electrical and electronics devices.
- Measurement of Immunity to Induced Voltages: The main purpose of this test is to measure an EUT's ability to suppress voltage induced interference from AM modulated signals in the frequency range 0.15 – 150 MHz.
- Measurement of Immunity Radiated Fields: The main purpose of this test is to measure the ability of an EUT to suppress the effect of an interfering RFI field produced by AM modulated signals in the frequency range 0.15 – 150 MHz.
- Measurement of Electrostatic Discharge (ESD): This test shows the performance of electronic and electrical devices under electrostatic discharge (EN 55020, 2005).

2.5.2 EN 55013

This standard explains the radio disturbance characteristic of Sound and Television Broadcast Receivers and Associated Equipments and includes limits and methods of measurement.

EN 55013 specifies limits and methods of measurement of electromagnetic disturbance caused by sound broadcast receivers, television receivers and associated equipment. It also covers cable and satellite receiving equipment.

Associated equipment is either intended to be connected directly to sound or TV receivers, or to generate or reproduce audio or visual information. (e.g. audio amplifiers, active loudspeaker units, record players, CD players, magnetic recording and playback systems and electronic organs). Information technology equipment is excluded even if it is intended to be connected to a TV broadcast receiver.

Related test are:

- Disturbance Voltage at the Mains Terminals (Conducted Emission): The aim of this test is to measure the disurbance voltage that EUT radiates to the mains terminal. The RF conducted back down the mains lead is measured preferably with a LISN (Line Impedance Stabilization Network), or alternatively with a voltage probe if a LISN is not suitable, and from other terminals with a voltage probe. Frequency range is 150 KHz to 30 MHz.
- Disturbance Voltage at the Antenna Terminals (Anzac): This test measures the unwanted electromagnetic signals from antenna ports. Frequency range is 30 MHz to 2,15 GHz. The antenna terminals on the EUT are connected to an auxiliary signal generator and an EMC analyser via a combining network and matching pads. The auxiliary signal generator feeds the EUT with a standard test signal at the receiver tuning frequency during the test.
- Disturbance Power: The radiation from each port (mains, scart, headphone, FAV etc.) of an associated equipment (DVD, DVB, and DVD Player/Recorder) is measured by connecting 6 meter cable to that port. The main point in connecting these 6 meter cables is to make them full radiating antenna. Requires the use of an RF Absorbing clamp to measure the level of RF energy transmitted from the product back down the mains lead or other connected lead. This test does not require any other antenna or the use of Open Area Test Sites. Frequency range is 30 MHz – 300 MHz.
- Radiated Power: This test is similar with radiated emission. The electromagnetic noise that EUT radiates is measured, but this test is applied to sattelite receivers only. And the frequency range is 1 GHz to 3 GHZ.
- Radiated Disturbances (Radiated Emission): The electromagnetic noise that EUT radiates is measured in this test. Measurements of the disturbance field due to the local oscillator at it’s fundamental and harmonic frequencies and due to all other sources are included. It requires the use of a broadband antenna to measure the level of RF energy radiated from the product into ‘space’. Ideally an Open Area Test Site (OATS) or equivalent (Semi Anechoic Chamber) should be used. Uncalibrated test sites will require the

use of an ERS to quantify test site distortion. Frequency range is 30 MHz to 1 GHz (EN 55013, 2003).

2.5.3 EN 61000-3-2

This standard states the limits for harmonic current emission of the equipments which has an input current ≤16 A per phase.

Harmonic current test measures the power that audio and video devices require from the mains and the harmonic signals.

This test is applied to audio and video devices, which are suitable for Class D, requiring more than 75 W power, less than 16 A current, and 220/380 V voltage and Class A. Harmonic currents which are less than 0.6% of measured input current and currents which are less than 5 mA are not taken into consideration.

An RF TV signal, which has a level of 65 dBμV, is applied to EUT over 75 Ω. RF signal is a TV signal carrying modulated color picture and sound carrier TV signal (EN 61000-3-2, 2005).

2.5.4 EN 61000-3-3

This standard states the limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equpment with rated current ≤16 A per phase and not subject to conditional connection.

Flicker test measures the voltage changes and fluctuations and flicker impreseed on the public low-voltage system.

This test is applied to audio and video devices, requiring less then 75 A rated input current and 220/380 V voltage and Class A.

An RF TV signal, which has a level of 65 dBμV, is applied to EUT over 75 Ω. RF signal is a TV signal carrying modulated color picture and sound carrier TV signal (EN 61000-3-3, 2001).

CHAPTER THREE
RADIATED EMISSION TEST IN DETAILS

3.1 Radiated Emission and Shielding Effectiveness

The main purpose of testing electronic devices for emission of electromagnetic radiation is to ascertain compliance with regulations and standards. Manufacturers of electronic related products are required to comply with mandated levels of emissions in order to sell legally their products.

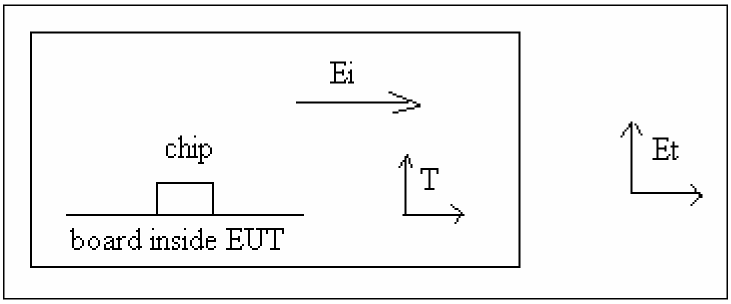

Figure 3.1 Emission from a chip inside the EUT

Every chip, circuit interconnect, etc., inside the EUT radiates some electric field. The net effect is an "ambient" field strength E_i insde the case of the equipment.

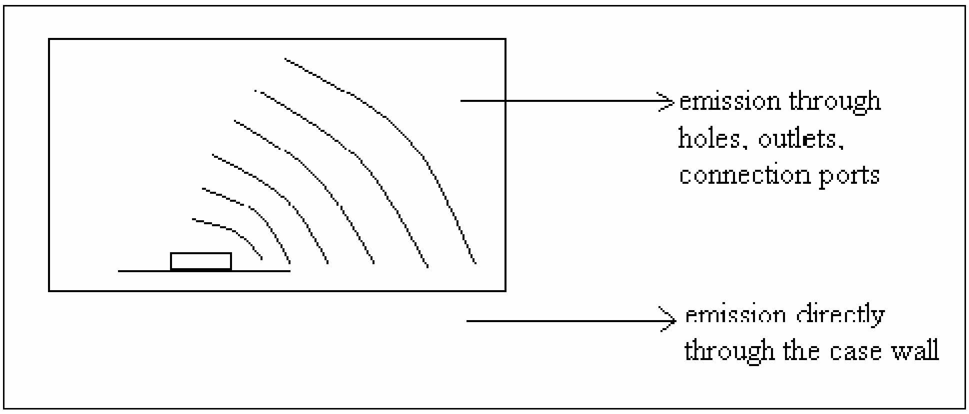

Figure 3.2 Transmission from inside to outside

Transmission from inside to outside can occur:

- directly through the walls of the case;
- through openings in the case such as slots to insert CD discs or floppy discs, or holes to allow connectors to be attached to connect to USB devices, the nework, printers, etc.;
- Along cables or wires that go from boards inside the box to external devices.

The “shielding effectiveness” of the box measures the ability of the box to prevent the internal field E_i from getting out of the box and becoming an external field Et. The “shielding effectiveness” in dB is defined as (IEEE-STD 299, 1991):

$$SE = -20\log\left(\frac{|E_t|}{|E_i|}\right) \qquad \text{Eq. (3.1)}$$

The walls of the box have a transmission coefficient T given by the formulas below:

$$|T| = \left|\frac{4\eta_0\eta_w e^{j\beta_w d}}{(\eta_0+\eta_w)^2-(\eta_0-\eta_w)^2 e^{-2j\beta_w d}}\right| \qquad \text{Eq. (3.2)}$$

The SE of a wall of thickness d is given by:

$$SE = -20\log(|T|) \qquad \text{Eq. (3.3)}$$

This is the largest possible reduction in field strength that would be obtained if the box were solid with no holes or openings and no connections. Including openings reduces the “net” shielding effectiveness very substantially as fields “leak out” through such openings.

Manufactured devices are restricted by government regulations to a very limited “radiated” field strength leaking out of the case. To market a device, it must be proved by measurement that the device “leaks” or emits fields that are smaller than the permitted values. Hence, radiated emission test is required by operating the equipment in a controlled environment, measuring the emitted field over the required frequency range and showing that the emission is less than the permitted value. The test must be done in a "quiet" electromagnetic environment such as a shielded anechoic chamber or in a facility located well away from urban areas, where the ambient field strength is small. Typically the EUT is on a turntable so that it can be rotated 360^o, to measure the field all around it. An antenna is used to measure the field strength at various locations around the EUT. The signal from the receiving antenna is typically fed to a field strength meter which measures the amplitude of the received voltage as a function of frequency (Trueman, 2005). These issues will be described detail in the next chapters.

3.2 Understanding Radiated Emission Testing

In a radiated emissions test, electromagnetic emissions emanating from the equipment under test (EUT) are measured. The purpose of the test is to verify the EUT's ability to remain below specified electromagnetic emissions levels during operation. A receive antenna is located either 3 or 10 meters from the EUT. In accordance with ANSI C63.4, the receive antenna must scan from 1 to 4 meters in height. The scanning helps to locate the EUT's worst-case emissions level. The test set-up is composed of a receive antenna, an interconnecting cable, and a radio noisemeter (EMI receiver or spectrum analyzer).

Measurement frequency range of radiated emission test for "sound and television broadcast receivers and associated equipment" is 30 MHz – 1 GHz.

The test set-up is composed of:

- Standart signal generator
- A Radio noisemeter (Spectrum Analyzer or EMI Receiver)
- Antenna
- Measurement Site
- 4 meter mast
- Turntable

The calculation of the measured E-field signal level is then given by;

$$E(dB\mu V/m) = V(dB\mu V) + CL(dB) + AF(dBm^{-1}) \qquad \text{Eq. (3.4)}$$

where;

E (dBμV/m) = Measured E-field

V (dBμV) = Radio Noise Meter Value

CL (dB) = Loss in Cable

AF (dBm^{-1}) = Antenna Factor

This computed value can be compared to the published specification limit for determination of whether the measured value is less than the specification limit, thus showing compliance with the requirement.

If the total loss in the system is calculated as:

$$\text{Total System Loss} = CL(dB) + AF(dBm^{-1}) \qquad \text{Eq. (3.5)}$$

If this loss over the measurement frequency range is computed inside the Radio Loss Meter before test, measured Radio Noise Meter Value is directly equal to the E-field emitted from the EUT.

3.3 Radiated Emission Measurement Setup

As seen in Figure 3.3, during the radiated emission testing, EUT is placed on the turntable and connected to the mains by a filter to protect from the disturbance arising from the mains line. The standard test signal is applied to the tuner of the EUT from the standard signal generator.

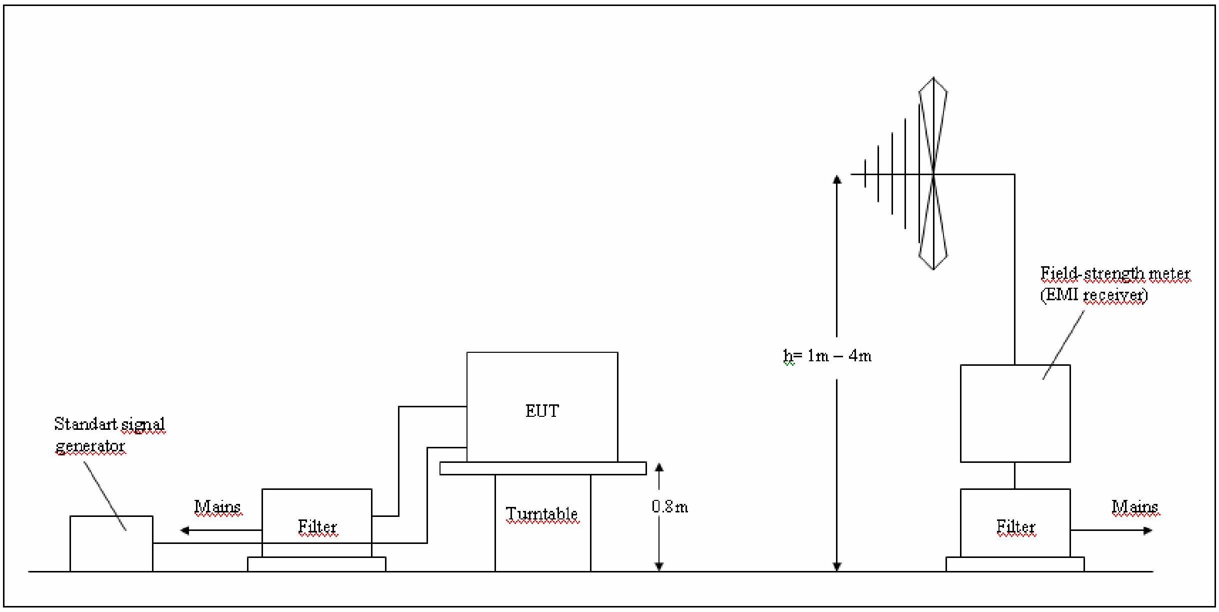

Figure 3.3 Radiated Emission Test Setup.

Standard test signal for television receivers and for other equipment with video signal input/output and/or an RF modulator is a standard television colour bar signal according to ITU-R BT 471-1. The modulation of the video and the audio signals on the RF carrier shall be according to the system for which the equipment is intended.

In the case of television receivers, the wanted signal shall be a vision carrier modulated by a complete video waveform including a colour burst together with an unmodulated sound carrier of the correct relative amplitude and frequency.

The standard test signals for radio receivers are:

a) Band II: An RF signal frequency modulated with a monophonic signal at 1 KHz with 37,5 KHz deviation;
b) LW/MW/SW: An RF signal amplitude modulated with a signal at 1 KHz with 50 % modulation (EN 55013, 2003).

The standard test signals for associated equipment are:

a) audio amplifiers and infrared headphones : a sinusoidal signal at 1 KHz;

b) associated audio equipment e.g. audio tape recorders, record players, CD players: a tape or disc recorded 1 KHz audio signal with a standard sound level specified by the manufacturer of the equipment under test;
c) associated video equipment, e.g. video tape players, camcoders, laser disc players; a tape or disc recorded standard television colour bar signal with 1 KHz audio signal, with a standard sound level specified by the manufacturer of the equipment under test (EUT);
d) electronic organs: a signal derived from depressing the upper C note (approx. 523 Hz);
e) infrared remote controls: a permanent transmission of a typical control function (EN 55013, 2003).

For equipment for which the wanted signals are not explicitly described in the standard, the nominal signals as specified by the manufacturer shall be applied during the tests (this is e.g. the case for broadcast receivers for digital signals, decoders etc.). The manufacturer shall specify in his technical report which input signal was applied during the tests.

An infrared remote control is considered as a part of the main unit and tested together.

Bilog antenna is placed 3 meters distance from the EUT and connected to a field strength meter (EMI Receiver). Measurement is taken when the antenna height is varied from 1 to 4 meters for horizontal polarization, and 2 to 4 meters for vertical polarization. EUT is turned 360^o and the maximum level measured. During the test, disturbance field due to the local oscillator at its fundamental and harmonic frequencies and due to all other sources is measured by the quasipeak detector of the field strength meter (EMI Receiver). Applicable limits described in the standard EN 55013 is given in Table 3.1.

Table 3.1 EN 55013, applicable limits of radiated emission test

Equipment type	Source	Frequency MHz	Limit values dB(µV/m) Quasi-peak
Television receivers video recorders and PC tuner cards	Local oscillator	≤1000 30 to 300 300 to 1000	Fundamental 57[a] Harmonics 52 Harmonics 56
	Other	30 to 230 230 to 1000	40[b] 47[b]
Television and sound receivers for broadcast sattellite transmissions (except outdoor units) infrared remote control units and infrared headphone systems	Other	30 to 230 230 to 1000	40[b] 47[b]
Frequency modulation sound receivers and PC tuner cards	Local oscillator	≤1000 30 to 300 300 to 1000	Fundamental 60 Harmonics 52 Harmonics 56
	Other	30 to 230 230 to 1000	40[b] 47[b]

3.3.1 Standard Signal Generator

Signal generator is an electronic instrument used for the production of electromagnetic or acoustic signals with certain desired characteristics. It is useful in testing and calibration. In this test, signal generator applies a "standard colour bar" signal to the tuner of the EUT, to make it work in receiving mode.

3.3.2 Field Strength Meter

EMI measurements require a different approach than other types of general RF tests. In EMI, it is never quite known what signals may be present. Since each new EUT will be different, having the correct tools for characterization of the EMI signals is of key importance. Also, knowing the strengths and weaknesses of the tools being used is vital. Two instruments are used for EMI testing, Spectrum Analyzers and Test Receivers. Each requires a different approach to the test, and each has advantages and disadvantages.

Spectrum Analyzers and Test Receivers are often lumped together as the same thing. Although both instruments measure the amplitude of signals in the frequency domain, the units are not the same, and require knowledge to extract correct measurements. Each can be abused, and each can return incorrect measurement results.

The differences between the two can be explored by examining a common test setup (i.e. the parameters necessary to configure each instrument).

Spectrum Analyzer tests set the following parameters:

- Start/Stop Frequency
- Resolution Bandwidth Filter and Type (3 or 6 dB)
- Detector(s)
- Sweep Time
- Video Bandwidth

Most spectrum analyzers "couple" or lock the resolution bandwidth, video bandwidth and sweep time together so that critical timing requirements are not violated. These parameters can be manually controlled however, and even forced into modes where incorrect measurements are displayed.

Test Receivers follow a similar setup:

- Start/Stop Frequency
- Resolution Bandwidth Filter and Type (3 or 6 dB)
- Detector(s)
- Measurement (dwell) Time
- Step Size

These settings are often listed in the specification or standard being used to qualify the product. Using a “compliant” test receiver and calibrated test environment set according to the standard, should yield correct results.

If a compliant EMI test receiver, properly configured, will yield correct results, why use any other tool? There are several reasons to consider using a spectrum analyzer for EMI type measurements.

Versatility is the main advantage of a spectrum analyzer. The same unit can be used for general transmitter and receiver measurements such as adjacent channel power or noise figure. Most labs have one in house already, so it makes financial sense to use the same unit for EMI.

Familiarity is another advantage of spectrum analyzers. Most engineers have been exposed to them, even if they are not RF specialized.

And finally, spectrum analyzers “tailored” for EMI are the *Comfortable* solution in the US because that is what most engineers are used to.

Spectrum Analyzers are a versatile tool, but one that must be used with caution for EMI applications. Operators must be aware that for EMI, the spectrum analyzer is required to mimic a test receiver and its testing methods. This is analogous to using a flat head screwdriver to drive a type head. It can be done, but there are “issues” to keep in mind.

Issue #1: Sub-ranging the span: Most spectrum analyzers make 500 or 1000 measurements within the span (stop frequency – start frequency = span). If that span is set wide, say from 30 MHz to 1 GHz like the typical CISPR test, the measurement points will be made nearly 2 MHz apart. Obviously, these settings will skip over emissions since the resolution is too course for EMI applications. Sub-ranging the span into smaller chunks allows the measurement points to fall closer together, thus improving the resolution of the test. Sub-ranging the span is an attempt to make the spectrum analyzer mimic a test receiver’s method. Since our goal is to improve the resolution, if sub-ranging the span, the following rule of thumb is used:

Measurement points = XXXX
½ RBW = max step size
Step size X # points = sub-range size

For instance, CISPR specifies a 120 KHz resolution bandwidth filter for the radiated emission range (30 MHz – 1 GHz). A proper sub-range for testing this band will make the measurement points fall a maximum of 60 KHz apart (½ RBW). Using a spectrum analyzer with 500 measurement points, and running the calculation yields:

500 points
120 KHz / 2 = 60 KHz
60 KHz x 500 points = 30 MHz span

In this case, a proper test method is to test the first 30 MHz span (30 – 60 MHz), then the next (60 – 120 MHz), and so on until you arrive at 1 GHz. This process is highly time-consuming. If your spectrum analyzer tests 1000 points, your sub-ranges will be 60 MHz rather than 30 MHz wide. Also note that some devices may require a smaller resolution than ½ RBW (e.g. 1/3 RBW), requiring even more sub-ranges.

Issue #2: QP and AVE detectors: Most EMI applications specify two types of detectors that may not be present on generic spectrum analyzer units. The first is called the Quasi-Peak or QP detector. This detector attempts to quantify the "annoyance factor" of a signal by weighing its repetition rate in addition to its frequency and amplitude. The QP detector must also conform to the CISPR requirements. Pre-compliant QP detectors are not acceptable for those who will "self-certify" compliance, or for test labs offering compliance services. The second detector to look for is called a CISPR-AVE detector. The differences between a typical AVE detector and a CISPR AVE detector have to do with the averaging time constants used.

Issue #3: Resolution bandwidths: General purpose spectrum analyzers may not have the proper resolution bandwidth filters for EMI applications. Often "personalities" for the EMI bandwidths must be purchased as an option. EMI type RBW filters are narrower, rolling off at 6 dB per decade rather than 3 dB. Common CISPR RBW filters are 200 Hz, 9 KHz, 120 KHz and 1 MHz. MIL-STD 461 calls out 6 dB RBW filters between 10 Hz – 10 MHz. Using the incorrect filter can influence both amplitude and frequency values returned by the instrument.

Issue #4: Power vs field strength: General spectrum analyzers measure either power or voltage on the amplitude axis. Most EMI standards and limit lines are specified in field strength at some distance from the EUT. In order to arrive at a measurement that is comparable to a limit line and one that eliminates the differences between test environments, the spectrum analyzer must allow for "correction" of system transducers. When measuring radiated emissions, the effect of each particular antenna (antenna factor) and cable (cable loss) must be normalized through the use of files that give a correction value at some frequency. When transducer correction is active, the Y axis of the EMI spectrum analyzer will read dBμV / meter (field strength) rather than voltage or power. Since limit lines for radiated emissions are specified in field strength, a limit line can now be displayed on the screen for direct pass / fail evaluations of the measurement results. Conducted emissions are specified in dBµV, or a pure voltage, but a correction value for cables and the transducer (usually a line impedance stabilization network or LISN) is still used to eliminate the differences between various equipment and manufacturers.

Issue #5: Measurement dwell time: The QP, average and CISPR-AVE detectors have dwell time requirements in order to output correct results. For the QP, a one second dwell time is required in order to fully charge and discharge the filters in the detector. Both average detectors require 100 ms or more. Some spectrum analyzers now offer "zero-span". This capability is another "work around" to make the spectrum analyzer work like a test receiver and provide this dwell feature.

Issue #6: Preselection & overloads: Some of the signals encountered in EMI testing are high amplitude and can cover a wide frequency band. Spectrum analyzers measure everything that falls in the pass band of the RF front end. In other words, even though it is not looking at a signal on the screen, the RF front end is still measuring the total signal power over the entire frequency spectrum. Now, considering the scenario when a wide band signal is of sufficient amplitude to cause an RF overload condition - usually seen on the SA as spectral lines on the display, these "signals" will appear as though they come from the EUT, when in fact they are induced by the overload condition. An additional filter can be placed in the RF section to help prevent this condition. Called a preselector, this filter cuts out any signals not being displayed on the screen (with some limitations). This is critical for conducted EMI measurements when a very high amplitude signal may prevent measurements on the rest of the spectrum. While using the RF attenuator, it may help, but in some cases it may attenuate wanted signals so much that they can no longer be displayed. Plus, setting the attenuation is a manual process on spectrum analyzers, one more thing to complicate the testing process. Pre-selector filters are seldom found on spectrum analyzers, but are a valuable option if available. Automatic attenuators can't work fast enough for a spectrum analyzer. Manual RF attenuators are available but they require constant adjustment during the test process and add room for inconsistency.

In summary, spectrum analyzers can be used for EMI, but various work-around methods must be used in order for the results to be accurate. Obviously, there are many opportunities for error. Incorrect sub-ranging, violation of dwell time requirements, use of incorrect RBW filters, overloads, and many other issues force us to conclude that the spectrum analyzer may not be the best tool for the job. Look at the tedious nature of sub-ranging alone. Even a high-end spectrum analyzer with 1000 points forces a 60 MHz sub-range, seventeen ranges must be tested between 30 MHz and 1 GHz. The results of each range must be collated, corrected for transducer values, checked for overload conditions, and finally compared to a limit line for a pass / fail decision. Software helps, but it is one more complexity and one more cost. Also, software may be tied to only one spectrum analyzer or vendor. Fortunately, there is a better way.

CISPR, EN, FCC, MIL-STD and all the other standards bodies recommend using a test receiver for EMI applications for all of the above reasons. With a test receiver, what you set is what is measured, and these settings are listed right in the test standard. A typical test receiver setup illustrates the point. Using the same basic case used before, the keystokes are:

Frequency start: 30 MHz
Frequency stop = 1 GHz
RBW = 120 KHz (6 dB)
Step size = 60 KHz (1/2 RBW)
Activate transducer set
Overlay limit line

As it is seen, these parameters are called out in the standard, entered directly as a test parameter, and now the operator needs only to press start. No sub-ranging, no zero-spanning, no mental conversions from voltage to field strength. Furthermore, with automatic attenuators and pre-selection, it is possible for a compliant test to run without intervention. There are obviously reasons for an operator to interrupt the test, but the possibility does exist for a fully automatic test to yield accurate results.

In order to explore test receivers a bit more, some key features are called out in the next section that illustrate why a test receiver is a better tool for EMI testing.

Feature #1: Measurement Points: A scanning receiver will measure many tens of thousands of points if needed. For instance, in the previous test setup, the test receiver will measure:

1000 MHz - 30 MHz = 970 MHz
970 MHz/ 60 KHz = 16,170 pts

This level of accuracy is much improved over a spectrum analyzer's 500 or 1000 points. Tests with 100,000 measurement points are not uncommon in some MIL-STD applications.

Feature #2: Tune & Dwell: The second key feature is the tune and dwell capability native to a scanning receiver. Dwell time is set as a keystroke parameter, and violations to dwell time requirements of the various detectors are often "flagged" as incorrect.

Feature #3: EMI Specificity: This key feature rolls up all the "issues" discussed during the spectrum analyzer exploration, namely the availability of EMI specific features such as 6 dB RBW filters, transducer sets, limit lines and preselector filters.

Feature #4: Automatic Control: Scanning receivers can also take advantage of automatic control of certain parameters. At the beginning, it was stated that certain modes could be forced on a spectrum analyzer that will yield incorrect results. This is also true for receivers, but much less likely since the receiver will "take care of itself" if left in auto-control mode. Automatic control of RF attenuation, preselection filtering, preamplification settings, RBW settings, and the step size is common. Auto-control of these settings can keep the user out of trouble in most cases. The auto-control of these parameters will follow what is called out in the standards. Since no one starts as an expert, EMI novices may be saved from collecting incorrect data, and worse, making judgments on bad data.

Using test receiver has some disadvantages. Similar to spectrum analyzers, there are also disadvantages to test receivers. Scanning receivers are the right tool for the job mainly because they were built with EMI in mind. Specialized tools often cost more, and have limited use outside of the area of specialization. Many proponents of spectrum analyzers will suggest that receivers are slower than analyzers. On the face, this is true, but if apples are compared to apples, there is no time penalty associated with using a receiver. The type of detector and its associated dwell time impose the true timing limitation. Also the number of measurements that must be made to ensure proper signal capture will be the same, regardless of which unit is being used. A true side-by-side comparison of a receiver scan and the sub-ranged spectrum analyzer sweep will show a time advantage to the receiver, not the spectrum analyzer.

In the end both tools may be used for EMI measurements. There may be overriding factors that guide the choice that were not discussed. One factor might be the requirements imposed by an accreditation body like A2LA or NVLAPP. These bodies and military / government agencies may disallow generic spectrum analyzer measurements for EMI. The number of “work-arounds” is high, and the room for error is great (Rohde&Schwarz, ud).

3.3.3 Antenna

According to Krause (Krause, 1950), “A radio antenna may be defined as the structure associated with the region of transition between a guided wave and free space, or vice versa”. The EMC test community uses specialized versions of radio antennas for measuring electric and magnetic field amplitudes over a very broad frequency spectrum.

Selecting the right antenna for the job can be a difficult task. In many cases, manufacturer terminologies and specifications are so varied that it is difficult to compare them. A firm grasp of the basic terminologies and their limitations is essential. The right antenna is an essential part of a test system. Depending on the specific application and the equipment used, one type of antenna may be better suited than another. The discussion here is focused on antennas, which by definition are devices that convert time-varying voltages into a radiated electromagnetic field. The keyword here is “radiated”. Many field generating devices, such as TEM (or Crawford) cells, GTEM, parallel plates, or tri-plates (widely used in automotive component testing), are strictly speaking not antennas. Energies stay within the devices and are not radiated into space.

In EMC applications, antennas are primarily used for radiated emission measurements, radiated immunity testing, site qualification testing (normalized site attenuation), or other applications such as exciting a reverberation chamber. In a specific application, one set of parameters maybe more important than another. For example, the gain of an antenna may not be of any concern if it is used to excite a reverberation chamber (Chen, 2003).

3.3.3.1 Directivity and Gain

Passive devices, such as most of the antennas used in EMC, can not amplify signals they receive, or radiate more energy than provided. Gain and directivity specify an antenna’s ability to concentrate a transmitted signal in a desired direction, or receive a signal from that direction.

Directivity describes how well an antenna concentrates radiation intensity in a certain direction, or receives a signal from this direction. This is in comparison to an omni-directional (isotropic) antenna. Note that an isotropic antenna is simply a theoretical model, and is not possible to construct one physically. A theoretical isotropic antenna has a directivity 0 dBi (“dBi” means dB over an isotropic source). A half wave dipole has a directivity of 2.14 dBi. This means a half wave dipole can concentrate 2.14 dB more energy in its maximum radiation direction than an isotropic source. Higher directivity is associated with narrower beamwidth.

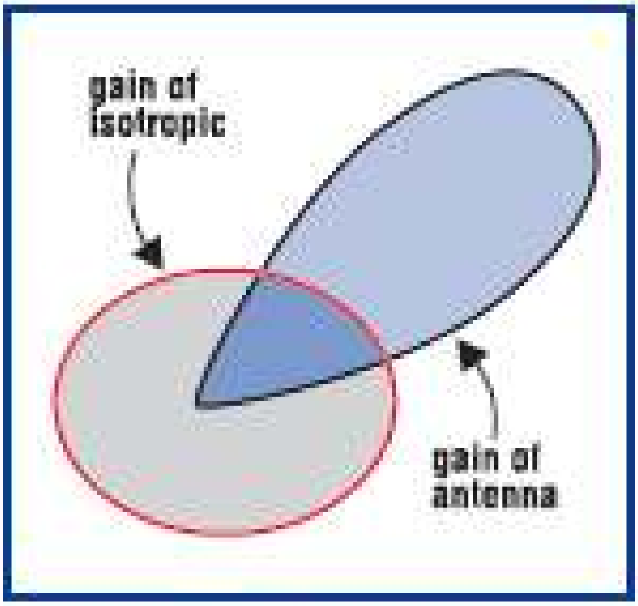

Figure 3.4 Gain of the antenna

The gain of the antenna is a parameter that describes the directional response of the antenna compared to an isotropic source, a theoretical antenna that radiates the same amount in all directions. The higher the gain, the better the antenna concentrates its beam in a specific direction. The simple example is a light bulb compared to a flash light. The flashlight, with its reflector, concentrates the light in one direction, where the light bulb produces light in all directions.

Gain, by IEEE definition, is the product of the directivity and the ohmic efficiency (sometimes called ohmic loss factor). Most EMC antennas are made of aluminum or other highly conductive metals. In these antennas, the ohmic loss is insignificant; therefore, gain is the same as directivity. This is where confusion arises, since such a gain definition is rarely the one you encounter in an EMC application.

Gain in EMC applications typically includes an additional mismatch factor. To illustrate this, let us assume the antenna is in transmitting mode (the argument applies to receiving antennas as well). Note the IEEE definitions above are based on the net power delivered to the antenna. In reality, antennas are never perfectly matched to the source, and energies are reflected at the antenna port. The net power is the subtraction of the forward power and the reverse power (in dB terms).

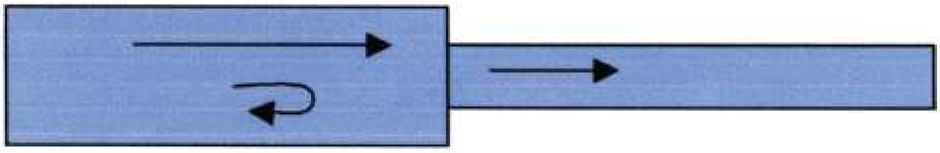

Figure 3.5 Power transmission in the antenna port

Although it is different from the IEEE definition, it is a practical one (this is sometimes referred to as apparent gain). For example, an antenna can have a very directive pattern but, if it is not close to 50 Ω in characteristic impedance, very small electric field levels will result when connected to a 50 Ω source (used for most instruments). In most EMC applications, gains published in the antenna catalogs include this mismatch factor (Chen, 2003).

3.3.3.2 Reflection Coefficient/VSWR/Return Loss

Reflection coefficient, VSWR and return loss all describe the same physical phenomenon, that is, the mismatch factor.

The voltage reflection coefficient, typically ρ, is the ratio of the voltage reflected from the load of a transmission line to the voltage imposed on the load of the same transmission line. Its values vary from zero to one. When the load impedance is "matched" to the source impedance (has the same value), and the characteristic impedance of the transmission line, then the reflection coefficient is quite small (no reflection), approaching zero. When there is "mismatch" (the load impedance differs from the characteristic impedance) the reflection coefficient can approach one (almost all incident power is reflected). Reflection coefficient can be a complex number, as the reflected voltage does not always line up in phase with the forward voltage. Return loss is simply the magnitude of logarithmic form of the reflection coefficient. The reflection coefficient is usually determined by a measurement of the Voltage Standing Wave Ratio. It is then computed from (Chen, 2003):

$$|\rho| = \frac{(VSWR - 1)}{(VSWR + 1)} \qquad \text{Eq. (3.6)}$$

where $|\rho|$ is the magnitude of the reflection coefficient, and RL is the return loss is dB. In terms of power relationship (Chen, 2003):

$$P_{net} = \left(1 - |\rho|^2\right) P_{fwd} \qquad \text{Eq. (3.7)}$$

where P_{net} is the net power and P_{fwd} is the forward power. For example, if an antenna has a VSWR=2:1, the magnitude of the reflection coefficient is 1/3, the return loss is 9.5 dB, and 11% of the power is reflected (or 89% net power is delivered to the antenna).

The Voltage Standing Wave Ratio (VSWR) is a measure of the mismatch between the source and load impedances. Numerically, it is the ratio of the maximum value of the voltage measured on a transmission line divided by the minimum value. When the value is high, most of the power delivered from a generator is reflected from the antenna (load) and returned to the generator. The amount of power not reflected is radiated from the antenna. This means that the generator rating for an antenna with a high VSWR can be quite high.Users should choose an antenna with a low VSWR when possible. As a practical matter, this may not always be possible, particularly at lower frequencies.

3.3.3.3 Antenna Factor

This is the parameter of an EMC antenna that is used in the calculations of field strength during radiated emissions measurement. It relates the voltage output of a measurement antenna to the value of the incident field producing that voltage. The units are volts output per volt/meter incident field or reciprocal meters (Chen, 2003).

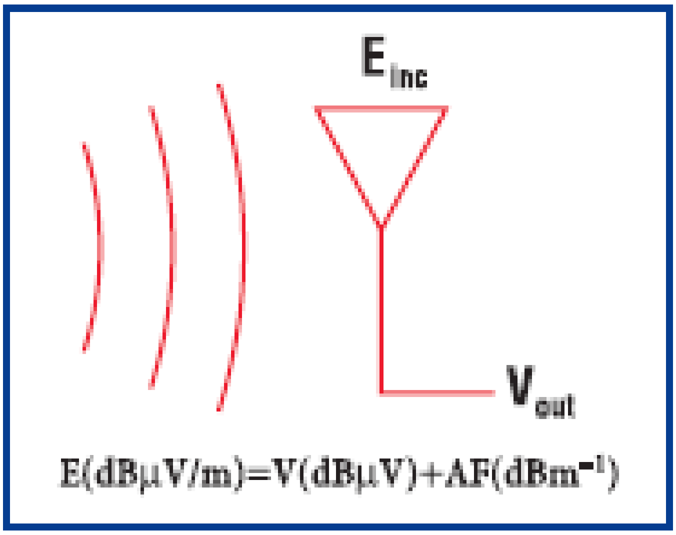

Figure 3.6 Antenna factor parameters

$$E(dB\mu V/m) = V(dB\mu V) + AF(dBm^{-1})$$ Eq. (3.8)

Antennas with smaller AFs are more sensitive to the incident field. It is interesting to note that AFs generally increase with frequency. As can be seen in the derivations, the analytical expression for Antenna Factor (AF) has the equivalent of frequency in the numerator, thus AF will typically increase with increasing frequency. It comes as no surprise then that to measure the same field level, more sensitive receivers are needed for higher frequencies. AFs are normally provided by antenna manufactures or calibration labs. The accuracy of AFs directly affects radiated emissions measurement. It is recommended antennas be calibrated annually to minimize the measurement uncertainties.

3.3.3.4 Transmit Antenna Factor

The Transmit Antenna Factor (TAF) is similar to the AF in that it describes the performance of an EMC antenna over its frequency range of operation.

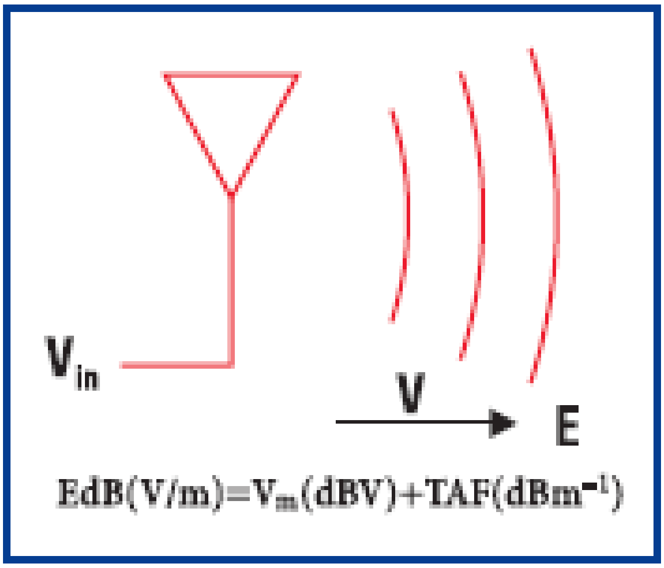

Figure 3.7 Transmit antenna factor parameters

This parameter relates the E-field produced by an antenna, at a given distance, to the input voltage at the input terminals of the antenna. The units are volts/meter produced per volt of input, so the final units are reciprocal meters just as the AF. The AF and TAF are not the same nor are they reciprocal, though the AF and TAF can be computed from each other. The TAF is not a direct function of frequency, but it is a function of distance (Osburn, 1996).

$$EdB(V/m) = V_m(dBV) + TAF(dBm^{-1}) \quad \text{Eq. (3.9)}$$

3.3.3.5 Antenna Pattern

The antenna pattern is typically a polar plot of the relative response of an antenna as a function of viewing angle.

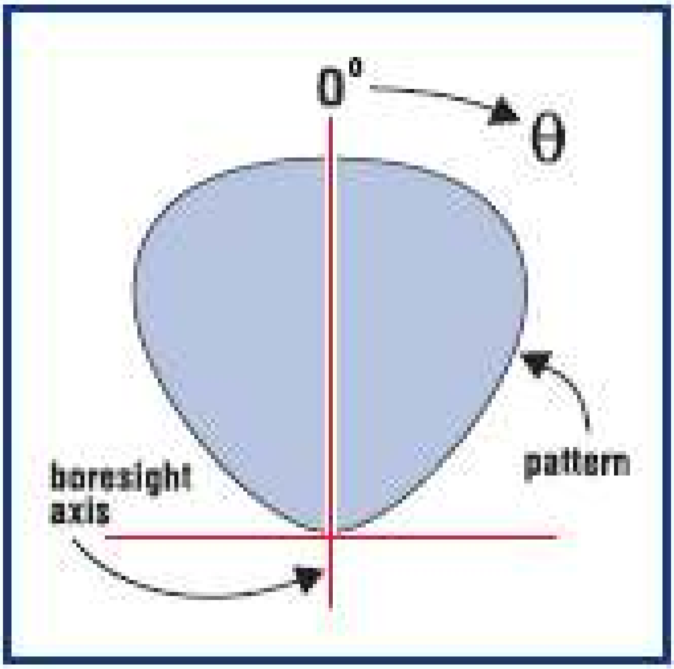

Figure 3.8 Polar plot of the response of tha antenna

In a strict sense, antenna pattern is a descriptor for the far field response. In practice, EMC measurements are often performed in the near field, and antenna pattern is taken quite liberally as well to include near field responses. The "on-axis" viewing angle where the response of the antenna is a maximum is called "the boresight axis". The pattern shows the response of the antenna as the viewing angle is varied. Typically, simple antennas exhibit a "dipole response" where the pattern of the antenna is donut shaped with the dipole on the common axis of the donut. More complex antenna patterns are approximately pear shape with the bottom of the pear facing away from the antenna.

3.3.3.6 Beamwidth

This parameter is the descriptor of the viewing angle of the antenna, in the plane of measurement, typically where the response has fallen to one half the power received when the antenna is perfectly aligned.

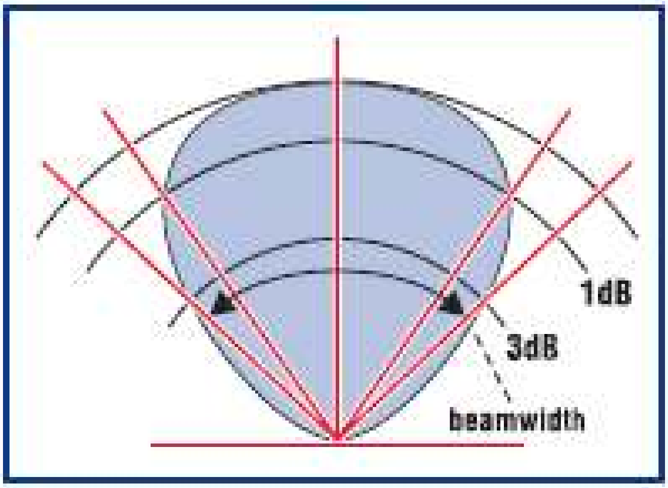

Figure 3.9 Beamwidth of the antenna pattern

EMC antennas are normally designed to provide a viewing angle in the primary plane, approaching 60° between the half power points where the response of the incident is 3 dB down, if at all possible. The only specific requirements are found in IEC 801 - 3 and IEC 1000 - 4 - 3, which, if the analysis of the requirement is performed, translates into a minimum viewing angle of 28° (± 14°) at the 1 dB down points. The 1 dB down response is usually compatible with the 3 dB down value of 60°.

Beam width can be used to roughly estimate the size of a uniform field area in an immunity test. However, many other factors come into play for establishing uniform field, such as reflection from the ground or walls of a chamber. Moreover, patterns could be measured at a different distance than the one used in the immunity setup, thus the near field effect is different. Beamwidth is not a magic number that establishes the size of the uniform field plane.

3.3.3.7 Phase Center

A radiated wave front has a curvature when in near field. In far field, the curvature is so large that it can be regarded as a plane wave. The apparent center of the curvature is the phase center. For many EMC antennas, such as biconical antennas or dipoles, the phase centers are quite obvious. For log periodic antennas, the phase center moves from the back to the front as frequency goes up. The measurement distance from the antenna to the EUT is unclear. In practice, a compromise has to be made for the distance (Chen, 2003).

3.3.3.8 Polarization

The polarization of a radiated wave has to do with the radiated vector field traced out as a function of time. Fortunately, many EMC antennas are linearly polarized, such as dipoles, biconical antennas, log periodic dipole arrays, and horns. Linearly polarized antennas radiate vector field in a single direction which is less complicated than other polarizations. Any imperfections are measured by the cross-polarization ratio (the ratio of the field level in the intended direction to that of its orthogonal direction). Some antennas are circularly polarized for special applications, such as conical log spiral antennas as required by MIL-STD 461.

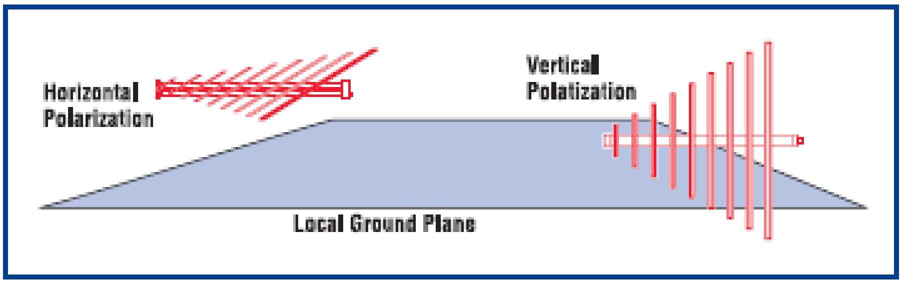

Figure 3.10 Polarization of the antenna

The orientation of the measurement axis of a linearly polarized antenna with respect to the local ground plane is also called as polarization. Vertical polarization occurs when the measurement axis of the antenna is perpendicular to the local ground plane. Horizontal polarization occurs when the measurement axis is parallel to the local ground plane. Most EMC test specifications require measurements in both vertical and horizontal polarizations of the measurement antenna.

3.3.3.9 Balance

Coaxial cables attached to the antennas are inherently imbalanced, because they are asymmetrical with respect to ground. In other words, the cable shield to the ground is different from the center pin to the ground. Some antennas, such as biconical antennas, employ balun (short for Balanced-to-Unbalanced transformer) to overcome the imbalance. Basically, a balun provides low impedance or an easy pass through to the differential current and high impedance to the common mode current. An unbalanced antenna has different responses depending on which side is up when polarized vertically. A large amount of common mode current exists between the shield of the feed cable and the ground plane. This causes large measurement uncertainties.

3.3.3.10 Bandwidth

Bandwidth is “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specific standard” (Balanis, 1997).

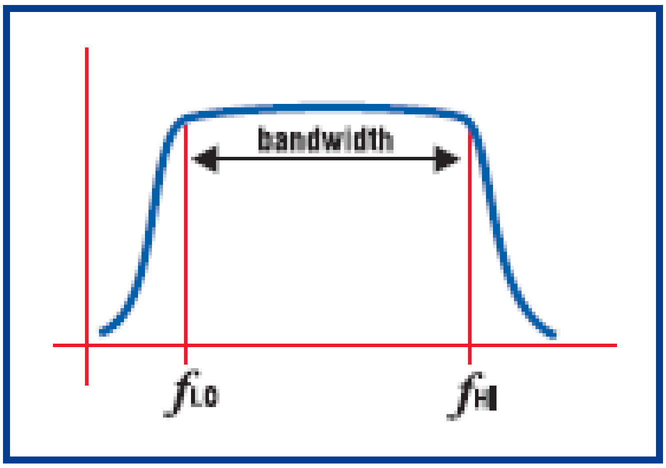

Figure 3.11 Bandwidth of the antenna

The definition is quite broad. It does not explicitly specify what the "characteristics" or "specific standard" are, so the term bandwidth is subjective. Depending on the application, the typical characteristics can include all or some of the terms discussed previously. Engineering judgments are needed to determine what is acceptable for the application.

Typical EMC antennas will have a ratio of upper useful frequency to lowest useful frequency on the order of 5 to 1. Some unique designs provide ratios of as much as 25 to 1. This ratio is a dimensionless ratio, i.e., it has no units.

3.3.3.11 RF Power Terms as Applied to Antennas

There are several ways of discussing RF power as used to excite antennas for the generation of electromagnetic fields. This set of related definitions is provided to understand the definitions as used in this research.

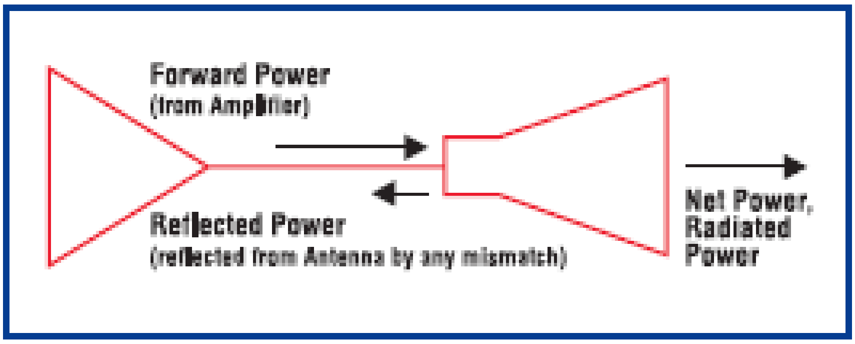

Figure 3.12 Power terms of the antenna

Forward Power is the output from an amplifier that is applied to an antenna input to generate an electromagnetic field.

When mismatch exists at the antenna port, a fraction of the power applied (the forward power), is reflected from the antenna back toward the amplifier. This is termed the reflected power.

The power applied to the antenna that is actually radiated is called the net power or radiated power. It is the difference between the forward power and the reflected power. Usually, this value cannot be directly measured, but is computed from the direct measurement of forward and reflected power by taking the difference:

$$P_{net}(W) = P_{forward}(W) - P_{reflected}(W) \quad \text{Eq. (3.10)}$$

In this document the Net Power is the power value that is required as an input to an antenna to generate a specific E-field level (Common EMC Measurement Terms, nd).

3.3.3.12 Antenna Calculations

Antenna Factor is traditionally tied to the recieve antenna factor, the ratio of field strength at the location of the antenna to the output voltage across the load connected to the antenna (Common EMC Measurement Terms, nd).

$$AF = \frac{E}{V} \quad \text{Eq. (3.11)}$$

where;

AF = Antenna Factor, meters^{-1}

E = Field Strength, V/m or µV/m

V = Load Voltage, V or µV

Converting to dB (decibel) notation gives;

$$AF_{dB(m^{-1})} = 20\log\left(\frac{E}{V}\right) \quad \text{Eq. (3.12)}$$

or

$$AF_{dB(m^{-1})} = E_{dB(V/m)} - V_{dB(V)} \quad \text{Eq. (3.13)}$$

The antenna factor is directly computed from:

$$AF = \frac{9.73}{\lambda\sqrt{g}}(m^{-1}) \quad \text{Eq. (3.14)}$$

where;

λ = Wavelength (meters)

g = Numerical Gain

In the same sense, for magnetic fields, as seen by loop antennas (Common EMC Measurement Terms, nd):

$$AF_{HdB(S/m)} = H_{dB(A/m)} - V_{dB(V)}$$ Eq. (3.15)

In terms of flux density (B-Field) (Common EMC Measurement Terms, nd):

$$AF_B = AF_H + 20\log(\mu)$$ Eq. (3.16)

$$AF_B = AF_H - 118 \text{, T/V}$$ Eq. (3.17)

Loop antennas are sometimes calibrated in terms of equivalent electric field, where (Common EMC Measurement Terms, nd);

$$AF_{EdB(m^{-1})} = AF_{HdB(S/m)} + 20\log\eta$$ Eq. (3.18)

$$AF_{EdB(m^{-1})} = AF_{HdB(S/m)} + 20\log(120\pi) \text{ or,}$$

$$= AF_{HdB(S/m)} + 51.5dB$$

where ;

η = the Impedance of Free Space

= 120π Ω

Conversion of Signal Levels from mW to μV in a 50Ω System is sometimes needed. Voltage and power are equivalent methods of stating a signal level in a system where there is a constant impedance (Common EMC Measurement Terms, nd). Thus:

$$P = \frac{V^2}{R}$$ Eq. (3.19)

where;

P = Power in Watts

V = Voltage Level in Volts

R = Resistance Ω

For power in miliwatts (10^{-3}W), and voltage in microvolts (10^{-6}V),

$$V_{dB(\mu V)} = P_{dBm} + 107 \qquad \text{Eq. (3.20)}$$

An alternative measure of field strength to electric field is power density (Common EMC Measurement Terms, nd):

$$P_d = \frac{E^2}{120\pi} \qquad \text{Eq. (3.21)}$$

where;

E = Field Strength (V/m)

P_d = Power Density (W/m^2)

Table 3.2 Common values for power density.

E (V/m)	P_d
200	10.60 mW/cm^2
100	2.65 mW/cm^2
10	26.50 µW/cm^2
1	0.265 µW/cm^2

Power density at a point can be calculated from the below equation (Common EMC Measurement Terms, nd);

$$P_d = \frac{P_t G_t}{4\pi r^2} \qquad \text{Eq. (3.22)}$$

In the far field, where the electric and magnetic fields are related by the impedance of free space:

P_d = Power Density (W/m^2)

P_t = Power Transmitted (W)

G_t= Gain of Transmitting Antenna

r = Distance from antenna (meters)

The Friis Transmission formula describes Power received by anantenna in terms of power transmitted by another antenna (Common EMC Measurement Terms, nd):

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi r)^2} \quad \text{Eq. (3.23)}$$

where;

P_r = Power Received (W)

P_t = Power Transmitted (W)

G_r = Numeric Gain of Receiving Antenna

G_t = Numeric Gain of Transmitting Antenna

r = Separation Between Antennas (meters)

λ = Wavelength (meters).

The electric field strength at a distance from a transmitting antenna (far field) such that the electric and magnetic field values are related by the impedance of free space is (Common EMC Measurement Terms, nd):

$$E_{V/m} = \frac{\sqrt{30 P_t G_t}}{r} \quad \text{Eq. (3.24)}$$

where the terms are defined above.

For simple radiating devices having low gain, far field conditions exist when (Common EMC Measurement Terms, nd):

$$r \geq \frac{\lambda}{2\pi} \quad \text{Eq. (3.25)}$$

where;

λ = Wavelength (meters)

For more complex antennas having higher gain values, far field conditions exist when (Common EMC Measurement Terms, nd):

$$r \geq \frac{2D^2}{\lambda} \quad \text{Eq. (3.26)}$$

where;

D = Maximum Dimension of Antenna (m)

Relationship of antenna factor and gain in a 50Ω system is shown below equation (Common EMC Measurement Terms, nd);

$$G_{dB} = 20\log(f_{MHz}) - AF_{dB(m^{-1})} - 29.79$$ Eq. (3.27)

To calculate power required to generate a desired field strength at a given distance when antenna factors are known, below equation is used (Common EMC Measurement Terms, nd);

$$P_{dB(W)} = 20\log_{10}\left(E_{desired(V/m)}\right) + 20\log_{10}\left(d_m\right) - 20\log_{10}\left(f_{MHz}\right) + AF_{dB(m^{-1})} + 15$$ Eq. (3.28)

Relationship Between Frequency and Wavelength in Free Space is (Common EMC Measurement Terms, nd);

$$f\lambda = c$$ Eq. (3.29)

where;

f = Frequency (Hz)

λ = Wavelength (meters)

c = Velocity of Light

= 3 x 10^8 m/s

A simpler relationship is (Common EMC Measurement Terms, nd):

$$\lambda = \frac{300}{f_{MHz}}$$ Eq. (3.30)

A decibel is one tenth of a Bel, and is a ratio measure of relative amplitude. In terms of power, the number of decibels is ten times the logarithm to the base 10 of the ratio.

In terms of power:

$$dB = 10\log_{10}(P_1/P_2)$$ Eq. (3.31)

where P_1 and P_2 are in watts.

In a constant impedance system, power references can be made between different measurement points. It can also be related to voltage or current measurements:

$$\text{Power Ratio} = 10\log_{10}\left({P_1}/{P_2} \right)$$

$$= 10\log_{10}\left(\frac{{V_1^2}/{R_1}}{{V_2^2}/{R_2}} \right)$$

$$= 20\log_{10}\left(\frac{V_1}{V_2} \right) - 10\log_{10}\left(\frac{R_1}{R_2} \right) \qquad \text{Eq. (3.32)}$$

For a constant impedance system:

$$R_1 = R_2$$

$$\text{Power Ratio(dB)} = 20\log_{10}\left(\frac{V_1}{V_2} \right) \qquad \text{Eq. (3.33)}$$

Also;

$$G_{dB} = 10\log(g) \qquad \text{Eq. (3.34)}$$

$$V_{dB(reference)} = 20\log\left({V}/{V_{reference}} \right) \qquad \text{Eq. (3.35)}$$

$$P_{dB(reference)} = 10\log\left({P}/{P_{reference}} \right) \qquad \text{Eq. (3.36)}$$

where a typical reference for voltage is microvolts and a typical reference for power is milliwatts.

The reverse relationships are:

$$g = 10^{G_{dB}/10} \qquad \text{Eq. (3.37)}$$

$$V = 10^{V_{dB(reference)}/20} \qquad \text{Eq. (3.38)}$$

$$P = 10^{P_{dB(reference)}/10} \qquad \text{Eq. (3.39)}$$

The transmit antenna factor of an antenna is computed from the gain or receive antenna factor, and is a measure of the transmitting capabilities of that antenna. It is valid under the conditions of measurement of the receive antenna factor, in a 50 Ω system (Common EMC Measurement Terms, nd).

$$TAF_{dB(m^{-1})} = G_{dB} - 2.22 - 20\log_{10}(d_m) \qquad \text{Eq. (3.40)}$$

where;

$TAF_{dB(m^{-1})}$ = Transmit Antenna Factor

G_{dB} = Antenna Gain of Transmitting Antenna

d_m = Distance (m)

Alternatively,

$$TAF_{dB} = 20\log(f_{MHz}) - AF_{dBm^{-1}} - 32.0 - 20\log(r_m) \qquad \text{Eq. (3.41)}$$

Antenna transmitting capabilities are often given in terms of the input power to an antenna to generate 1V/m at one or more distances. The input power required to develop a different electric field level value is found by (Common EMC Measurement Terms, nd):

$$P_{dB(W)} = P_{dB(W)(1V/m)} + 20\log_{10}(E_{desiredV/m}) \qquad \text{Eq. (3.42)}$$

3.3.3.13 Typical EMC Antennas

Several types of antennas can sometimes all satisfy the basic requirements of a measurement. The following list provides brief features, application notes and possible drawbacks of the typical EMC antennas.

Figure 3.13 Loop antenna

Loop and magnetic field coils are typically used in the frequency range from 20 Hz to 30 MHz for measuring magnetic fields. At these frequencies, measurements are in effect within the near field region. Unlike in the far field, in the near field region, electric fields do not relate to the magnetic field by 377 Ω. Magnetic field cannot be derived simply from the electric field. The designs of these antennas ensure they predominantly produce or respond to magnetic fields.

Figure 3.14 Monopole antenna

Rod antennas are the counterparts of loop antennas are designed to respond to electric fields from 30 Hz to50 MHz. Since rod antennas are so small compared to the wavelengths (at 30 Hz, the wavelength is 10,000 km), amplifiers within the antennas are sometimes necessary for small signals. Rod antennas are typically required for the GR-1089-core standard for network telecommunications equipment (where radiated emission and immunity tests for electrical field at 10 KHz are required).

Figure 3.15 Dipole antenna

Dipoles are tuned to specific frequencies, from approximately 30 MHz to a few GHz. They are narrowband. To cover a wide bandwidth, they need to be tuned manually. Dipoles are often used as reference antennas because the dipole elements performance can be theoretically calculated.

Interestingly, Roberts' dipoles, which are specified in the ANSI C63.5, have balun designs that are difficult to characterize, so performance of the Roberts' dipoles is hardly calculable. Dipoles are seldom used in everyday measurements, due to the need for individual tuning at each frequency.

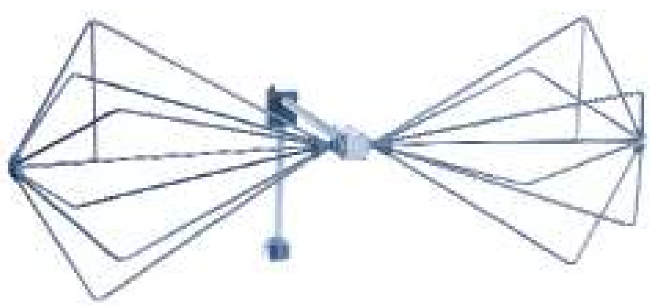

Figure 3.16 Biconical antenna

Biconical antennas typically cover the frequency range from 20 MHz to 300 MHz. All wire-cage biconical antennas on the market have similar size and shape (approximately 1.36 meter wide). This is because they are based on MIL-STD-461 specifications from the 1960s, which has become the de facto standard.

Due to the small electrical size at below 50 MHz, they have very high input impedance (high VSWR). Balun performance is crucial for biconical antennas. Common mode current can be easily induced on the feed cable (common mode impedance is no longer large compared to the input impedance of the antenna). Ferrite beads are often used on the feed cable to suppress the common mode. In addition, feed cables should be extended out a meter or more horizontally before dropping vertically to the ground to reduce possible interference.

Figure 3.17 Calculable biconical antenna

Calculable biconicals combine the best elements of a biconical antenna and a dipole antenna in that they are theoretically calculable and broad band. They look very much like regular biconical antennas. The main differences are that the baluns can be entirely characterized with a network analyzer, the elements are precisely constructed, and their responses are numerically computed. These result in theoretically computed antenna factors that can be used for site validation testing or free space factors for radiated emissions testing. The accuracy of a calculable biconical antenna is actually better than those of a Roberts' dipole, because the balun performance is individually calibrated. The uncertainty is better than 0.25 dB for its antenna factor (Chen, & Cook, 2000).

Figure 3.18 Log periodic dipole antenna

Log periodic dipole arrays (LPDA) typically cover the frequency range of 80 MHz to a few gigahertzes. As discussed previously, the phase center of a LPDA moves from the back of the antenna boom to the front as the frequency is increased. In ANSI or CISPR standards, emissions measurements are performed from the center of the log antenna boom. For immunity tests, EN61000-4-3 requires measurements be made from the tip of the log antenna.

The gain of a LPDA is typically around 5 dBi, which provides a good compromise between beamwidth and sensitivity (or power and field strength requirement).

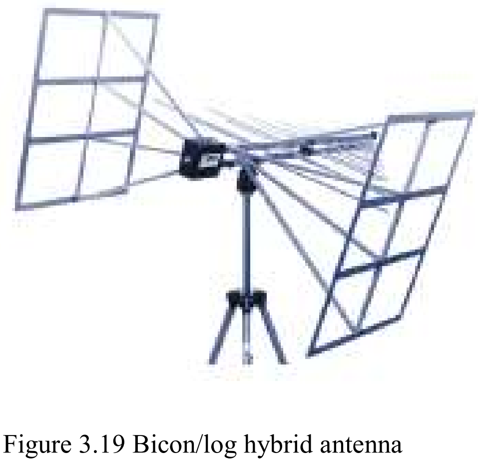

Figure 3.19 Bicon/log hybrid antenna

Bicon/log hybrid antennas are sometimes referred to by their trade names, Biconilog or Bilog. The hybrid combines the frequency range of a biconical antenna and a log antenna, which is approximately 20 MHz to several gigahertzes. They have become increasingly popular, as there is no band break during a test.

Just like biconical antennas at 20 – 50 MHz, hybrid antennas are electrically small. To increase the transmit efficiency, some hybrids employ end loading techniques to compensate for the size. They typically have T-shaped or L-shaped bowtie elements. These antennas should only be used for immunity testing. The coupling between the loading elements and their surroundings are very strong, and they introduce large measurement uncertainties for emissions testing (Chen, 1999).

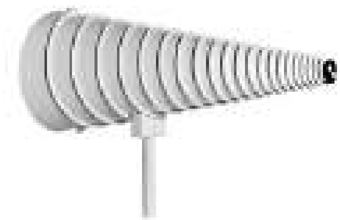

Figure 3.20 Conical-log spiral antenna

The distinctive difference between the conical log spiral antenna and most other antennas is that the electric field is circularly polarized. The circularly polarized field eliminates the need for horizontal and vertical measurements separately.

It is mostly used for MIL standard measurements. The frequency range is typically from 100 MHz to 1000 MHz. Note that when measuring the gain of a circularly polarized antenna with a linearly polarized one, the gain appears 3 dB lower because of the polarization mismatch.

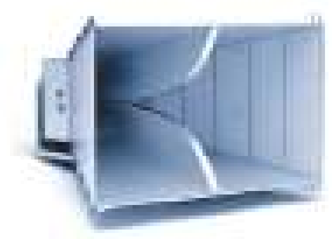

Figure 3.21 Broadband ridged waveguide horn antenna

These versatile and broadband ridged waveguide horns can cover 200 MHz to 40 GHz. The horns for low frequencies can be physically large. For example, the horn that covers 200 MHz to 2 GHz is approximately 37x39x29 inches.

Since gain for these antennas are generally larger (around 10 dBi), the beamwidth is narrower. One should make sure that the beamwidth meets the measurement requirement.

Figure 3.22 Standard gain horn antenna

Standard gain horn antennas are very similar to dipoles or calculable bicons in that the gains can be theoretically computed. Compared to the ridged waveguide horn, they are narrow band. Many horns are needed to cover a broad frequency range (Chen, 2003).

Full-compliance test for radiated emissions use antennas designed for use in the far field, and EMC standards only give emissions limits in the far field. The far field is generally defined as greater than one-sixth of a wavelength, which for 30 MHz is 1.7 meters.

When measuring radiated emissions below 30 MHz, getting far enough away to measure in the far field is impractical. So below 30 MHz it is usual to measure the magnetic field and electric field components separately, in the near field, using large loop probes (typically 600mm diameter) and whip antennas (typically about 1 meter long).

Between 30 MHz and 1 GHz dipoles can be used, but they have a limited frequency range which makes testing very time-consuming. Because dipoles have a calculable response they are still the standard transducer for radiated emissions site calibration.

A variety of antennas have been designed to help the EMC engineer test quickly over the range 30 MHz to 1 GHz, and they can have quite interesting shapes (Williams, 1999). The biconical (which looks like two egg-whisks back-to-back) is a favorite and typically covers 20 to 200 MHz, while the typical log-periodic (like a rooftop TV antenna, but with elements that vary in length) covers 200 MHz to 1 or 2 GHz.

Nowadays the industry standard antenna for full compliance testing is the Bilog, which normally covers 30 MHz to 1 GHz although versions are available that go down to 20 MHz and up to 2 GHz. But some Bilogs can be large, heavy, and cumbersome. Smaller, lighter and lower-cost alternative antennas are available from a number of manufacturers (often using built-in amplification to compensate for their reduced sensitivity) and these may be acceptable for pre-compliance testing. Very small dipoles, horns, or double-ridged waveguides are used for measuring radiated emissions at frequencies above 1 GHz (Armstrong, & Williams, nd).

A very important point about all antennas is that they need to be calibrated, and their calibration factors (sometimes called transducer factors) must be taken into account in any measurement of radiated emissions (Alexander, nd). Many wide-band antennas can have calibration factors that vary between 0 and 20 dB over their frequency range, so it is very important to take these into account if the field from an EUT is not to be underestimated (Armstrong, & Williams, nd).

The most appropriate antenna type for 30 MHz – 1 GHz measurement is bilog antenna. During the comparison test explained in this thesis, measurement is taken with CBL6112 bilog antenna.

Bilog antenna operates a wide range 30 MHz to 1 GHz. It effectively combines the performance of three standard EMC antennas, the Biconical, The Log Periodic and the Waveguide Horn. The nominal impedance value is 50 Ω and the gain is 6 dB.

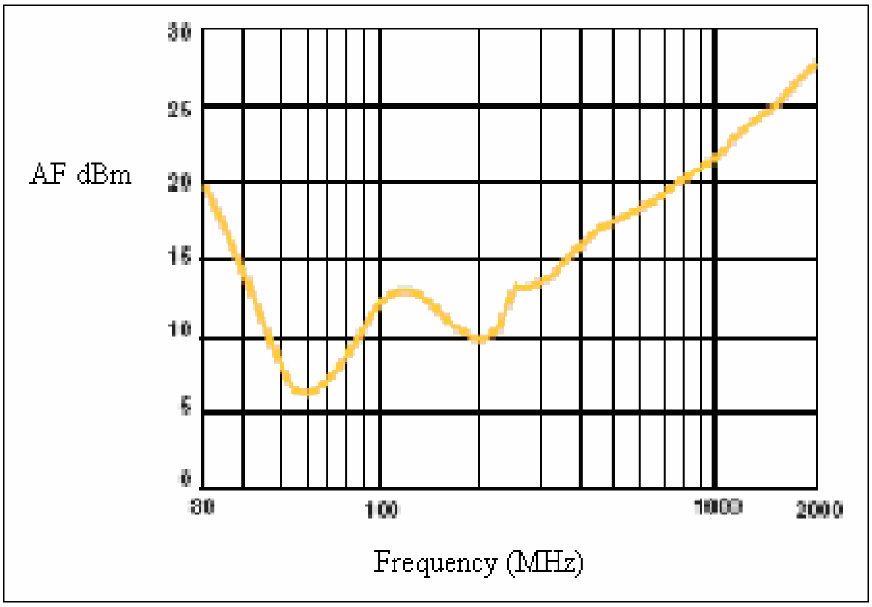

Figure 3.23 CBL 6112 Antenna Factor

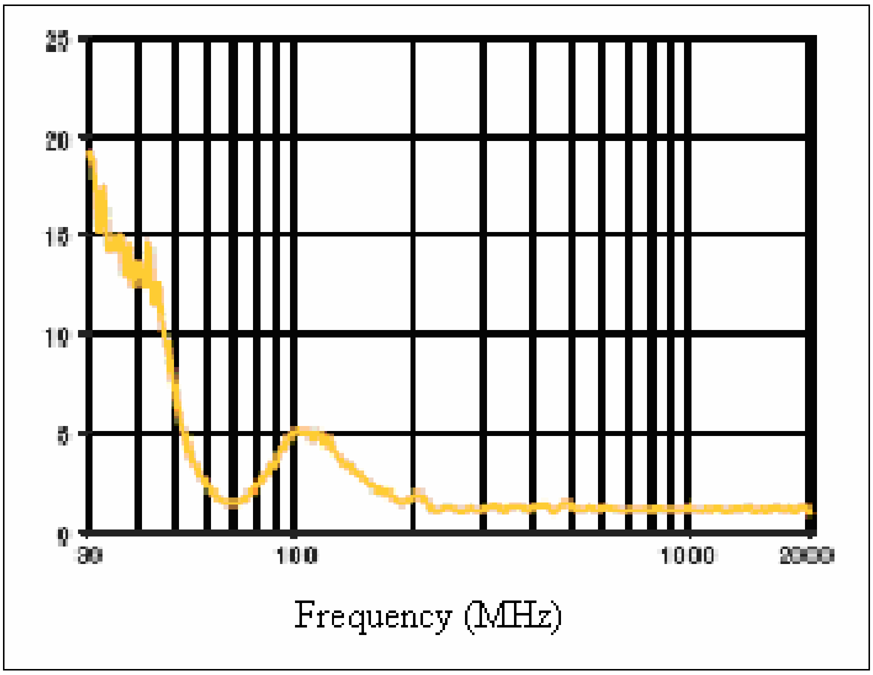

Figure 3.24 CBL 6112 VSWR

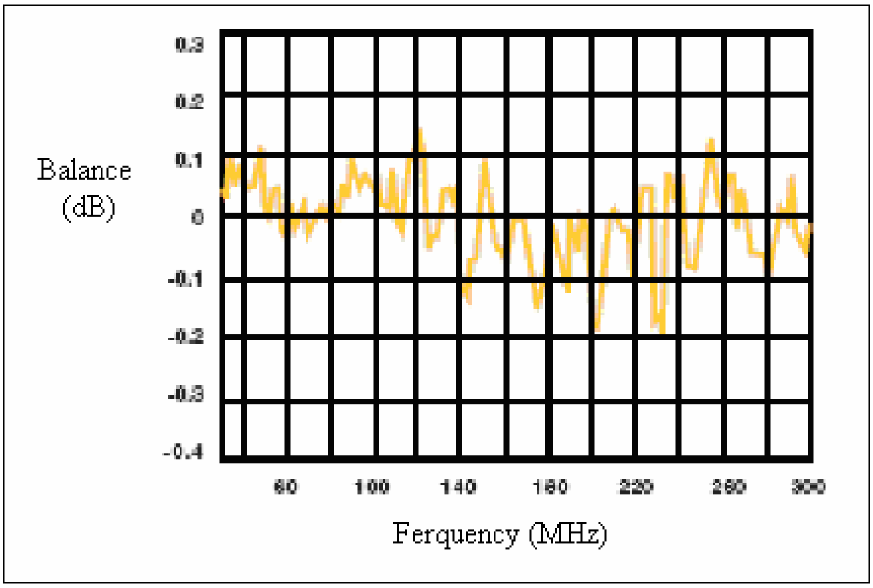

Figure 3.25 CBL 6112 balance

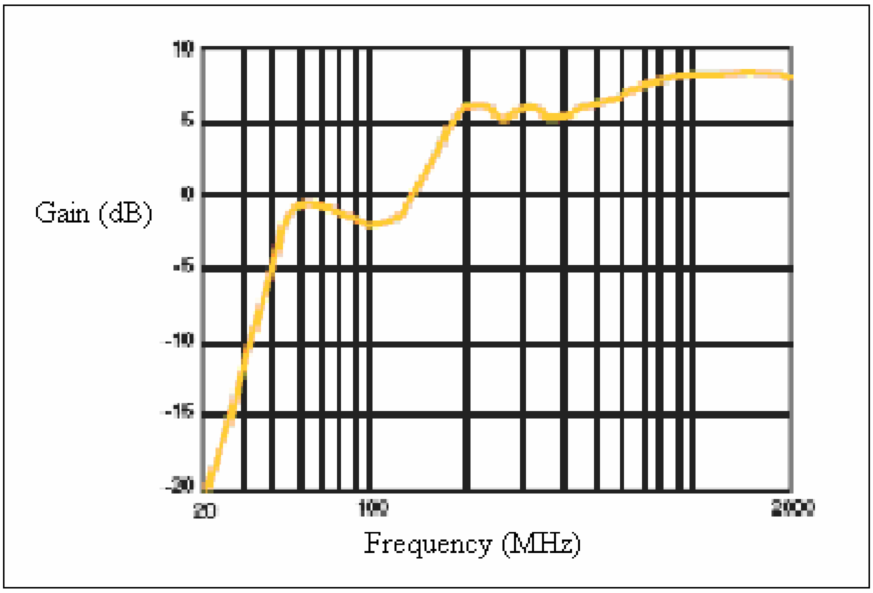

Figure 3.26 CBL 6112 gain (dB)

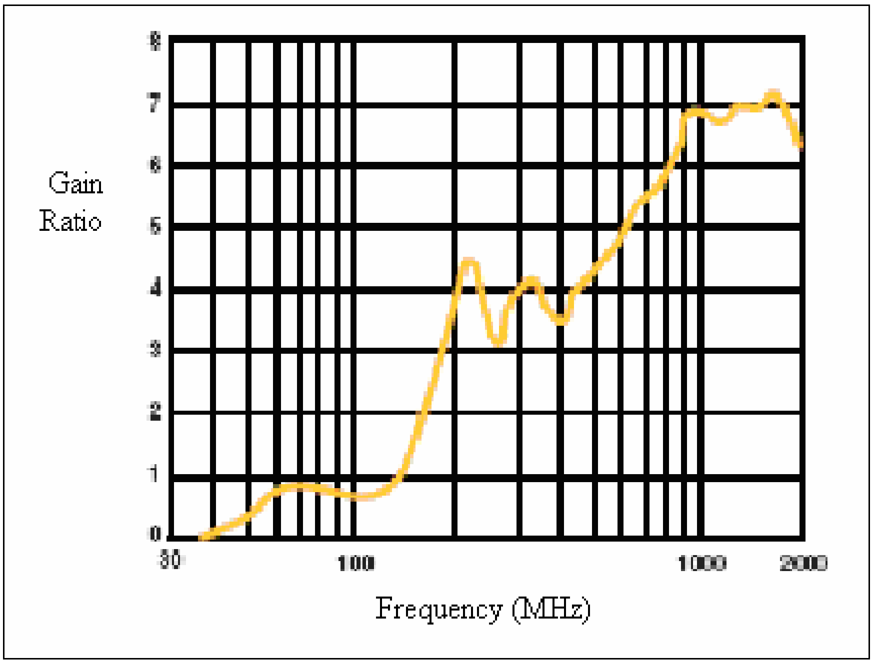

Figure 3.27 CBL 6112 gain ratio

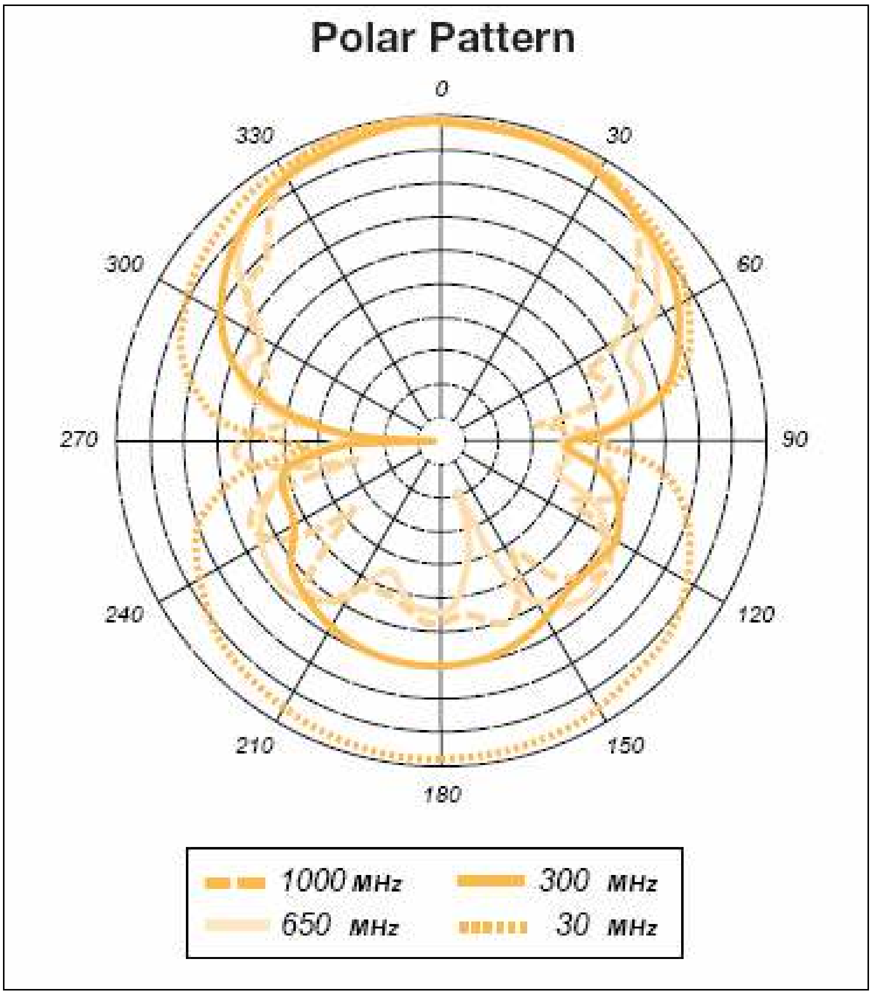

Figure 3.28 CBL 6112 polar pattern

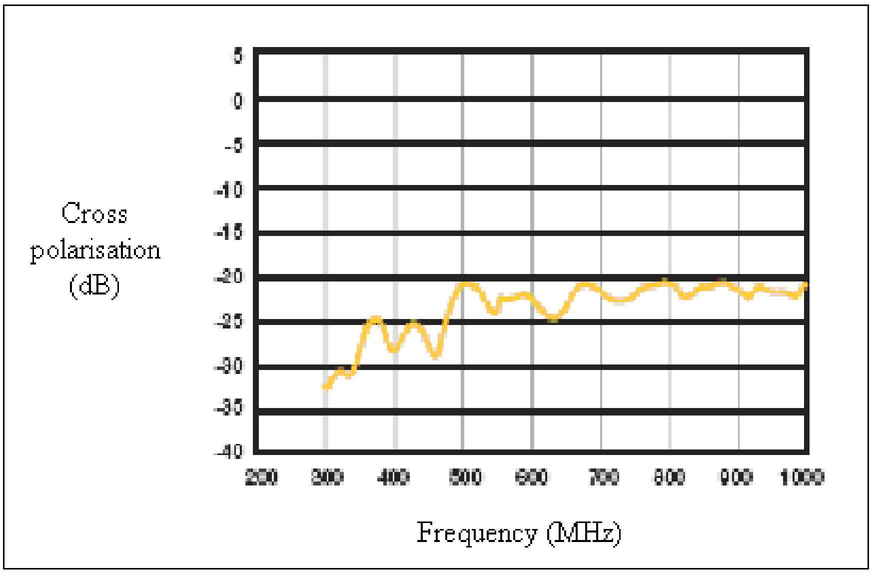

Figure 3.29 CBL 6112 cross polarisation (dB)

3.3.4 Measurement Site

The Federal Communications Communication (FCC) regulates emission levels and test techniques in the U.S. the european community (EC), comprising twelve countries, has issued a set of European Norms (EN) that regulate product emission/immunity levels and test techniques. Both FCC and EN regulatory documents presume the use of an Open-Area Test Site (OATS) for measurements. Alternate testing facilities (like as Semi Anechoic Chamber) are acceptable provided data taken at such can be correlated with data taken at an OATS.

There are two types of measurement site for final radiated emission measurement mentioned in the standard:

- Semi Anechoic Chamber (SAC),
- Open Area Test Site (OATS).

Firstly, it would be better to define what is Anechoic Chamber. An anechoic chamber is a room that is isolated from external sound or electromagnetic radiation sources, sometimes using sound proofing, and prevents the reflection of wave phenomena (reverberation). Anechoic chambers are widely used for measuring the electromagnetic emission that electrical or electronic devices radiate, the acoustic properties of acoustic instruments, measuring the transfer functions of electro-acoustic devices, testing microphones and performing psychoacoustics experiments (such as measuring the quality of audio codecs or measuring head-related transfer functions). In electromagnetics, anechoic chambers equipped with absorber material (ferrites) to dampen the reflection of electromagnetic (radio) waves are used to measure the properties of antennas or of electronic devices which emit or are susceptible to interference from electromagnetic (radio/microwave) energy.

Anechoic chambers are typically comprised of three separate products: RF modular shielding, ferrite tiles and RF absorber. The absorber material is typically pyramidal in shape and made of carbon impregnated foam to act as a resistance and dissipate any energy that strikes it. These RF/microwave anechoic chambers can range in size from a small room to a large airplane hangar, depending on the size of the object to be measured, and the frequency range of the radio or microwave signals to be measured. Most RF/microwave anechoic chambers are located in a screen room, which is a shielded facility that prevents the leakage of RF/microwave energy in or out of the chamber, thus ensuring the accuracy of measurements and preventing interference to outside systems. Absorber material can be quite flammable and is often protected with an automatic fire extinguishing system for safety.

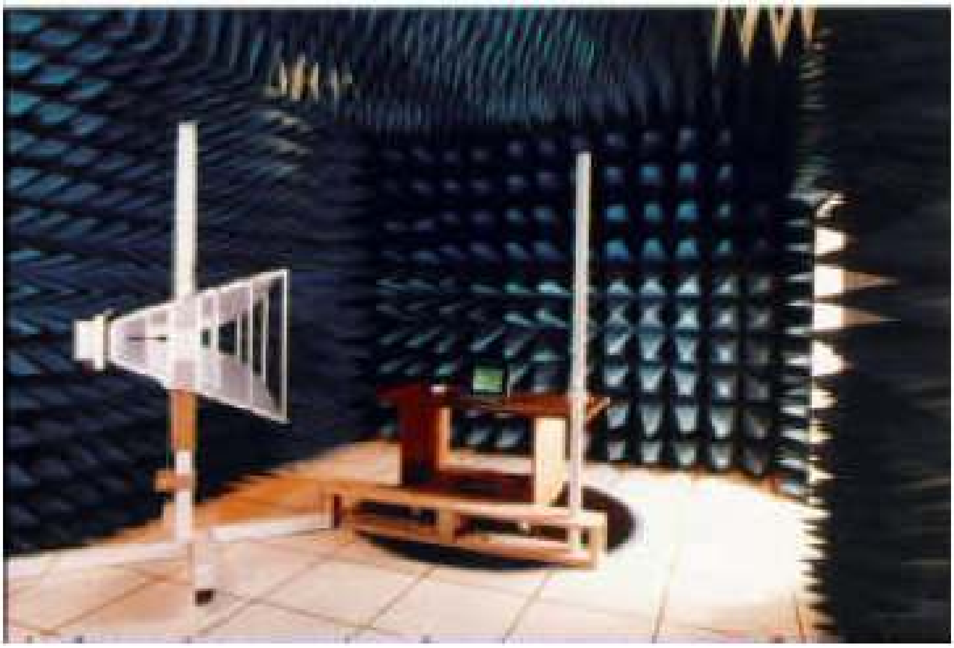

Figure 3.30 Typical anechoic chamber covered with ferrite

The most important features for anechoic chambers are; size, frequency range, field uniformity, site attenuation, RF shielding and absorbers used.

Mainly there are three types of anechoic chamber used:

- Full Anechoic Chamber;
- Semi Anechoic Chamber;
- GTEM.

3.3.4.1 Semi Anechoic Chamber (SAC)

SACs are indoor radiated emission test facilities. Using sheet steel bonded to a plywood core, an electromagnetically quiet enclosure can be constructed. Ventilation ports, power access, and personnel access are each carefully addressed so that the plane wave shielding effectiveness can be 100 dB over the frequency range interest. To dampen the quality factor, Q, and simulate an OATS, carbon filled polyurethane cones or ferrite tiles are mounted on the ceiling and walls. The exterior dimensionsof such a chamber can vary from 10 x 10 x 10 ft to 80 x 24 x 12 ft-or even more.

The FCC an EC have alternate site provisions for radiated emission measurements at other than an OATS. ANSI C63:4-1992 recognizes SACs as an alternate site, provided they meet the volumetric NSA requirements. Radiated emission data taken in SACs which meet this requirement can be submitted to the regulatory agency and are recognized as having a direct correlation to radiated emission data gathered at an OATS. If the SAC does not meet the volumetric NSA requirement, radiated emission data can vary more than acceptable to the regulatory agency.

Unlike an OATS, which must meet the NSA requirements at a single point, the SAC must meet the NSA over the volume occupied by the EUT. The better the ability of the anechoic material to dampen the Q-factor of the chamber or to absorb RF radiation, the closer actual NSA matches the theoretical NSA.

Carbon-filled polyurethane cones perform well when the length of each cone is at least one quarter wavelength. At 30 MHz this requires approximately 8-ft-long cones. Cone shape and doping levels can optimize performance. The dielectric loss mechanism in the carbon filter is due to the frequency-dependent, complex permittivity.

A complimenting technology for RF absorption is the use of ferrite tiles. They are approximately ¼ inch thick and 4 inches square. The loss mechanism of ferrite tiles is due to their frequency-dependent complex permeabilty. The tiles are usually applied in combination with carbon-filled polyurethane cones; above 100 MHz even small cones of that material are effective RF absorbers. Typically, the ferrite tiles are first attached to the chamber wall and the carbon filled polyurethane cones are then attached to the tiles. The combination of tiles and cones give wide bandwidth performance without the need for very long cones. Thus, the size of the chamber can be reduced.

Using a geometric ray-tracing algorithm the NSA can be predicted. Required input data are the chamber size and RF absorber material return loss as a function of frequency and incident angle. A manufacturer of SACs has generated NSA graphs for two different chambers. These graphs compare ideal and predicted NSA for vertical and horizontal polarizations. Only the frequency range of 30 MHz to 200 MHz has been computed since this range is the SAC design challenge. Predictions were made for both a large (80 x 48 x 25 ft) 10 meter compliance facility and a smaller (24 x 14 x 12 ft) precompliance facility. Results for the 10 meter compliance facility show a maximum departure of only 2 dB from the theoretical NSA. The precompliance chamber achieves a ±4 dB variation at frequencies above 80 MHz. Below this frequency departure from the theoretical value can be as much as 16 dB. To correlate precompliance radiated emission data from an EUT with data taken at an OATS requires statistical averaging. This averaging of many products is required only at frequencies where the measured NSA deviates from the theoretical NSA by more than 4 dB. A first-order approximation is that the deviation between theoretical and measured NSA is the margin of error. For immunity testing acceptable to regulatory agencies, field uniformity may have a maximum amplitude variation of ±3 dB over the product volume. As with the NSA, this requirement is most difficult to meet at lower frequencies (30 MHz to 100 MHz) and may require ferrite tiles or 8-ft cones. A common technique to achieve better field uniformity is to add cones or tiles on the floor when this testing is performed since a ground plane is not required for immunity testing. For military product testing, the only technique allowed by MIL-STD-462D is with a SAC. The SAC must have absorber material above, behind, and alongside the EUT, as well as behind the measurement antenna. The specified absorption characteristics are easily met with 2-ft carbon-filled polyurethane cones.

A major advantage of a SAC is the ability to vary the EUT cable configuration to find the maximum emission. The dominant radiation source of many products are the cables, which requires the ability to orient them for maximum emission. The major disadvantages of a SAC are its size and the initial cost (Nadolny, 1995).

Figure 3.31 Semi Anechoic Chamber

3.3.4.2 Full Anechoic Chamber (FAC)

Full Anechoic Chamber is a shielded enclosure like the SAC, explained above, except the ground plane is also RF-absorbing material. The intent is to simulate a free-space environment. The antenna height is fixed – usually centered on the test volume at a height greater than 1.5 m.

Figure 3.32 Full Anechoic Chamber

3.3.4.3 Gigahertz Transverse Electromagnetic (GTEM) Cell

The GTEM cell has emerged as the most recent emission/immunity test facility. It is a hybrid between an anechoic chamber and a TEM cell; it has many advantages over OATS and SACs. The GTEM is a rectangular-flared coaxial structure. One of its ends, the cell apex, is equipped with a connector for interfacing to standard coaxial cables. The other end is a wide bandwidth termination made of resistors and RF absorbing cones. The wide bandwidth of operation is denoted by “gigahertz”. As with SACs, the size varies with the application. For desktop equipment testing a GTEM cell would be 25 ft long with a cross section of 11 ft by 13 ft at the flared end.

The fundamental theory behind GTEM measurement is that any radiating structure, for instance, an EUT, can be accurately modeled as a sum of electric and magnetic dipole moments. This theory is actually applied twice: first, when the total radiated power from EUT is measured and, second, when predicting the radiated emission of the EUT that will be measured at an OATS. The GTEM is described analytically as a parallel plate waveguide where the dominant (lowest) frequency of propagation mode is TEM.

Two key assumptions are made in the theoretical development:

1. All dipole moments are assumed to be in phase. Unintentional radiators are not designed to act as highly directive antenna or behave with complicated phase differentiation in their radiation patterns.
2. OATS measurements are made in the far field that allows the EUT to be modeled as a resonant dipole. Near-field predictions are possible but would require twelve measurements.

The EUT can be thought of as a system of electric and magnetic dipoles with its integral behavior being the result of a superposition of the effects of the individual dipoles. Using this model, the EUT is characterized by a set of twelve independent parameters, because each of the two resulting dipoles will have in general three spatial components with each component comprising a real and an imaginary part. Thus to determine all values for the resulting electric and magnetic dipoles, in principle twelve independent measurements are required to find the twelve unknown parameters. Introducing two reasonable assumptions simplifies the problem considerably and reduces the number of parameters to three. First, assuming that all dipole moments are in phase reduces the number of unknowns and consequently the number of equations to six. The problem can be reduced further to three unknowns and three equations by assuming TEM power only at the cell apex and by taking advantage of symmetry considerations.

It has been shown that if the three apex voltages correspond to three orthogonal rotations of the EUT, the vector sum of these voltages measured in three independent directions is equal to the sum of the dipole moments for this geometry under the assumptions stated above. Three orthogonal rotations are required to couple the dipoles to the cavity and excite the TEM mode. The total radiated power emitted by the EUT can be determined from the propagation constant and the sum of the dipole moments.

As stated above, the analysis assumes that the GTEM is a parallel plate waveguide and that the dominant propagation mode is TEM. For this structure the higher order modes TE_n and TM_n will propagate, but are weakly coupled and the broadband match provided by the termination suppresses the formation of higher order modes. Thus, essentially the total power radiated from the EUT in the TEM mode is measured.

To predict OATS performance of the EUT, it is assumed that the total radiated power, as calculated from the apex voltages, is present at the terminals of a fictitious resonant dipole. The predicted radiation pattern from the resonant dipole accounts for ground plane effects and the effect of scanning in height with the receiving antenna. The calculated peak amplitude is recorded and compared to the radiated emission limit line.

The GTEM cell can be an excellent tool for radiated immunity testing. It's advantage is the generation of a uniform TEM wave over an appreciable volume and high field strength per unit input power. This feature and the GTEM's ability to measure radiated emissions make attractive as a precompliance facility.

The major drawback of the GTEM is in measuring cable emissions. Orthogonal rotations of a cable are not very practical and this is required for the theory to predict the total radiated power from the EUT. In practice, the cables are orientated to generate the highest apex voltage. Products which have test setups or cabling dimensions larger than about 1.5 meters cannot be accurately tested in a GTEM (Nadolny, 1995).

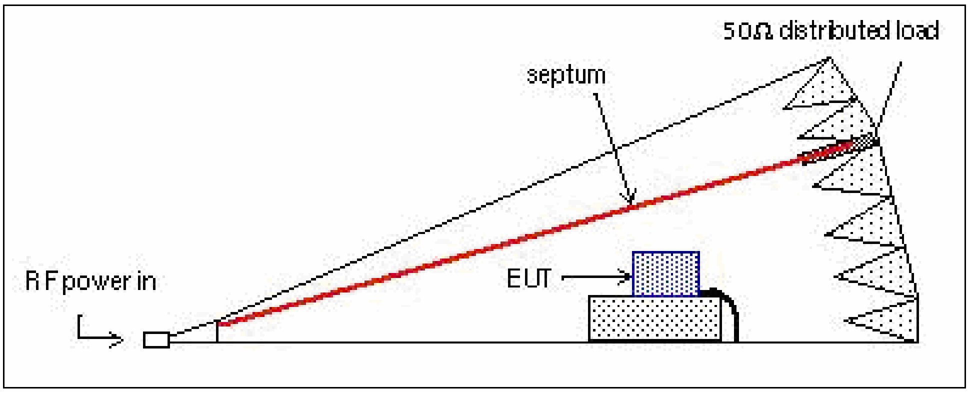

Figure 3.33 The GTEM cell – side view

3.3.4.4 Open Area Test Site (OATS)

Another measurement site different from anechoic chambers is Open Area Test Site. An OATS is situated on flat terrain, free from obstructions (buildings, fences, etc.). It has a ground screen which acts as a standardized reflective surface, a turntable, and a measurement mast. The OATS is exposed to the local electromagnetic ambient environment; many are exposed to the weather. Products are placed on the turntable and measurements are made at a distance specified by the appropriate agency (3 meter, 10 meter, or 30 meter). The height of the receiving antenna is adjusted by the mast which varies the antenna height within a range of 1 to 4 meters. Maximum emissions are recorded as the turntable is rotated, the mast height varied and the EUT cable orientation is changed.

A recognized problem with OATSs is the variablity of results depending on the facility used. One study compared 17 certified OATSs and found wide variation due primarily to worn or broken connectors and cables, antenna factors, and poor ground planes. Variations of 20 to 30 dB in emission amplitude were reported for identical test setups measured at different OATSs. Other factors that can affect emission readings, which were not varied in the cited study, are random effects in all-weather facilities, turntable effects, and termination of the ground screen. All these issues led to the release of ANSI C63.4-1992 which specifies site attenuation requirements to be met by the test site.

A key feature of ANSI-C63.4-1992 is that an OATS must meet a specified performance level referred to as normalized site attenuation (NSA). The theoretical NSA is the electric field insertion loss between a transmitting and a receving antenna accounting for ground reflection, antenna height variation, and free-space loss. If dipole antennas are used with 3-meter seperation, mutual impedance terms are added to account for lower frequency near-field effects between the antennas the shape of the theoretical NSA curve carries the frequency-dependent term $-20\log_{10} f$, which comes from the Friis Transmission equation (Nadolny, 1995):

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4 \cdot \pi \cdot R}\right)^2 \cdot G_{0t} \cdot G_{0r} \qquad \text{Eq. (3.43)}$$

where

P_r = received power,

P_t = transmitted power,

λ = wavelength,

R = distance between transmitting and receiving antennas,

G_{0t} = gain of the transmitting antenna, and

G_{0r} = gain of the receiving antenna.

Since the radiation power is proportional to the square of the field strength, the received electric field is proportional to the wavelength λ or inversely proportional to the frequency f according to $-20\log_{10} f$.

By specfiying the measurement technique and values for error margin and NSA, regulatory agencies are achieving better site to site correlation. Broken or worn cables and connectors, wrong antenna factors, and ground plane effects will lead to an NSA which does not meet the requirements of ANSI C63.4-1992. For an OATS, the measured NSA must correlate to within 4dB of the theoretical NSA value at a single point, usually the center of the turntable.

As a compliance test facility, the OATS is the standard to which other facilities are compared. However, an OATS is not designed for precompliance test activities and consequently has major drawbacks if used for this purpose. One of them is that for precompliance testing ready access to an engineering laboratory with diagnostic tools is highly desirable. Such are usually not available at an OATS. Furthermore, iterative testing at an OATS is time consuming, a high electromagnetic ambient is present, and the device to be tested is exposed to the weather. Radiated immunity testing is another aspect of precompliance testing which an OATS is not very well suited simply because FCC regulations prohibit the outdoor broadband transmitted power required for such testing. All these circumstances make OATSs not very attractive as precompiance test facilties (Nadolny, 1995).

Figure 3.34 Typical Open Area Test Site

Figure 3.35 Covered Open Area Test Site

CHAPTER FOUR
INVESTIGATION ON USING FULL ANECHOIC CHAMBER FOR RADIATED EMISSION FINAL TESTING

4.1 Test Sites for Radiated Emission Final Testing

Worldwide regulatory requirements specify the use of Open Area Test Sites (OATS) or Semi Anechoic Chambers (SACs) for the measurement of radiated emissions from unintentional radiators.

The intent of any emissions specification is to prevent unwanted interference to radio reception. This includes preventing interference to such services as broadcast radio and TV, as well as amateur radio and emergency services. The emissions specification limits were derived from comprehensive studies that determined the interference threshold to TV and radio receivers versus the proximity of potential noise sources. These studies, which covered a large geographical area, amassed a very large body of data. Based on the results, statistically significant specification limits were derived (Boyd, Malack, & Rosenbarker, 1975; German, & Calcavecchio, 1980; Computer and Business Equipment Manufacturer's Association [CBEMA], & Environment and Safety Committee Five [ECS5], 1977).

In every study, the measured values were made in an environment where the reflected wave from the earth had a major effect on the measured value. It was concluded that a uniform ground plane would provide a controlled environment that not only simulated real-world conditions but also greatly enhanced the repeatability of the measurements. As a result, international standards-making bodies developed measurement procedures based on the use of test sites with a reflecting ground plane. Regulatory agencies then adopted these procedures and set specification limits for emissions measurements made at facilities using a reflecting ground plane (ANSI C63.4, 1992).

Since then, thousands of measurement facilities that use a reflecting ground plane to make radiated emissions measurements have been installed successfully worldwide. When devices are found compliant to the applicable limits at these facilities, the potential for interference is very small. Virtually all interference complaints are a result of a noncompliant product-not deficient measurement standards or facilities.

In recent years, the number of wireless devices and their associated services has greatly increased. The resultant ambient radio-frequency interference (RFI) has also increased at most OATS facilities. Measurements in high-ambient environments are more difficult and can affect the accuracy of the results. Currently, the only alternatives to OATS facilities are large, expensive, Semi Anechoic Chambers that permit antenna scan heights of 1 – 4 meter and meet the site attenuation requirements.

An effort is under way to develop alternative test facilities that provide measurement accuracy at a lower cost than Semi Anechoic Chambers (prEN 50147-3:1998, 1999). One such effort is the use of Full Anechoic Chambers (FACs) for certification measurements. Because the measurement antenna is kept at a fixed height, the hope is that chambers can be built smaller, and thus make this option more affordable (Kiemel, 2002).

A series of tests was performed in an effort to validate the proposed use of a fully anechoic chamber for certification measurements to semianechoic limits. To make this comparison byself, two comparison tests are performed using a 37” TFT LCD Television and a Field Reference Source as Equipment Under Test (EUT); first in Full Anechoic Chamber and then in Semi Anechoic Chamber.

4.2 Comparison Tests

The best way to understand why Full Anechoic Chamber can not be used for certification measurement like as Semi Anechoic Chamber for radiated emission final measurement is to make a comparison testing. Two equipments are used as EUT for comparison testing:

- A 37” TFT LCD TV;
- Field Reference Source.

Firstly, TFT LCD TV is tested in Full Anechoic Chamber, and then, the same TFT is tested in Semi Anechoic Chamber for radiated emission. To make the comparison more reliable, a second EUT (Field Reference Source) is tested first in Full Anechoic Chamber, and then in Semi Anechoic Chamber. Then, the test results belong to same EUT for different measurement sites are compared.

4.2.1 Measuring Radiated Emission from a TFT LCD TV in Full Anechoic Chamber

Full anechoic chamber used in the comparison tests has a diameter of 5 x 8 x 4 meters. Frequency range of the chamber is from 30 MHz to 3GHz. TFT is placed on 0.8 meter height turn table and standard test colour bar signal is applied to the EUT by it’s tuner to make it work as intended to use. Measurement test setup is shown in Figure 4.1.

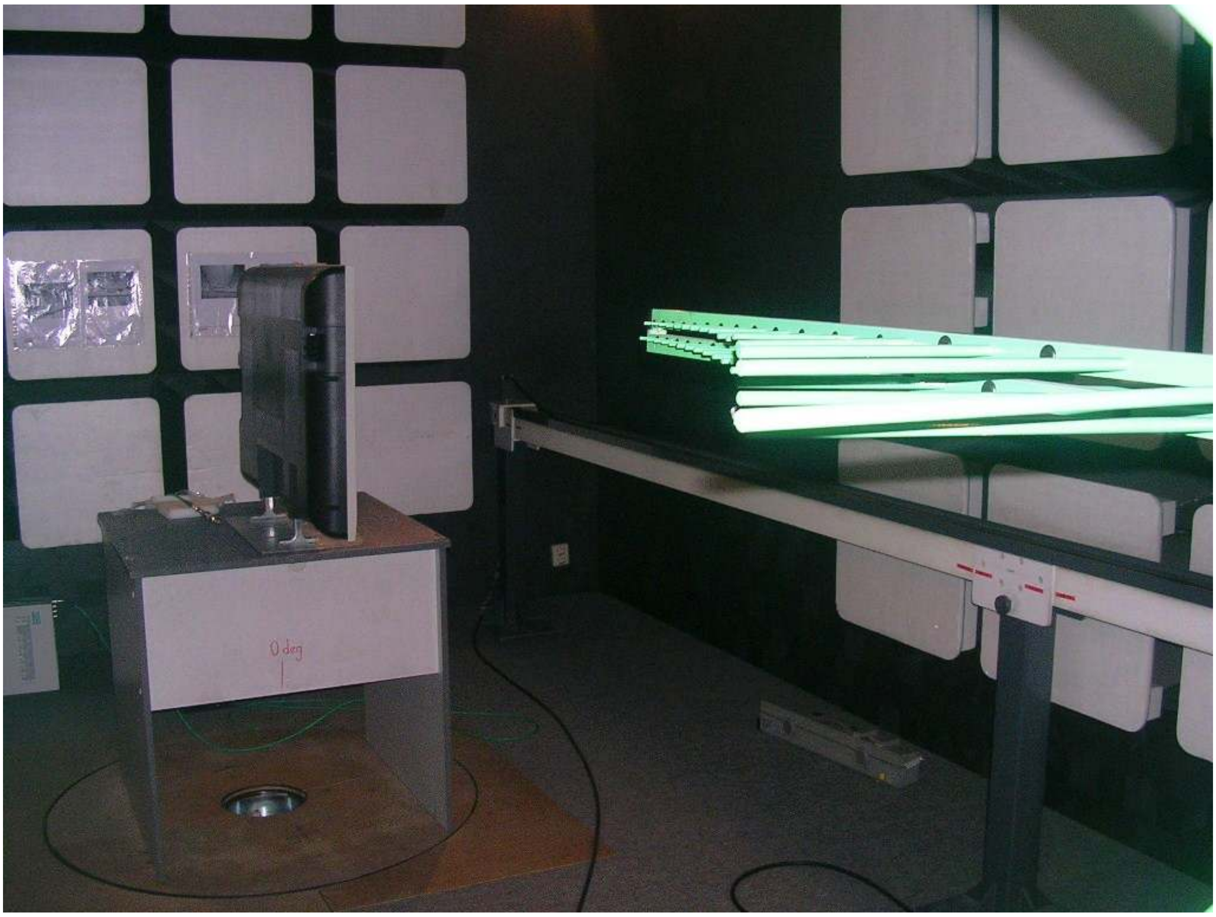

Figure 4.1 Measurement setup of a TFT LCD TV in Full Anechoic Chamber

Radiated emission from the TFT is measured by a bilog antenna which has a frequency range of 30 MHz to 1 GHz. The antenna height is kept constant at 2m. Measurement is done for both horizontal and vertical polarization of the antenna. To measure the radiation from all sides of TFT, EUT is turned over 360^o by the turntable. The measured radiation signal is applied to ESCI Rohde&Schwarz EMI receiver which has measurement frequency range of 30 MHz to 1 GHz.

Below values are set on the EMI Receiver:

Start Frequency: 30MHZ

Stop Frequency: 1GHz

Step Size: 40 KHz

Resolution Bandwidth: 120 KHz

Measurement Time: 100 μs

RF Attenuation: 0 dB

Preamplifier: ON

Detector: Quasi peak

Pre-scan measurement is done for both horizontal and vertical polarization of the measurement bilog antenna, and turntable is rotated 360^o during both of the polarization. And then, automatically the frequencies which have highest emission levels are recorded for final measurement. For each of these frequencies, final measurement is done by rotating the table 360^o, and the highest level is recorded at that frequency.

The radiated emission test pre-scan result in Full Anechoic Chamber is shown in Figure 4.2. Red Line shows the radiated emission test limit defined in EN 55013 standard and the blue coloured signal is the value of electromagnetic signal emitted by the EUT.

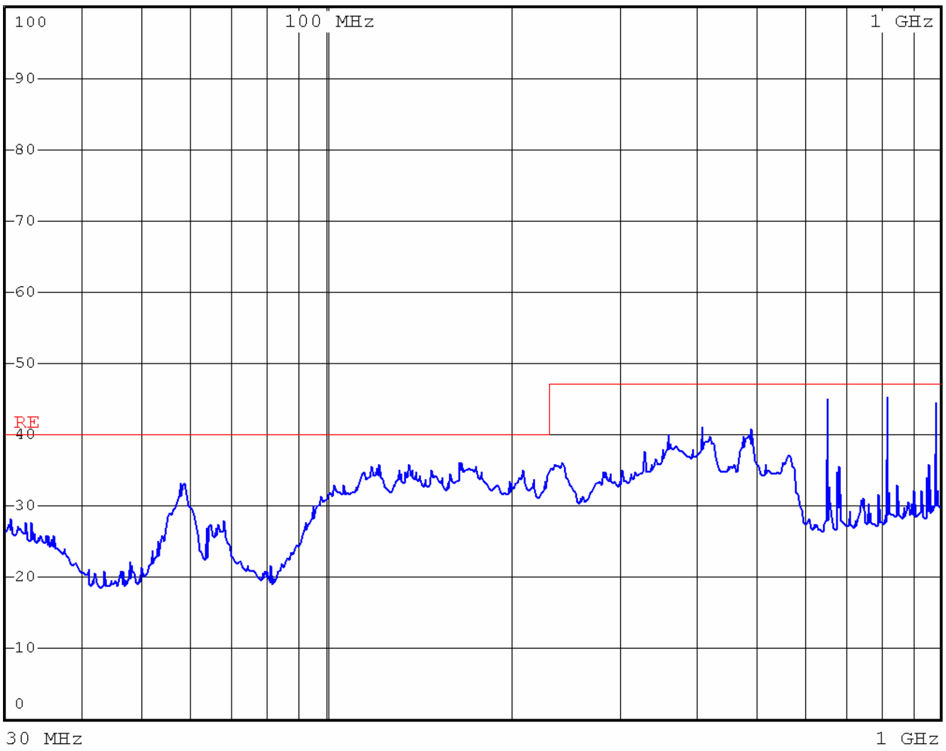

Figure 4.2 Radiated Emission test scan result of a TFT LCD TV in Full Anechoic Chamber

Final result mesured by EMI receiver with quasi peak detector is shown in Table 4.1.

Table 4.1 Final measurement results of radiated emission from a TFT LCD TV in Full Anechoic Chamber

Frequency (MHz)	**Level (dB)**	**Polarization**
58.48	30.41	Horizontal
60.65	28.07	Horizontal
130.12	32.42	Vertical
120.24	25.85	Horizontal
153.00	29.38	Horizontal
167.28	32.29	Vertical
175.88	32.57	Vertical
220.92	28.86	Horizontal
415.20	38.30	Vertical
494.00	38.98	Horizontal
658.60	39.87	Vertical
658.64	40.20	Horizontal
823.28	41.38	Vertical
823.32	40.21	Horizontal

4.2.2 Measuring Radiated Emission from a TFT LCD TV in Semi Anechoic Chamber

As the next step, same TFT was tested in Semi Anechoic Chamber. The dimension of Semi Anechoic Chamber is 6 x 12 x 8 meters. Frequency range of the chamber is from 30MHz to 1GHz. Again TFT is placed on 0.8 meter turntable and standard test colour bar is applied to the tuner of EUT. Test setup is shown in Figure 4.3.

Figure 4.3 Measurement setup of a TFT LCD TV in Semi Anechoic Chamber

Radiated emission from the TFT LCD TV is measured by a bilog antenna which has a frequency range of 30 MHz to 1 GHz. The antenna height is varied 1 – 4 meters for horizontal polarization, and 2 – 4 meters for vertical polarization of the antenna. To measure the radiation from all sides of TFT, it is turned over 360^o by the turntable. Then the measured radiation from the antenna aoutput is applied to Rohde&Schwarz ESCI EMI receiver which has measurement frequency range of 30 MHZ to 3 GHz. All the parameter settings on the EMI Receiver are the same as the first test performed in Full Anechoic Chamber.

The radiated emission test scan result is shown in Figure 4.4.

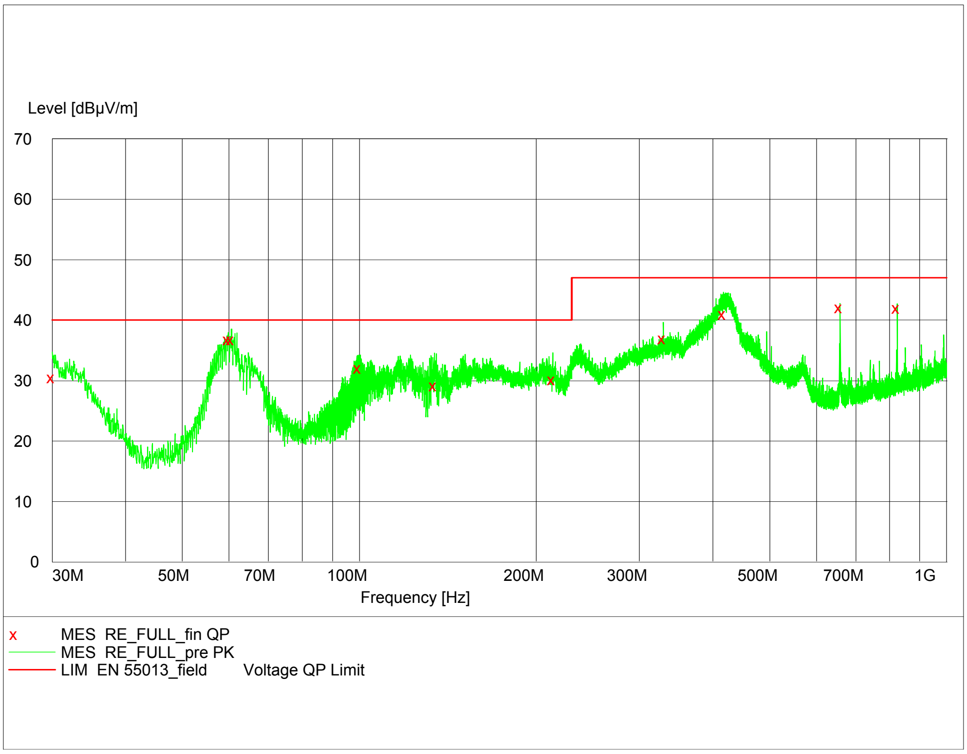

Figure 4.4 Radiated Emission test scan result of a TFT LCD TV in Semi Anechoic Chamber

Final results mesured by EMI receiver quasi peak detector is shown in Table 4.2.

Table 4.2 Final measurement results of radiated emission from a TFT LCD TV in Semi Anechoic Chamber

Frequency (MHz)	**Level (dB)**	**Polarization**
30.00	30.50	Vertical
59.90	36.80	Vertical
60.60	36.80	Vertical
99.80	32.10	Horizontal
134.30	29.20	Vertical
213.60	30.20	Horizontal
329.30	37.00	Vertical
416.80	43.00	Vertical
658.65	42.10	Horizontal
823.30	43.60	Vertical

Table 4.3 shows the comparison of measured emission levels of TFT LCD TV in Full Anechoic Chamber and in Semi Anechoic Chamber.

Table 4.3 Comparison of Table 4.1 and Table 4.2

Frequency (MHz)	Result in Full Anechoic Chamber (dB)	Result in Semi Anechoic Chamber (dB)	Absolute Difference Between Results (dB)
58.48 – 59.90	30.41	36.80	6.39
130.12 – 134.30	25.85	29.20	3.35
213.60 – 220.92	28.86	30.20	1.34
415.20 – 416.80	38.30	43.00	4.70
658.64 – 658.65	40.20	42.10	1.90
823.28 – 823.30	41.38	43.60	2.22

According to comparison, it is clearly seen that measured emission levels in Semi Anechoic Chamber is higher than the measured levels in Full Anechoic Chamber, with a difference of minimum 1.34 dB to maximum 6.39 dB.

4.2.3 Measuring Radiated Emission from a Field Reference Source in Full Anechoic Chamber

Field Reference Source is an emission source, which emits a specified level of signal with a frequency range of 1 MHz to 1.5 GHz by a spacing value 1 MHz or 5 MHz. It has a rechargeable battery inside. The photo of Field Reference Source is shown in Figure 4.5.

Figure 4.5 Field Reference Source

Field Reference Source is placed on the turntable and pre-scan is taken by rotating 360^o for first horizontal and then vertical polarization of the antenna separately in Full Anechoic Chamber. Spacing value is choosen as 5 MHz. Measurement test setup is shown in Figure 4.6.

The pre-scan result of Field Reference Source measured by EMI receiver for horizontal polarization of the antenna is shown below graphic in Figure 4.7.

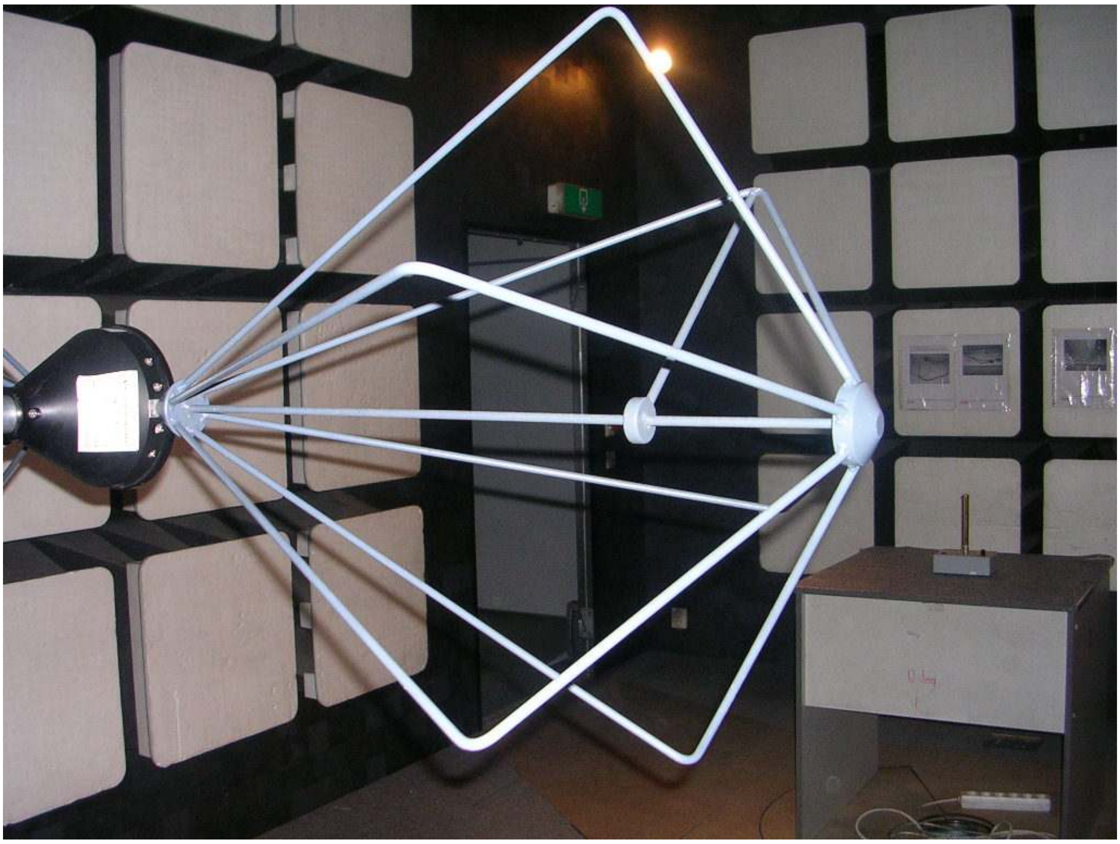

Figure 4.6 Measurement setup of a Field Reference Source in Full Anechoic Chamber

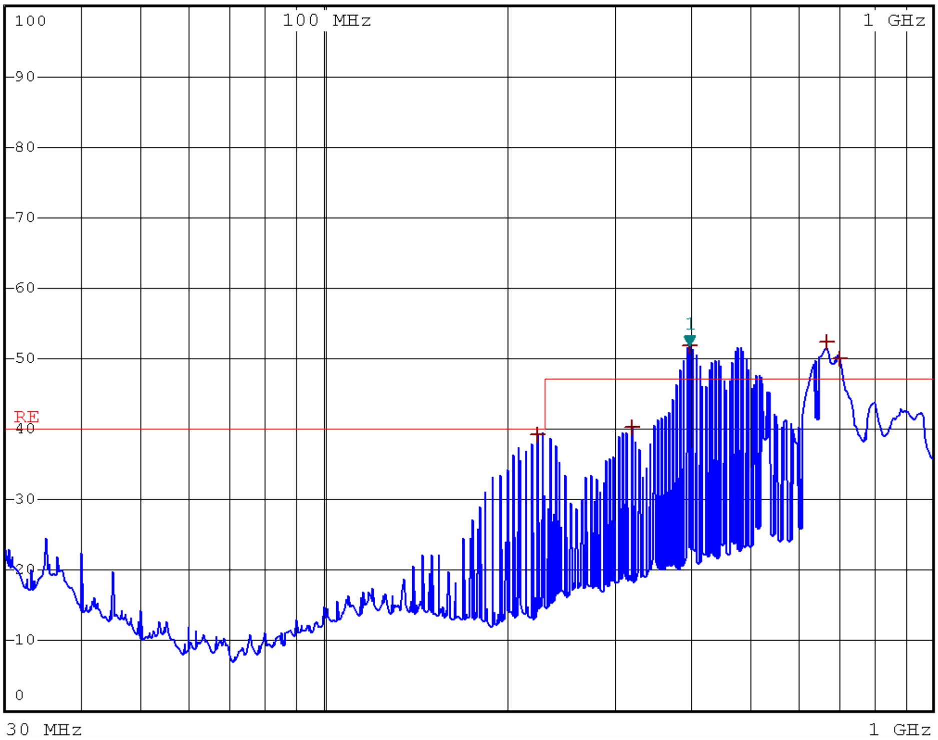

Figure 4.7 Radiated Emission test scan result of a Field Reference Source for horizontal polarization of the antenna in Full Anechoic Chamber

Test is repeated for vertical polarization of the antenna. The pre-scan graphic is shown below in Figure 4.8.

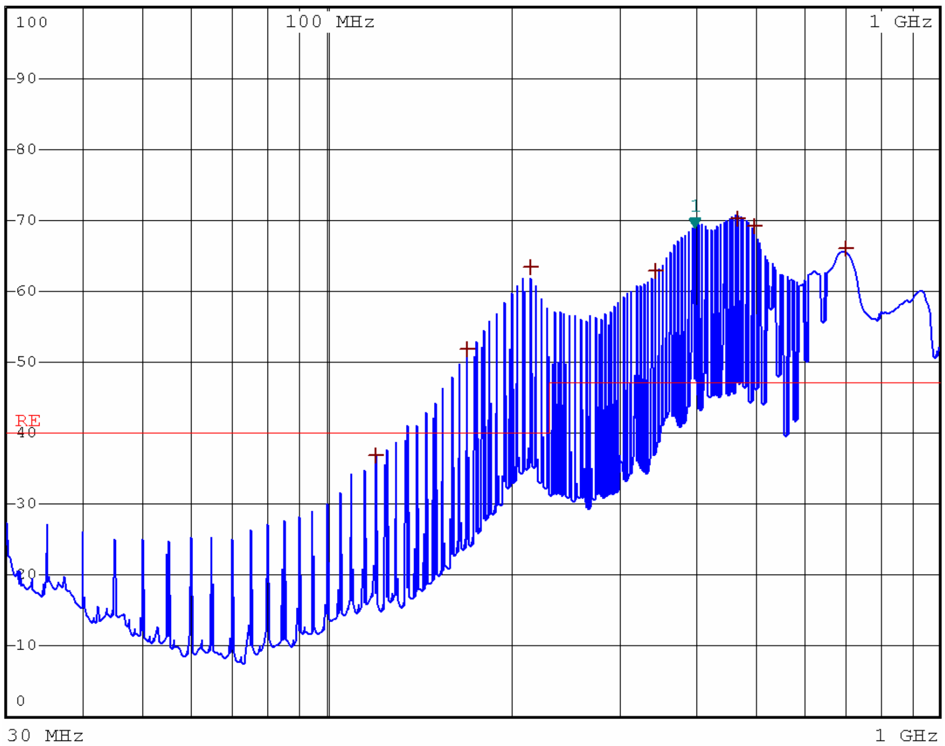

Figure 4.8 Radiated Emission test scan result of a Field Reference Source for vertical polarization of the antenna in Full Anechoic Chamber

4.2.4 Measuring Radiated Emission from a Field Reference Source in Semi Anechoic Chamber

For the next step, Field Reference Source is tested in Semi Anechoic Chamber. Again it is placed on the turntable and scan measurement is performed by rotating 360^{o} for separately horizontal and vertical polarization of the antenna. Again spacing value is choosen as 5 MHz. Measurement test setup is shown in Figure 4.9.

Figure 4.9 Measurement setup of a Field Reference Source in Semi Anechoic Chamber

The scan result of Field Reference Source for horizontal and vertical polarization is shown Figure 4.10 and Figure 4.11.

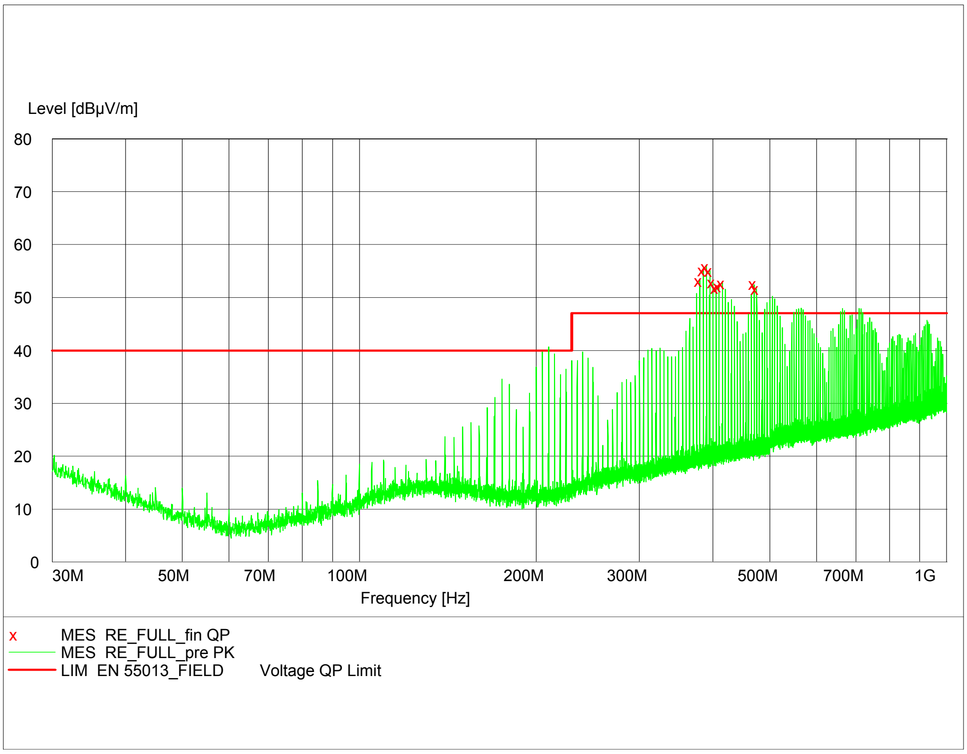

Figure 4.10 Radiated Emission test scan result of a Field Reference Source for horizontal polarization of the antenna in Semi Anechoic Chamber

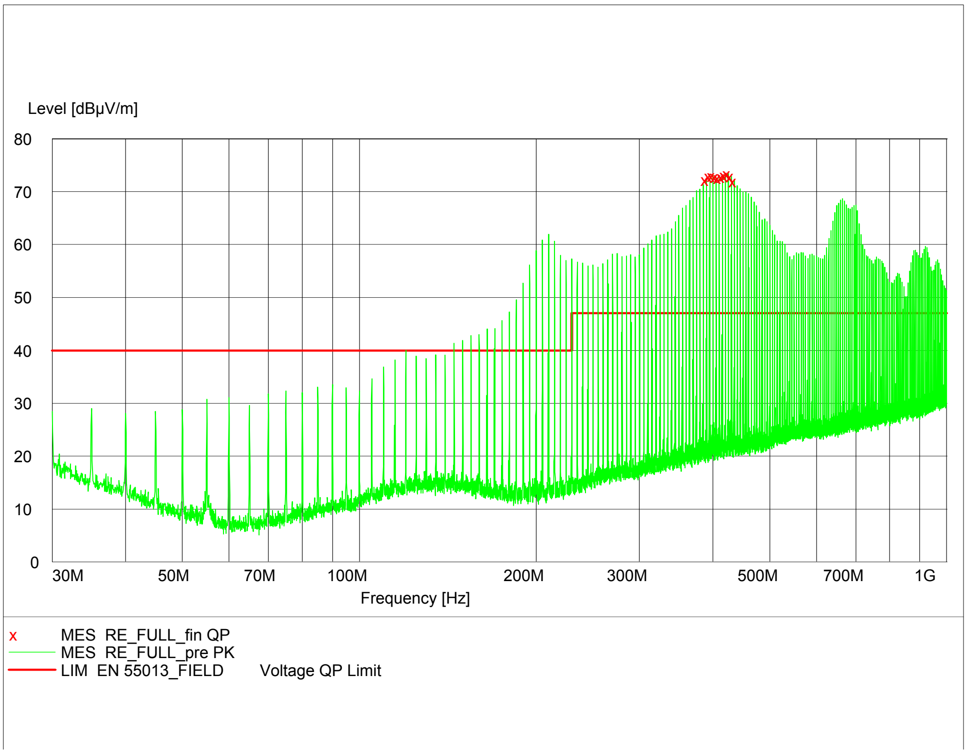

Figure 4.11 Radiated Emission test scan result of a Field Reference Source for vertical polarization of the antenna in Semi Anechoic Chamber

If we compare these graphics, it is clearly seen that measurement levels in Semi Anechoic Chamber is higher than the measured levels in Full Anechoic Chamber, especially at high frequencies.

CHAPTER FIVE
CONCLUSION

5.1 Conclusion

Two comparison tests are performed, one with a 37” TFT LCD TV and the other one with a Field Reference Source. For both of them, when the emission levels and scan graphics are compared, it is clearly observed that emission levels measured in Semi Anechoic Chamber is higher than the levels measured in Full Anechoic Chamber for the similar frequencies.

The main reason of this difference is the metal plane that is placed on the floor of Semi Anechoic Chamber. But the walls, ceiling and the floor of the Full Anechoic Chamber are covered with electromagnetic absorber ferrites, so during the test, we measure only the direct signals coming from EUT to the receiving antenna. But while walls and the ceiling of the Semi Anechoic Chamber are covered with electromagnetic absorber ferrites, the floor is covered with a metal reflecting plane. So, addition to the direct signals coming from EUT to the receiving antenna, the reflected signal from the floor is also reaches to the antenna, so the total signal level measured by the antenna is getting higher.

The other reason of this difference is the variable antenna height in Semi Anechoic Chamber. While the measurement antenna height is kept constant at 2 meter in Full Anechoic Chamber (because the limited size of the chamber), this height is varied from 1 to 4 meter in Semi Anechoic Chamber. This variation allows measuring high levels of signals that can be come across in the height of more than below and above 2 meter.

So far, no compelling evidence has been offered by proponents of Full Anechoic Chambers to prove that a free-space environment simulates real-world conditions. Regulatory agencies have not yet adopted specifications that allow the use of Fully Anechoic Chambers for compliance testing. Therefore, until new free-space specification limits and methods are widely adopted, Full Anechoic Chambers should not be used for certification measurements or as a precompliance tool. However, should a free-space model become accepted by regulatory agencies, large Semi Anechoic Chambers could be easily converted to Full Anechoic Chambers.

Anyway, Full Anechoic Chambers can be used for pre-scan measurements to get the frequency information of emission from EUT in radiated emission tests. Then, real emision levels can be measured in Open Area Test Site at the frequencies determined in Full Anechoic Chamber. As it is explained before, Open Area Test Site can not be used alone for emission mesurement, because it is not a shielded site, it has high ambient noise and it is difficult to understand if any measured signal is coming from the EUT or it is an ambient noise. So list of emission frequencies from EUT must be detected in Full Anechoic Chamber with a pre-scan before using Open Area Test Site. This is a low cost option for radiated emission measurement compared to Semi Anechoic Chambers. Because the size of the Semi Anechoic Chamber is very big to get the overall measurement antenna height, and ferrite that must cover inside of the chamber increases the cost.

REFERENCES

Alexander, M.J. (n.d.). Calibration and use of EMC antennas. *Measurement Good Practice Guide No.4 from the National Physical Laboratory.*

American National Standards Institute. (1992). *ANSI C63.4. American national standard for methods of measurement of radio-noise emissions from low-voltage electrical and electronic equipment in the range of 9 kHz to 40 GHz.*

Armstrong, E. I. K., & Williams, T. (n.d.). *EMC testing, Part 1 – Radiated emission*. Retrieved March 05, 2006, from http://64.70.157.146/pdf/EMCTestingPart1.pdf .

Balanis, C.A. (1997). *Antenna theory analysis and design* (2nd ed.). NY:John Wiley & Sons.

Boyd, R. E., Malack, J. A., & Rosenbarker, I. E. (1975). EMI control for data processing and office equipment. *Proceedings of the First Symposium and Technical Exhibition on Electromagnetic Compatibility,* Montreux, Switzerland.

CENELEC. (1989). *EMC Directive, 89/336/EEC, Article 4*.

CENELEC. (1999). *prEN 50147-3:1998 – Electromagnetic compatibility basic emission standard, Part3: Emission measurements in fully anechoic rooms.* TC210-WG4-9905, Brussels.

CENELEC. (2001). *EN 61000-3-3:1995+A1:2001 – Electromagnetic compatibility (EMC) – Part 3: Limits – Section 3: Limitation of voltage fluctiations and flicker in low-voltage supply systems (equipment rated current up to and including 16 A per phase).*

CENELEC. (2003). *EN 55013:2001+A1:2003 – Sound and television broadcast receivers and associated equipments – Radio disturbance characteristics – Limits* *and methods of measurement*.

CENELEC. (2005). *EN 55020:2001+A1:2003+A2:2005 – Sound and television broadcast receivers and associated equipments – Immunity characteristics – Limits and methods of measurement*.

CENELEC. (2005). *EN 61000-3-2:2000+A1:2005 – Electromagnetic compatibility (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emission (equipment input current up to and including 16 A per phase).*

Chen, Z. (1999). Understanding the measurement uncertainties of the bicon/log hybrid antennas. *Item.*

Chen, Z. (2003). Spotlight on EMC antenna fundamentals. *Conformity*, 8 (4), 1-5.

Chen, Z., & Cook, A. (2000). Low uncertainty broadband EMC measurement using calculable precision biconical antennas. *IEEE International Symposium on Electromagnetic Compatibility,Washington, DC.*

Common EMC measurement terms, (n.d.). Retrieved March 12, 2006, from http://www.emctest.com/pdf/Ant11.pdf .

Computer and Business Equipment Manufacturer's Association (CBEMA), & Environment and Safety Committee Five (ECS5). (1977). *Limits and methods of measurement of electromagnetic emantions from electronic data processing and office equipment.*

C.R.S. (1998). *Electromagnetic Compatibility.* Retrieved September 4, 2005, from http://www.analab1.com/emc.html .

Department Of Defense. (1967). *MIL-STD 461 – Electromagnetic interference characteristics requirements for equipment.*

EMI measurements, test receiver vs. spectrum analyzer. (n.d.). Retrieved February 20, 2006, from http://www.ieee.li/pdf/essay_receiver_v_sa.pdf .

German, R. F., & Calcavecchio, R. (1980). On radiated EMI measurement in the VHF/UHF frequency range. *Proceedings of the First Symposium and Technical Exhibition on Electromagnetic Compatibilit,* Baltimore, MD: IEEE EMC Society, 91-97.

IEEE. (1991). *IEEE-STD 29 – Standard method for measuring the effectiveness of electromagnetic shielding enclosures.* NJ: Piscataway.

Kiemel, G. (2002). *Comparing fully anechoic chambers to semianechoic limits.* Retrieved October 26, 2003, from http://www.ce-mag.com/archive/02/Spring/kiemel.html .

Krause, J.D. (1950). *Antennas.* NY: McGraw-Hill.

Nadolny, J. (1995). Testing for radiated emission by electronic devices. *AMP Journal of Technology Vol. 4,* 111-114. Retrieved December 16, 2005, from http://www.tycoelectronics.com/documentation/whitepapers/pdf/4jot_13.pdf .

Osburn, J.D.M. (1996). EMC antenna parameters and their relationship. *Item,* 1.

Trueman, C.W. (2005). *Electromagnetic compatibility*. Retrieved March 12, 2006, from http://emclab.concordia.ca/~trueman/elec353/ELEC353_2005_21.pdf .

Williams, T. (1999). What to look for in an EMC antenna. *Compliance Engineering European Edition 1999 Annual Reference Guide, 77-79.*