TAMPERE UNIVERSITY OF TECHNOLOGY

MUHAMMAD MUNIR

DEVELOPMENT OF RADIATED EMISSION AND RADIATED IMMUNITY TEST SETUPS FOR AN ANECHOIC CHAMBER

MASTER OF SCIENCE THESIS

EXAMINERS: JOUKO HEIKKINEN,
JARI KANGAS
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ABSTRACT

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Electromagnetic interference/electromagnetic compatibility (EMI/EMC) testing is a compulsory part of today's electronics compliance and reliability. The importance of EMI/EMC arose with the advent of wireless devices to provide interference free environment. Spurious emissions emitted by electronic devices cannot be predicted without EMC measurements. If these emissions emanating from a specific device are above a certain limit, they can be harmful for devices operating in its close vicinity. Interference is an unwanted signal that causes disturbance in the normal operation of an electronic device. As a result there occurs degradation in the functionality of the victim device that is unacceptable. To avoid this undesired behavior of the devices, international regulatory authorities have introduced different standards and regulations. All devices consisting of electrical circuits are tested to comply these international standards and rules. The main objective of EMI/EMC testing is to make sure that a device

i. Does not create interference to other devices.
ii. Is not susceptible to emissions produced by other devices.
iii. Does not cause interference with itself.

The prime objectives of this thesis work include the development of testing programs in Agilent VEE intended to conduct radiated emission (RE) and radiated immunity (RI) tests automatically and to study the suitability of an anechoic chamber for radiated immunity test. The thesis is divided into two major parts. First part contains the introduction and theoretical background and covers first three chapters. It describes the need and importance of RE and RI testing. Second part presents the development of testing programs, test equipment, procedures and results in detail. Testing programs developed during current thesis include most of the necessary features requisite by IEC and CISPR standards and available in commercial testing software for example in Total Integrated Laboratory Environment (TILE), EMC 32 and Schaffner. The study of anechoic chamber, testing programs and results illustrate that the expected goals of the thesis have been successfully achieved. For future studies and improvements practical analysis and tests are recommended to be performed on the chamber. It could not be done during current thesis work due to unavailability of power amplifiers for radiated immunity test.

PREFACE

This M.Sc. thesis was completed in the Department of Electronics of Tampere University of Technology (TUT) as a compulsory part of the International Masters Degree Program in electrical engineering.

I am thankful to my thesis supervisor, DSc Jouko Heikkinen for giving me an opportunity to learn graphical programming, develop RE and RI test setups and such interesting and useful programs in Agilent VEE. I am really grateful to him for introducing me new concepts and research topics in the field of EMI/EMC testing and for his patience in answering my questions and ensuring the availability of everything requested or needed by me to complete my thesis work. Special thanks to Mr. Arif Zuberi, Simo Koppa, Ari Honkala, Teijo Nietola, Rehman Akbar, Rana Azhar Shaheen and Mubashir Ali for the guidance and assistance that they provided me to complete my degree.

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Tampere, March 18, 2014

Muhammad Munir

CONTENTS

List of Acronyms

AF	Antenna Factor
AM	Amplitude Modulation
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CISPR	Comité International Spécial des Perturbations Radioélectriques (International Special Committee on Radio Interference)
CW	Continuous Wave
DLL	Dynamic link library
DOD	Department of Defence
DT	Dwell Time
DUT	Device Under Test
E	Electric Field
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETSI	European Telecommunications Standards Institute
EUT	Equipment Under Test
FCC	Federal Communication Commission
GPIB	General Purpose Interface Bus
H	Magnetic Field
IEC	International Electrotechnical Commision
IF	Intermediate Frequency

ISO	International Standards Organization
ITE	Information Techonolgy Equipment
MIL-STD	Military Standard
OATS	Open Area Test Site
QP	Quasi peak
RBW	Resolution Bandwidth
RCS	Radar Cros-Section
RF	Radio Frequency
RE	Radiated Emission
RI	Radiated Immunity
RS	Radiated Susceptibility
SNR	Signal to Noise Ratio
ST	Sweep Time
TST	Total Sweep Time
TUT	Tampere University of Technology
UFA	Uniform Field Area
VBW	Video Bandwidth
VSWR	Voltage Standing Wave Ratio

LIST OF SYMBOLS AND DEFINITIONS

λ	wavelength
μ	permeability
ε	permittivity

1. INTRODUCTION

Electromagnetic compatibility (EMC) is a growing field due to ever-increasing density of electrical and electronic circuits in modern systems for computation, communication, control and many other functions. The extension of spectrum use, both in frequency and amplitude is affecting the number and increasing the severity of Electromagnetic interference (EMI) situations. EMI may exist when two or more electronic devices are operated in a common environment and it leads to malfunctioning of devices [1].

The importance of EMI/EMC testing arose with the latest developments in digital radio communications and wireless devices. An international regulatory authority was set up to ensure that communications could be interference-free [2]. Regulatory authorities keep on squeezing frequency band allocations closer and closer due to ever-increasing use of mobile communications and other broadcast media channels. A number of international EMI/EMC testing standards and design methods have been introduced to limit the cross-channel interference to acceptable levels [2].

All devices consisting of electrical circuitry regardless of application should be EMC qualified. The purpose of this testing is to make sure that the device neither interferes with other surrounding devices nor is disturbed by them. Regulatory authorities and decision-making bodies like International Standards Organization (ISO) and International Electrotechnical Commission (IEC) have laid down certain rules and limits that all the electronic devices must follow. The testing standards introduced by IEC have prescribed limits on the amount of electromagnetic energy that a particular device can emit at specific frequencies. The susceptibility levels for the interference free operation of certain devices have also been defined in immunity testing standards [3].

In practice, EMI/EMC testing of an electronic device is carried out in two operating modes. In one mode a device is tested as a source of interference where it is powered up and its emissions are measured. These emissions can be of two types; radiated and conducted. The emissions that a device radiates in the air are categorized as radiated emissions whereas the emissions emitted through cables are referred as conducted emissions [3]. In other mode the device is tested as a victim of interference where it picks up the emissions emitted by other devices. The emissions detected by a receptor may approach it through air or cables [2]. The detailed description of these topics is given in chapter 2. The scope of this thesis work is to develop test setups for radiated emission (RE) and radiated immunity (RI) so the discussions in following chapters will be confined to RE and RI tests only.

Figure 1.1 gives a general view of radiated emission and radiated immunity tests. It also depicts the basic idea to perform both tests. Normally RE and RI tests are performed in an anechoic chamber having a turntable and an antenna mast. Equipment under test (EUT) is placed on a wooden table lying on the turntable. The turntable is used to rotate the EUT and antenna mast is utilized to vary the height of the antenna, however in RI changing the height of the antenna is not required [4]. These mechanisms are mandatory so that emission and immunity tests can be run according to International Special Committee on Radio Interference (CISPR) and International Electrotechnical Commission (IEC) recommendations.

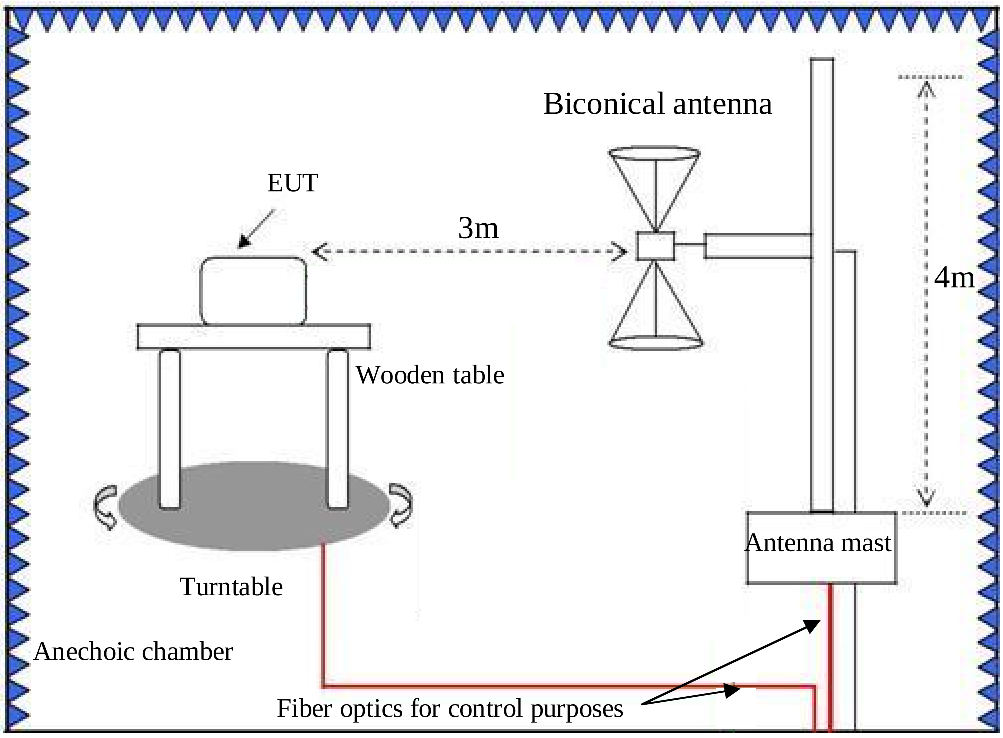


Figure 1.1 General test setup of RE and RI tests [5]

As shown in figure 1.1 the EUT is placed on a wooden table that is placed in a chamber having ferrite tiles and microwave absorbers on the walls and ceiling. The antenna is mounted on an antenna mast and located at 3 or 10 meters away from the EUT depending upon the chamber dimensions. Mostly RE and RI tests are executed at 3m distance between EUT and antenna.

There are different types of antennas being employed for EMI/EMC measurements, for example biconical, log periodic and horn [4][6]. Moreover, a bilog antenna that is a combination of biconical and log periodic can also be used. In test setup presented in figure 1.1 a biconical antenna is exploited for RE and RI measurements. During RE test the antenna acts as a receiver that captures the emissions radiated by the EUT, whereas in RI it is used as a transmitter to generate desired electric field levels. The turntable is moved between 0 to 360 degrees while antenna height is varied from 100 to 400cm [4]. However, in RI test the antenna does not need to be mounted on antenna mast. Usually it is fixed on a tripod stand. Fiber optic cables shown in figure 1.1 are used to control the movement of both these devices. The movement of turntable and antenna mast is accomplished with a device controller placed outside of the chamber [4][6].

The main objective of this thesis work is the development of testing programs, description of test equipment and procedures for both tests. It gives the reader an idea of why EMI/EMC testing is important, what are the RE and RI tests, what kind of test equipment is required and how to perform these tests. The feasibility study of the anechoic chamber of TUT's EMC lab for RI test is an additional task for current thesis. The study of chamber includes studying the behaviour and properties of microwave absorbers, ferrite tiles and overall construction of the enclosure. With this study the reader will know the properties and specifications of ferrite tiles, microwave absorbers and general isolation that this particular chamber provides for EMC measurements. The reader will also get a picture of what kind of electric field levels can be generated in the chamber under study with present capabilities.

This thesis can be considered as the continuation of earlier research done by Mikko Keskilammi as MSc. thesis in 1999 [7]. The study of EMC standards and directives, measurement equipment and procedure for radiated emission test were the prime objectives of that thesis. In addition, it also included the development of a small program for RE test in Agilent VEE and RE measurements at different sites. The thesis of Mikko Keskilammi was limited to RE measurements but a brief study of TUT's anechoic chamber was also a part if. However, the detailed feasibility study of this chamber for RI test is presented by current thesis work. Moreover, testing programs developed during current thesis are more professional, precise, and easy to operate having most of the necessary features requisite by IEC and CISPR standards.

1.1. Organization of the thesis

The structure of this thesis has been organized in different chapters as given below.

Chapter 1: An introduction and a general overview of the topics covered in this thesis are given in chapter 1.

Chapter 2: Chapter 2 presents theoretical background of radiated emissions, radiated immunity, importance and need for RE and RI tests, introduction of test standards and specifications of test equipment used in both tests.

Chapter 3: A deep study of feasibility of EMC lab's anechoic chamber for RI test has been presented in chapter 3.

Chapter 4: This chapter contains development of radiated emission testing programs, test equipment, procedure and results.

Chapter 5: The development of radiated immunity testing program, test equipment, procedure and results has been discussed in chapter 6.

Chapter 6: Summarizes and concludes the thesis.

Appendix A: Appendix A consists of tentative schedule and work plan of the thesis.

Appendix B: A brief description of the Agilent VEE objects used in the development of RE and RI testing programs has been given in appendix B.

Appendix C: The objective of visiting two commercial EMC labs (one in Espoo and other in Rauma) is described in appendix C.

2. THEORETICAL BACKGROUND

Chapter 2 presents theoretical background of causes and types of radiated interference generated by a device when acting as a source or detected by it as a victim. Both of these aspects will be discussed in chapter 2. The detailed description of required equipment and procedures of radiated emission (RE) and radiated immunity (RI) tests will also be provided in chapter 2. Since current thesis is limited to develop test setups for RE and RI, the main focus of following sections will be on radiated interferences.

2.1. Electromagnetic Interference (EMI)

An unwanted signal coupled from one electronic device (emitter) to another device (receptor) which degrades the normal functionality of the receptor is called electromagnetic interference [3]. The interference may interrupt, obstruct or degrade the effective performance of the victim. The introduction of small high speed wireless devices into the market is continuously cluttering the EMI environment [3]. EMI/EMC standards (commercial and military) have been introduced to limit the amount of interference. These standards set approved limits for electromagnetic (EM) energy that a particular device can emit at certain frequencies [3]. The role of emitter and receptor can be best understood with the help of figure 2.1 whereas coupling path has been described in section 2.2.

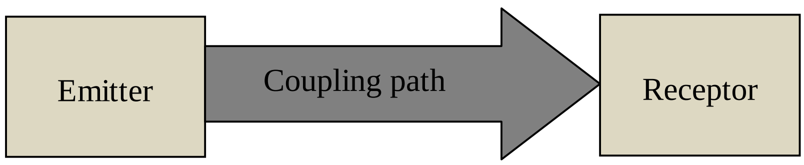


Figure 2.1 Electromagnetic interference

EMI has two basic types; radiated interference and conducted interference.

2.1.1. Radiated interference

Radiated interference is an undesired signal that is radiated by an electronic device in the air as electromagnetic (EM) fields. Whether radiated interference emanating from a device can cause disturbance in the normal function of a nearby device or not, depends on

- The directivity of the energy leaving the source.

- Losses during propagation.
- The susceptibility of the device that is being interfered.

Radiated interference can be observed when an un-intentional flicker occurs in TV's screen or a noise is experienced in the audio of an AM radio receiver if a mobile phone located close to these devices receives a phone call [8]. Figure 2.2 shows how does an emitter produce radiations in the air that are detected by a receptor.

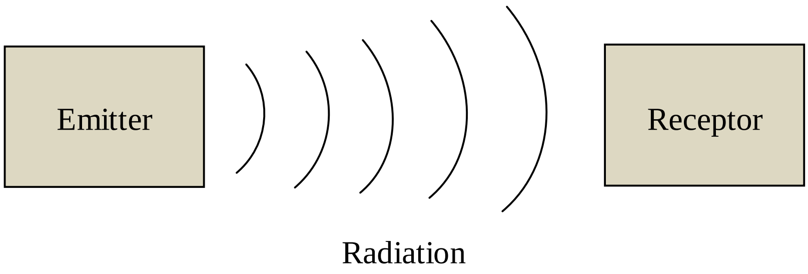


Figure 2.2 Radiated interference

2.1.2. Conducted interference

The interference that is coupled from a source device to victim through a direct physical contact is called conducted interference. The coupling path of conducted interference can be common power source (power cords), ground returns and interface cables [3]. The conducted disturbances travel from one device to other as conduction currents. Figure 2.3 illustrates the mechanism of conducted interference.

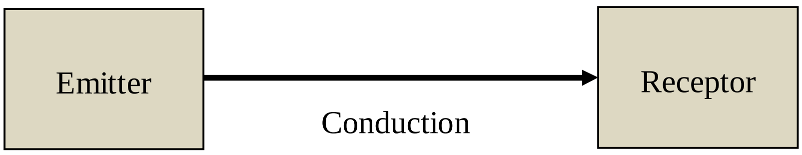


Figure 2.3 Conducted interference

2.2. Interference coupling mechanisms

The interference is produced by a source emitter and is detected by a susceptible victim (receptor) via a coupling path [3]. This coupling path may have different forms. Depending upon the coupling path, four major types of coupling mechanisms are associated with EMI. Figure 2.4 denotes a source emitter radiating EMI and a receptor that is a victim of this interference. It also shows the coupling mechanisms between source and victim.

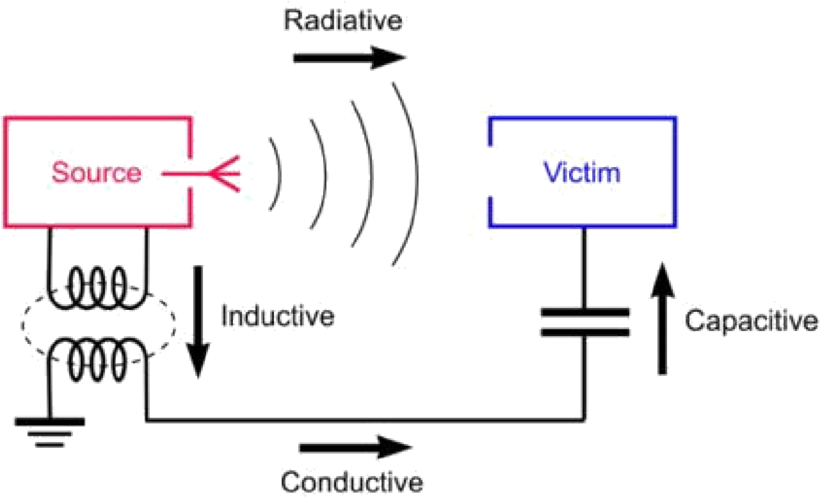


Figure 2.4 EMI coupling mechanisms [2]

2.2.1. Conductive coupling

Conductive coupling occurs due to a physical path between source and victim. Conductive coupling requires a direct connection between emitter and receptor. This direct path can be provided by common power cords, ground returns, interface cables, Printed Circuit Board (PCB) traces or metal enclosures of devices [3] [2]. As shown in figure 2.4 conducted interferences propagate from source to victim through cables in the form of currents.

2.2.2. Radiative coupling

Radiative coupling does not need a physical contact between source and emitter. Radiative coupling exists when source and victim are separated by a large distance, typically greater than a wavelength [2]. The emitter radiates interference signals in the air as electromagnetic fields. The receptor lies in the far field of the emitter and detects those interference signals. However, the strength of radiative coupling decays as 1/R where R is the separation between source and victim [3]. In figure 2.4 the source is producing radiated disturbances that are received by the victim device.

2.2.3. Inductive coupling

Inductive coupling (also known as magnetic coupling) exists when the emitter and receptor have a short distance between them (typically less than a wavelength) [2]. There is no direct conductive path between source and victim in inductive coupling. The victim is present in the near field of the source where the magnetic field is dominant. Due to close proximity of emitter and receptor, mutual coupling occurs that is called inductive coupling [3].

2.2.4. Capacitive coupling

A varying electric field between two adjacent conductors that are less than a wave-length apart results in capacitive coupling. The gap between two conductors acts as a capacitor which causes capacitive coupling where air acts as dielectric [2]. No conduction path is required between emitter and receptor. The victim usually lies in the near field of the source where electric field is dominant. The proximity of source and victim leads to capacitive coupling [3]. Both inductive & capacitive couplings can be minimized by increasing the separation between wires and by reducing wire lengths.

2.3. EMC testing standards and decision making bodies

EMC standards are prerequisites to ensure that electronic devices do not mutually cause malfunction or complete disability of their intended operation. These standards lay down requirements for devices for maximum permissible emission and immunity levels [9]. More detailed study on EMC standards and directives can be found for example in [7].

The main regulatory authority for EMC related issues is IEC that is closely operated by ISO [3]. There are different committees operating under IEC and one of them is CISPR that defines the standards for radiated and conducted interferences. IEC is a worldwide organization for standardization that has an objective of promoting standardization for electrical and electronic devices [4]. The standard CISPR 22 (describes the methods and limits for emission measurements of information technology equipment) issued by this committee was adopted in Europe and in several other countries. A lot of updates and revisions have been introduced in this standard to cope with recent technological requirements. CISPR 24 and 32 are examples of those updates.

Europe has its own regulatory authorities for example ETSI that deals with standards related to information and communication in Europe, and CENELEC that is responsible to develop electrotechnical standards for European market. EN 55022 is an example of radio interference testing standard introduced by CENELEC [3]. IEC 61000-4-3 is used to perform RI testing of a large number of devices. It covers a variety of commercial electronic devices that fall under the category of Information Technology Equipment (ITE). Some other immunity testing standards that have been in use are EN 61326-1 (for laboratory test equipment), IEC 61000-6-1 and IEC 61000-6-2 (generic standards for residential, commercial light and heavy industrial equipment) [10]. EN 60601-1-2 is used for the radiated immunity testing of medical equipment [11].

Federal Communication Commission (FCC) is an American standardization organization that regulates the interstate and international rules for radio, television, wire and satellite communications. The MIL-STD 461D and its updated versions introduced by the Department of Defense (DOD) of US are being used for the EMI/EMC testing of devices manufactured for military applications. RE and RI testing of military oriented products is performed according to MIL-STD 461E and F [3].

2.4. Classification of equipment and test limit

It is important to define the class of equipment and applicable test limit before actually conducting the RE test. Any equipment that has the capability of entry, storage, retrieval, display, transmission, processing, switching or control of data, telecommunication messages and which has one or more terminal ports operated for information transfer plus with supply voltages of less than 600V is categorized as Information Technology Equipment (ITE) [4].
Generally there are two classifications of ITE given in CISPR 22.

- The equipment intended to be used for domestic applications with no fixed place of use, telecommunication equipment powered by a telecommunication network. This category of equipment is called class B ITE, it satisfies the class B ITE test limits and the examples include portable equipment powered by built in batteries and personal computers [4].
- All other equipment fall under the category of class A ITE and satisfy test limits defined for class A ITE [4].

Test limits for each class of ITE at frequencies below 1 GHz are given in CISPR 22 page 25. The important thing to be mentioned here is that these test limits are for a distance of 10m whereas the dimensions of anechoic chamber to be studied in this thesis are 6.88 (L) x 3.2 (W) x 3.2m (H). It means radiated emission measurements at only 3m distance are possible in this chamber so the test limits need to be manipulated. The formula to calculate values of test limit at 3m distance is [4]

$$L_2 = L_1\ (d_1/d_2.) \qquad (2.1)$$

where L_1 is the specified original limit in microvolts per meter (μV/m) at a distance of d_1. L_2will be the new limit at d_2 distance [4].
For example at 10m distance test limit for class B ITE is 30 dBμV/m from 30 – 230 MHz. The new test limit at 3m distance for the same frequency and ITE can be calculated as follows:

$$L_1 = 30\ \mathrm{dB\mu V}/m$$

which in linear scale (μV/m) is

$$L_1 = 10^{\left(\frac{30}{20}\right)} = 31.6\ \frac{\mathrm{\mu V}}{\mathrm{m}}.$$

Using (2.1) we obtain

$$L_2 = 31.6\left(\frac{10}{3}\right) = 105.4\frac{\mathrm{\mu V}}{\mathrm{m}}.$$

which after change of unit reads

$$L_2 = 20\log(105.4) = 40.4\ \frac{\mathrm{dB\mu V}}{\mathrm{m}}$$

Thus the test limit at 3m distance would be 40 dBμV/m.

2.5. Radiated emission test

In order to avoid interference to the devices being operated in the close vicinity of a device it is mandatory to perform radio disturbance measurements on that device. Every electronic device radiates EM signals into air that can spoil the normal behavior of other devices. These radiations can be controlled up to a certain level so that they are not harmful for other devices. A number of international regulatory authorities were established to determine the allowed disturbance levels for all electronic devices.

One main regulatory authority is International Electrotechnical Commission (IEC) with some other sub authorities and committees [3]. These regulatory bodies have introduced certain limits for the radiated radio interferences for devices to be used for commercial and military applications. Measurement equipment and methods have also been specified in different testing standards. If the emissions from a device cross the specified limit during testing, the device is declared as fail and cannot be sold and used. In this context radiated emission test is very important since it determines the pass/fail criteria of a newly developed device [1]. The design engineers follow the guidelines of regulatory authorities at design stage so that EMC issues could be minimized. In addition a prototype testing that is also called precompliance testing is performed to predict the EMI/EMC behavior of the newly designed electronic device.

Commercial radiated emission test standard CISPR 22 and its latest versions describe measurements of radiations in the form of electric field with a unit of $\frac{\mathrm{dB\mu V}}{\mathrm{m}}$. Far field RE measurements are recommended in CISPR standards [4].

2.5.1. Requirements for RE test equipment

The specifications of the equipment required for RE test have been described in CISPR 16-1-1 in detail [4]. A brief description is given in the following sections.

Measurement receiver: Measurement receiver can be a spectrum analyzer or an EMI test receiver. An EMI test receiver is a very useful test instrument for the measurement of radiated emissions. The required features that an EMI test receiver should have when used as a measuring instrument for radiated emission test are detailed in CISPR 16-1-1. A test receiver is the same as a super heterodyne spectrum analyzer with some extra features for example pre-selector, preamplifier, peak, quasi peak and average detectors. The pre-selector of a test receiver is very useful because it contains input attenuator and a tunable bandpass filter. This combination of attenuator and bandpass filter not only improves the dynamic range of the receiver but also prevents the input mixer from overloading. The preamplifier is used to increase the signal strength and to improve the sensitivity of the measurement receiver [12].

The recommended detector for a measurement receiver in CISPR standards is quasi peak. However, quasi peak detector is very slow as it takes relatively long time to complete a measurement than peak or average detectors. The major reason behind its slow operation is weighted charge and discharge times. That is why a peak detector is normally utilized for RE measurements so that measurement time can be saved. A peak detector detects peak value of a signal and due to rapid discharging capability its response time is much faster than quasi peak detector [12].

The bandwidth of intermediate frequency (IF) filter of a measurement receiver is also known as resolution bandwidth (RBW) and if selected properly, it plays very important role in distinguishing, separating and resolving adjacent frequency signal components. The settings of RBW for different frequency ranges are specified in CISPR 16-1-1. The time taken to complete a measurement over a frequency band is directly affected by sweep time (ST) of the measurement receiver. The displayed amplitude levels are not accurate if the mixing products are swept faster through the IF filters. The time in pass band (TP) is the time taken by mixing products through IF filters and it is given as [12]

$$TP = RBW*ST/Freq.\ Span \quad (2.2)$$

where ST is sweep time of the measurement receiver; the time taken to scan a given frequency span. Freq. Span refers to a specific frequency span of the measurement receiver. It is worth mentioning here that dwell time and scan steps are also possible to be set by user to scan a given frequency span. The extra time taken to measure emission at each scan step is called dwell time. At each specific frequency the duration of measurement is determined by dwell time so it is very important feature of a measurement receiver. The accuracy of the measurements is directly proportional to dwell time that means higher dwell times result better accuracy for a specific measurement. For better accuracy of measurements scan step should be 50% or even smaller than RBW [12]. In case of measurement receivers which provide the facility of dwell time settings, ST equation becomes

$$TST = ST + (N * DT) \quad (2.3)$$

where TST = Total sweep time required to scan the entire frequency range.
ST = Sweep time automatically set by the receiver depending upon span and RBW.
N = Span/scan step = Total number of steps taken to complete the entire span.
DT = Dwell time

Antennas: An antenna is a transducer that is used to capture radiated emissions emitted by EUT. The antennas used for radiated emission test are designed for far field measurements because the test limits given in CISPR standards are in far field. The far field in general, is defined as the distance greater than one sixth of a wavelength [13].

Incident electric field on an antenna produces voltages at antenna terminals which are fed to a measurement receiver. As the antenna acts as transducer there is always some loss of energy before changing its form. It means an antenna presents loss of signals. The ratio of the incident electric field at antenna and voltage present at its terminals is called antenna factor (AF) and can be written as follows: [3]

$$\text{AF} = \frac{\tilde{E}_{inc}}{\tilde{V}_{ant}} \tag{2.4}$$

where $\tilde{E}_{inc}$ is the magnitude of incident electric field at antenna in $\frac{\text{V}}{\text{m}}$ and $\tilde{V}_{ant}$ is the magnitude of received voltage at antenna terminals in volts. As the antenna factor is a ratio between electric field and voltages so its unit is m^{-1} and it is normally expressed in dB. The antenna factor is a function of frequency and should be calculated over the entire operating frequency range of the antenna [3]. Usually antenna factor data is provided by the manufacturers of antennas in operating manuals.

The antenna captures the electric field and converts it into volts at its terminals. Finally these voltages are fed to a spectrum analyzer that is a measurement receiver. Generally, antennas like biconical and log periodic are used for RE measurements. Both these types are linearly polarized antennas and typically cover the frequency ranges of 30 MHz – 300 MHz and 300 MHz – 1 GHz respectively. They are combined in bilog antenna that exhibits the characteristics biconical and log periodic antennas for a specific frequency range [14].

CISPR 16-1-1 recommends antennas for RE test having low directivity so that the ground plane reflections are not significantly attenuated. In CISPR 16-1-1, the permissible system uncertainty offered by antenna, cable loss, receiver and other mismatch losses excluding test site is 3 dB. This standard also suggests antennas with linear polarization and voltage standing wave ratio (VSWR) less than 2:1 for RE measurements [14]. Gain is also an important feature of antennas. Every antenna provides some amplification to the detected low level signals. Thus the frequency range, gain and antenna factor of the antenna to be used for RE measurements should be carefully examined.

Bilog antenna CBL 6111C available in EMC lab of TUT was employed for the RE measurements of sample EUT. It covered the frequency range of 30 MHz – 1 GHz and presented a typical gain of 5 dB with an average VSWR of 2:1 [15]. These specifications meet the requirements of CISPR standards.

Preamplifier: A preamplifier is a device used to enhance strength of the signals picked up by the antenna. It is a low noise amplifier that amplifies the emission data before it is displayed on the screen of a measurement receiver. It provides enough gain for the weak signals captured by antenna and hence increases the sensitivity of the measurement receiver. It should not present any noise to the received signals. Normally the preamplifiers designed for EMI measurements are low noise and EMI/EMC qualified.

A preamplifier should be selected very carefully since it is supposed to amplify the incoming weak signals in such a way that the strength of these signals gets greater than the sensitivity of the measurement receiver but less than the maximum signal strength that a receiver can handle. Latter case is important since it avoids overloading of the receiver. In addition, a preamplifier should be wideband and stable to cover the whole frequency range of the test. The preamplifier is assumed to compensate all the losses offered by cables, connectors and antenna factor [16].

The available preamplifier that was utilized for RE test was Sonoma instrument 310 because it offered a gain of 32 dB from 9 kHz to 1GHz [17]. The gain presented by that preamplifier was enough to distinguish between noise floor of the measurement receiver and radiated emissions.

RF cables: RF cables with minimum attenuation are recommended for RE test since the radiated disturbances captured through the antenna have very weak power. The attenuation and frequency range of RF cables are to be kept in mind prior to their selection. The attenuation is measured in dBs per meter and it should be as small as possible. This attenuation is also known as insertion loss or cable loss. The insertion loss of the cables available in EMC lab of TUT which were employed for RE measurements was measured before using them for RE test. For automatic calculation of insertion loss a special program was developed in Agilent VEE. The results were saved for further use in correction factor calculations.

2.5.2. Correction factors

The implementation of correction factors is very important in RE test. The measurement data that is shown on measurement receiver's screen needs to be corrected before it is displayed in VEE and compared with a specified test limit. In order to know the exact emission spectrum of the EUT all the losses should be added into this raw data and all the amplification factors need to be subtracted from it. The finalized emission data to be displayed on the graph and compared with applicable test limit is given as follows:

$$RE\_data = (Raw\_data + antenna\_factor + cable\_loss) - Preamp\_gain \qquad (2.5)$$

where Raw_data is the emission spectrum of the EUT displayed on the screen of a measurement receiver without implementing the correction factors, RE_data is the original emission spectrum of the EUT after accounting for all the correction factors, antenna_factor is the loss offered by antenna that occurs during conversion from electric field to volts, cable_loss is attenuation presented by RF cables and Preamp_gain represents that amplification factor of preamplifier used during RE measurements. The values of correction factors were calculated with the help of (2.5) and the results were saved in a file so that correction factors data could be incorporated in RE data.

In practice correction factors were calculated with the help of a signal generator, preamplifier, RF cables and a spectrum analyzer. A signal from the signal generator was fed to the spectrum analyzer through RF cables intended to be used for RE test. The process continued from 30 MHz to 1 GHz with a fixed level of -20 dBm. The attenuation of the cables was calculated by this method. In next step, preamplifier was added into the path and the whole process was repeated for the whole frequency range of RE test. Subtracting the attenuation of the cables from this data gave the gain of the preamplifier. The values of antenna factor were taken from the operating manual of the antenna.

Correction factors are determined prior to RE measurements and for the entire frequency range of the test. The values of correction factors are valid as long as the test setup stays the same. It means correction factors calculated for a specific RE measurement can be utilized for future measurements if the antennas, cables, preamplifier under use and the measurement distance stay the same.

2.6. Radiated immunity test

The block diagram in figure 2.5 illustrates the necessary test instrumentation used for RI test along with a general idea of how to conduct this test. The antenna and EUT are placed inside the anechoic chamber whereas other devices are put in the control room. The signal generator generates electrical signals that are amplified by a power amplifier and fed to an antenna through a directional coupler. The antenna radiates this electrical energy in the air as electromagnetic field that is applied on the EUT. A power meter is used to measure the signal strength of forward and reverse powers produced by power amplifier. However, the directional coupler and power meter are optional and normally not used in RI test. The computer controls the signal generator levels so that the required electric field strength could be generated inside the anechoic chamber [18].

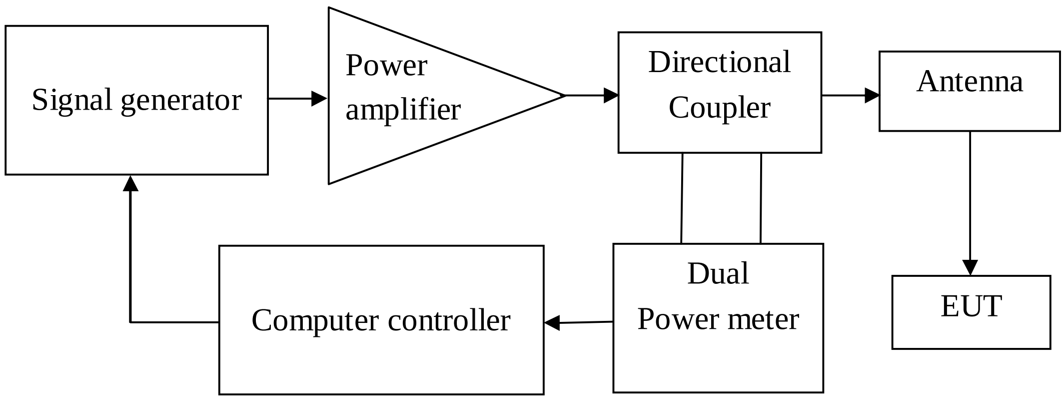


Figure 2.5 Block diagram of radiated immunity test setup

The original frequency range of RI test for a large number of EUTs that is recommended by IEC standards is 80 – 1000 MHz. Due to recent developments in digital radio phones and wireless devices it has been extended up to 6 GHz.

Electromagnetic compatibility (EMC) is essentially the opposite of EMI. EMC is the ability of an electronic device to sustain its normal function in the intended EM environment and not produce or be susceptible to interference.

A device is electromagnetically compatible if [1]

a. It does not cause interference with other devices.

b. It is not susceptible to emissions produced by other devices.
c. It does not cause interference with itself.

The objective of the radiated immunity test is to make sure that EUT does not suffer any malfunction when operated in its intended EM environment. From above mentioned points, b and c are verified by RI test for all EUTs. If a device qualifies RI test it means it would neither be susceptible to emissions produced by other devices operating in its vicinity nor be disturbed by interference generated by itself.

During RI testing, the EUT is tested as receiver of EM energy and an externally generated electric field, specified by an international testing standard is applied on it and its performance is monitored. EUT should sustain its normal function under this applied field in order to qualify RI testing requirements. The test frequency range and electric field strength both are defined by the applicable standard. A large number of electronic devices are tested against IEC 61000-4-3 testing standard.

2.6.1. Requirements for RI test equipment

The test equipment required for RI testing is given below:

a. Signal generators
b. Power amplifiers
c. RF cables
d. Antennas
e. Isotropic electric field probe
f. Electric field monitoring system
g. Computer with a testing software

The computer contains testing software to run the RI test automatically with the help of GPIB, parallel or serial interfaces. There are certain specifications and features recommended for each of above mentioned test equipment in IEC and CISPR standards. The mandatory specifications and properties of test instruments employed in RI testing are explained in detail in the following sections.

Signal generators: The signal generator intended to be utilized for RI test should be able to generate signals over the entire frequency range of the test with sufficient levels. It should also have the capability to generate continuous wave (CW) and modulated signals of all the modulation types and various depths mentioned in IEC and CISPR standards. The signal generator must have a good frequency and level resolution so that unwanted effects in EUT, antenna or power amplifier could be avoided. A poor resolution might produce transients that can be harmful for power amplifier, antenna and EUT [18]. A signal generator must be capable of covering the entire frequency band of interest. It should have ability to generate carrier signals being amplitude modulated by 1 kHz sine wave with 80 % depth. In case of synthesized sweepers step size of the frequencies and dwell time needs to be set carefully [6].

Power amplifiers: A power amplifier is the most important component of radiated immunity test since it determines the electric field strength to be applied on devices under test [19]. Power amplifiers must provide high power sufficient to generate the required electric field strengths over the whole frequency range of RI test. A power amplifier should also have ability to withstand with high VSWRs. Usually broadband power amplifiers having open and short circuit protections are used for RI testing. The linearity of a power amplifier is a very important property since nonlinearity would result undesired harmonics. These harmonics can be dangerous because they may create problems for transmitting antennas and EUT [18].

The harmonics generated by a power amplifier should be such that at each harmonic frequency any measured field strength in the Uniform Field Area (UFA) must be at least 6 dB below the fundamental frequency. If harmonics are significantly present during calibration, the measured field strength at intended frequency can be incorrect. When harmonics are significant during test, they may cause EUT failure. Nonlinearity and saturation in power amplifiers result harmonic distortion so both of these situations need to be avoided. Saturation may lead to incorrect modulation index during the execution of RI test [6].

A power amplifier must present a reasonable gain to the signals generated by a signal generator. The gain of the power amplifier should be sufficient so that the transmitting antenna can generate intended electric field strengths. The gain of an amplifier does not need to be constant over the entire frequency range. Amplifiers are considered linear up to 1 dB compression point. This is the point where the output of an amplifier differs from ideal predicted output by 1 dB and it normally occurs from 60-75 % of the saturated output power [18].

Power amplifiers have to be capable of handling modulated signals with various depths. IEC 61000-4-3 mandates amplitude modulation with 80 % modulation index and it is implemented with a 1 kHz sine wave [6].

Selection of correct power amplifier: In order to find an amplifier that meets the requirements of RI test we need to calculate the system losses. System loss includes the loss offered by cables, connectors and RF switched/adaptors. The power fed to the antenna is estimated by (2.7) and if the system loss is also calculated, the final power that an amplifier needs to deliver can be found by (2.6)

$$P = 10^{\left(\frac{(L_{cableloss} + 10\log(P_{ant}))}{10}\right)} \text{ W} \tag{2.6}$$

where P is power in watts delivered by power amplifier, $L_{cableloss}$ expresses the attenuation of cables in dB and P_{ant} represents the power fed to the transmitting antenna. Above equation gives linear power so an amplifier is chosen based on the specification of 1 dB compression point [6].

Immunity testing antennas: A variety of transmitting antenna can be used to generate required electric field strengths inside a shielded enclosure. Typical antenna types being employed for immunity measurements are high power biconical, log periodic and ridged rectangular horns [20]. The maximum electric field strength that can be achieved is a function of the power radiated from the antenna. The important parameters of a transmitting antenna to be utilized for immunity testing are directivity, gain, beamwidth, polarization, power handling and VSWR.

Gain and directivity: Gain and directivity specify the ability of an antenna to confine the transmitted signal in a desired direction. The ratio of radiated power in a given direction to the power radiated in all directions is called directivity [21]. By IEEE definition, the gain is the product of directivity and ohmic losses. As most of the antennas are made of aluminum or other metals having high conductivity so ohmic losses are insignificant. Therefore, gain is assumed as directivity [22]. For antennas intended to be utilized for immunity testing directivity is very important since it determines the illumination area. Antennas having relatively high directivity are preferred for RI testing because they maximize the area covered with a uniform electric field. IEC 61000-4-3 also mandates uniform field area (UFA) at the location where EUT is placed [14].

Polarization: The mandatory polarization of the antennas to be used for immunity measurements mentioned in CISPR 16-1 is linear. Transmitting antennas need to generate electric fields in horizontal and vertical polarizations.

Power handling: Power handling capability of an antenna intended for immunity testing is a very important feature. In principle it is a function of balun design because some of radiated power is dissipated in balun. This power dissipation in balun raises the temperature that decreases the power applied to the antenna [14].

Beamwidth: For radiated immunity testing narrow beam antennas are used so that a particular area can be exposed with strong electric field strength [14].

VSWR: To make best use of the power amplifiers the VSWR of the transmitting antennas employed for RI testing should be minimum. The VSWR allowed in CISPR 16-1 is 2:1. A good VSWR is essential to minimize the reflections from the antenna. The VSWR of an antenna limits the radiated power required for immunity measurements. A VSWR of 3:1 results half of the radiated power from the antenna to be reflected back. Therefore, RI testing antennas with low VSWRs are considered more efficient [14].

Selection of correct antenna: Selecting the correct antenna is very crucial. Based on the parameters explained above it is important to choose an antenna that is capable to generate desired field strengths. The required power at the antenna input to generate an intended electric field can be calculated as [6]

$$P = \frac{(E*d)^2}{30*10^{\left(G_{dBi/10}\right)}} \text{ W} \quad (2.7)$$

where P is radiated power in watts, E shows the strength of electric field in V/m, d represents the distance in meters and G_{dBi} is the isotropic gain of the antenna in decibels. For example for 10 V/m field with 80 % amplitude modulation that is equivalent to 18 V/m, the required input power would be calculated as given below. Antenna gain is assumed to be 5.5 dBi at 3 meter distance [6]. Once the values are substituted into (2.7) we obtain

$$P = \frac{(18 * 3)^2}{30 * 10^{(5.5/10)}} = 27.39\ \mathrm{W}$$

In an ideal RI test setup this power is required at antenna bore site. It is always good to allow a margin of 2-3 dB for errors caused by antenna setup, attenuations of cables and chamber variations. Adding a 3 dB margin to compensate errors, for a uniform field measurement an uncompressed power of 54 watts is required at the antenna input to generate 10 V/m electric field strength with 80 % amplitude modulation [23]. This is why power handling capability of a transmitting antenna intended to be used for RI measurements is very important.

Electric field probe: An electric field probe, also known as field sensor is a very important component of RI test. It senses the electric field generated by transmitting antenna, converts electrical energy into optical signals and sends them to field monitoring system through fiber optic cables. Calibration of the electric field over the whole frequency range of RI test is done with the help of electric field probe. IEC 61000-4-3 mandates 16 point field calibration that cannot be exercised without a field sensor. There are two independent fiber optic cables attached to field probe, transmitter and receiver.

An isotropic electric field probe consists of three axes and each axis has an independent antenna that senses the electric field. The error of reading must be within a permissible tolerance. An ideal field probe does not offer any loss and can be positioned anywhere to read accurate electric field data [23]. However, readings should be taken in CW mode because common probes do not exhibit linear response to modulated RF signals throughout their entire operating frequency range. The temperature variations also play an important role in field measurements.

Since an electric field probe is intended to be used inside the anechoic chambers it should have built in rechargeable battery. The battery discharge time also should be sufficient to perform the entire RI test comfortably. The important parameters of a field probe when engaged in RI testing are described below:

Frequency response: It is the frequency range for which a particular field probe is used to read the electric field. Generally, the frequency response of a probe is not flat over the entire frequency range. Therefore, an acceptable tolerance in ±dB is always permitted. A frequency response curve is usually supplied with probe by the manufacturers [24]. An electric field probe should cover the whole frequency range of the immunity test. Latest models of electric field probes are quite broadband. However, before selecting a particular probe frequency range requirements should be carefully examined.

Calibration factors: Calibration factors are always provided with every probe and must be updated at least once a year. Correction factors are given as multiplication factors in dBs and they flatten the frequency response of a probe when incorporated. Modern electric field probes have an ability to update their correction factors automatically [24].

Sensitivity/dynamic range: The sensitivity of a field probe is important since it determines probe's ability to respond weak RF signals accurately. The most sensitive probes can even read electric fields of few hundred $\frac{mV}{m}$. Dynamic range is the total range of electric field a probe would respond to. Probes with greater dynamic ranges are considered suitable for electric field measurements. Latest probes have dynamic range that start from 0.5 V/m and may go up to 800 V/m [24].

Linearity: It is the measure of deviation from an ideal response over the entire dynamic range of the field probe. A field probe must be linear because a slight variation from ideal response may cause additional errors in readings [24].

Overload/Power handling: It is referred as the field level where damage can occur to the field probe. The power handling capability of a field probe is very critical feature. A field sensor should be able to withstand with the desired electric field strengths generated inside the chambers for a particular EUT. Mostly field probes are designed for higher power ratings which are not used in practical applications. Almost all the models of field probes are designed to sustain their normal operation under the illumination of very strong electric fields of over 200 V/m. Overload can be stated as a maximum pulsed level or a CW level that may damage the probe [24].

Response time: The response time is the time that a probe takes to respond an applied RF field. Probes with faster response times are preferred for immunity measurements [39].

Sample rate: The rate at which the information can be retrieved from a field probe is known as the sample rate. A high sample rate results quick response to field variations and it reduces the test time as well. The sample rate is measured in samples per second [24].

Probe type: In general, the configuration of the probe sensors is considered as probe type. Most of the modern probes are isotropic and the total field value measured with isotropic probes is unaffected by polarity. This is achieved by summing field values from three sensors placed orthogonal to each other [24].

Temperature stability: It is the deviation of the probe reading over the entire operating frequency range as a function of temperature. If there is significant change in temperature between calibration and actual test run then the probe reading will contain error that is directly proportional to the temperature variations [25]. In this case probes need correction formula to be applied [24].

Control: The control refers to the method of communication used with a probe. Fiber optic is the most commonly used control in immunity measurements. The prime advantage of fiber optic cables is that they are non metallic and do not cause or suffer interference from strong RF fields. Therefore, electric field data is not corrupted when fiber optic control is implemented for field probes [24].

Data returned from probe: There are two methods to display the data read by a field probe. The first method is to read data of each axis separately and the second is to get composite data of all three axes. Normally, second method is used but in certain applications where polarity of the field needs to be determined, readings from individual axes are also required [24].

Battery discharge time: The battery discharge time of a battery powered field probe is also a crucial property. Once the battery is charged it should work for a long time enough to complete the whole calibration process of RI test. Modern field probes have very strong batteries with a good battery time. Charging cycles limit the life of a battery powered probe, therefore reliability is a big issue of these probes. Laser powered probes have been specially designed to counter the reliability issues. They have completely different charging mechanism than battery powered probes [24].

Electric field monitoring system: A device employed to display the data of electric field of a field probe is called a field monitor. Mostly it is used in manual mode of operation but due to versatility it can also be utilized for automated measurements. Typically a field monitor is capable to handle four field probes at a time. The readings of four different electric field probes can be displayed on a field monitor. Moreover, electric field of individual axes of a particular probe can also be displayed on it [24].

The alternative approach to display the electric field data of a probe is to connect it directly to the computer. When RI test is intended to be performed completely automatic, RF field probe is connected to a computer via RS-232, USB or GPIB interfaces. Most battery operated probes use fiber optic to RS-232 adaptor to connect to a computer whereas laser powered probes offer a variety of interfaces including RS-232, USB, GPIB (IEE-488) and fiber optic serial. This approach demands a field monitoring software that is usually provided by the manufacturer. However, a user created custom software can also be used [24].

The fiber optic to RS-232 or USB adaptor is also called a modem and it converts optical signals into electrical signals. These electrical signals contain information of electric field data and fed to a computer. Later on this electric field is displayed in software in numerical form.

2.6.2. Selection of RI test equipment

In the light of CISPR recommendations the appropriate test equipment for RI test was searched. Quotations for power amplifiers, electric field probe and field monitoring system from different manufacturers were fetched. Based on useful features and specifications a power amplifier, electric field probe and field monitoring system were recommended for purchase. The selection of finalized equipment to be purchased was done on the basis of specifications and price. As compared to Australian company RFI's power amplifiers; the power amplifier of a German company (Frankonia) was quite cheaper. In addition, only one power amplifier unit covered 80 MHz-1 GHz frequency range. Therefore, FLH-200B was recommended for RI test. In case of field probe and field monitoring system ETS-Lindgren was the prime manufacturer, therefore those equipments were purchased from ETS-Lindgren. The field probes of ETS-Lindgren meet mandatory requirements of IEC and CISPR standards and are easy to operate.

Signal generator SMR 20 and bilog antenna CBL 6111C available in TUT's EMC lab covered the essential frequency range of RI test (from 80 MHz to 1 GHz). The signal generator SMR 20 could handle almost all types of modulations with a soft control of modulation index. The dwell time of SMR 20 could also be controlled depending upon the requirements [26]. In addition, both equipment were meeting mandatory requirements of CISPR standards for immunity testing, therefore they were discarded from purchase list.

Bilog antenna CBL 6111C can be utilized for RI testing because it can generate an electric field of 10 V/m from 80 MHz to 1 GHz. The average gain provided by this antenna over the entire operating frequency range is 5 dB with a power handling capability of 300 watts (CW). The average VSWR of this antenna is 2:1 over the whole frequency range [15].

The most important component of RI test is power amplifier. The power amplifier which fulfilled our specifications and was planned to be purchased for RI test was Frankonia's FLH-200B [27] but due to lack of funds it could not be purchased for this study. An isotropic electric field probe HI 6005 was procured to read the electric field. It could handle electric field strength up to 800 V/m at frequency range of 100 kHz to 6 GHz [28]. To monitor and display the field a specially designed modem, HI-4413 (fiber optic to serial converter) was purchased from the same manufacturer.

3. FEASIBILITY STUDY OF ANECHOIC CHAMBER FOR RADIATED IMMUNITY TEST

This chapter presents study of anechoic chamber of TUT's EMC lab in detail. The chapter begins with a brief discussion about different types of chambers used for EMC measurements. This feasibility study consists of specifications, properties of microwave absorbers and ferrite tiles used in chamber under study. In addition, the information about the shielding effectiveness and isolation of the chamber as a whole is also presented in this chapter. A microwave anechoic chamber provides the facility of indoor measurements with isolation of 80 – 100 dB from external electromagnetic environment [29].

An anechoic chamber is a specially designed room that is used to absorb the reflections created by electromagnetic waves [30]. The design usually consists of a conductive housing with microwave absorbers and ferrite tiles pasted on the walls and ceiling. An anechoic chamber is used to perform RE and RI testing, antenna radiation pattern and radar cross-section measurements according to a variety of testing standards [30].

3.1. Anechoic chamber

A shielded enclosure having reflection free properties and primarily employed to perform EMI/EMC testing, antenna and radar cross-section (RCS) measurements is called anechoic chamber. Three major types of chambers are being used for different testing purposes depending on their design and isolation. A short introduction of these chambers in general as well as brief description of the microwave chamber under study has been summarized in this section.

3.1.1. Semi anechoic chambers

Anechoic chambers that do not have microwave absorbers on the floor of the housing are called semi anechoic chambers. Usually the floor is metallic and conductive but some chambers may have non conductive floor as well. To make the floor non conductive a special carpet is laid down on it. Semi anechoic chambers are extensively used for radiated emission and radiated immunity testing.

3.1.2. Fully anechoic chambers

A fully anechoic chamber also has microwave absorbers on the floor. It is normally used to characterize antennas. In this kind of chambers, EMI/EMC testing, radiation patterns and VSWR measurements of antennas and radar cross-section measurements of different devices are performed.

3.1.3. Reverberation chambers

A reverberation chamber is a special type of screened rooms that is primarily used to conduct radiated immunity testing. The main feature of this chamber is that it is totally conductive with no absorbing material on the walls, ceiling and on the floor. Very high electric fields can be generated in reverberation chambers due to complete absence of absorbing materials with low input powers because of their design. A reverberation chamber acts like a cavity resonator with a very high quality factor. The distribution of electric and magnetic fields in this kind of chambers is inhomogeneous. In order to control this inhomogeneity special tuners are used which are constructed from large metallic reflectors. Various boundary conditions are achieved by moving these tuners to different orientations. [31]

Figure 3.1 Reverberation chamber [31]

3.2. Ferrite tiles

A ferrite tile is a special type of RF absorber that offers smaller attenuation than microwave foam absorbers and is useful for low frequency applications. Ferrite tiles utilized in microwave anechoic chambers provide 10 – 25 dB [32] absorption between 30 MHz to 1 GHz frequency range. Materials used to make ferrite tiles are nickel and zinc [33].

The ferrite tiles to be used as absorbers in anechoic chambers are shaped in the form of plates. The back side of these plates usually has some dielectric for example plywood. Microwave absorbing properties of the ferrite tile as well as plate thickness and the zero-reflection frequency are determined by its magnetic permeability *(*µ*)* and dielectric constant *(ε)* [33]. The size of the tiles ranges from 60 mm x 60 mm to 200 mm x 200 mm but the industry standard that is commonly used in chambers is 100 mm x 100 mm (4 in x 4 in). The thickness varies from 3.9 mm to 19 mm but the most common thicknesses that are being used for IEC 61000-4-3 radiated immunity testing are 6.3 mm, 6.5 mm and 6.7 mm [34].

By minimizing tile to tile gaps maximum low frequency performance can be achieved. Therefore, tolerance of tiles (tile to tile gap) plays an important role when machined. To ensure a tight tile to tile fitting and easy installation, tolerance should be minimum. The tiles are pasted on a dielectric usually wooden spacer with the help of adhesive before mounting them on the walls of a chamber. This dielectric provides separation from the shielded wall of the chamber hence enhancing the high frequency performance of the tiles [34].

The material used in ferrites belongs to a class of ceramic with a cubic crystalline structure [34]. The chemical formula of ferrite is $MOFe_2O_3$ where Fe_2O_3 refers to iron oxide whereas MO is the combination of two or more divalent metal oxides. There are two basic varieties of the ferrite; soft and hard. Soft ferrite does not retain significant magnetization but hard ferrite is utilized for permanent magnets. That is why ferrite tile absorbers are made of the soft ferrites that are commonly zinc, nickel, manganese or copper oxides [34].

Ferrite tile absorbers are also known as magnetic absorbers. Maximum absorbing capability can be achieved by placing them on the metallic surface of conducting walls of the chamber. The important parameters of ferrite tile absorber performance are permeability and loss tangent that offer good absorption at low frequencies [35].

Like other ceramics, ferrite tiles become rigid and brittle when sintered in a kiln and pressed from a powdered precursor. The mixture of different ferrite materials and sintering process affect the mechanical and electromagnetic properties of the tiles. Moreover, sintering also causes shrinking of tiles from 10 % to 17 % in each dimension. Therefore, shrinking issues are catered with proper machining to maintain correct dimensions during manufacturing process [34].

A very important issue related to ferrite tile installations is the gap between two tiles because the minor changes in the gap dimension result large variations in the reflectivity especially at lower frequencies. This change in reflectivity causes degradation in the performance of the chamber. The studies have shown that even small gaps among tiles cause large changes (5 to 10 dB) in the reflectivity at lower frequencies. This problem not only seriously affects the performance of the chamber but also degrades its ability to meet specifications [36].

3.3. Microwave absorbers

In RF and microwave context an absorber is a material that attenuates the energy of an electromagnetic wave. Microwave absorbers are used in a variety of applications to eliminate stray and unwanted radiations so that interference among different electronic devices could be controlled. During manufacturing of these absorbers temperature and humidity constraints are taken into account so that absorbers can also work properly in extreme weather conditions [34].

A microwave absorber is an important element of an anechoic chamber. These absorbers absorb the electromagnetic energy and hence provide attenuation to unwanted reflections created by EM fields inside the chambers. The properties of microwave absorbers depend on frequency. The material that is commonly used in the manufacturing of microwave absorbers for anechoic chamber applications is a foam base with impregnated carbon. Typically foam base is made of silicon or polyurethane [37].

Usually the absorbers employed in chambers are cut into pyramidal shapes. The most important features of microwave absorbers are frequency range of operation, power handling capability and fire retardancy. Normally microwave pyramidal absorbers are broadband and based on tapered impedance principle. The impedance of the pyramidal absorbers is increased steadily from free space impedance at the incident surface. Lossy material is used at the rear side and as a result the absorber attenuates the signal as it travels along the depth of the absorber. A tapering shape simulates continuous changing dielectric. The performance of pyramidal absorbers is directly related to size - low frequency performance necessitates larger pyramids. [34].

To provide fire retardancy and resistance to moisture a double immersion process is employed in which foam is impregnated with a conductive carbon formula. Then the carbon impregnation is forced-dried and inspected. After drying, a water-soluble salt solution is used to submerge and impregnate the foam that is again inspected and forced-dried. Additional 6 inches absorbers positioned at the base of the large absorber enhance the high frequency performance of the microwave absorbers [37].

3.4. Anechoic chamber of TUT

The chamber present in TUT’s EMC lab is metallic with ferrite tiles pasted on the walls and ceilings. Additionally, after the ferrite tiles FS-400 microwave absorbers are installed on the inside walls and ceiling with extra removable absorbers on the floor [29]. Basically this is a semi-anechoic chamber but due to additional absorbers placed on the floor it depicts the properties of a modified semi anechoic chamber. Usually all the anechoic chambers have a door that is made of firm metallic spring contacts to provide good isolation. It is used to move EUT, antennas and other accessories in and out of the chamber. The chamber under study has metallic outer walls with metal spring contacts along the panel joints in order to prevent the leakage of electromagnetic energy [29].

The structure of this anechoic chamber is made of hot galvanized rigid steel panels. The joints of these panels are bolted together by using a special gasket. This gasket is made of copper clad, tin coated steel wire mesh with a thickness of 5 – 6 mm. It expresses excellent conductivity between the panels when pressed down to 2 mm. The bolts, nuts and washers used in the structure are all zinc plated to illustrate good conductivity. The floor is made of plywood and EUTs having 500 kg weight can be put on it. There is a ground plane made of galvanized steel plate on the top of the floor that has been covered with a carpet [38]. The dimensions of the chamber under study are 6.88 (L) x 3.2 (W) x 3.2m (H) and it is called a modified semi-anechoic chamber due to additional absorbers on the floor. A chamber is also called a measurement site and has been defined in CISPR standards as follow:

"A measurement site shall be considered acceptable if measured site attenuation is within ±4 dB of the reference values for both horizontal and vertical polarization and for the volume intended to be occupied by EUT" [4] [39].

A view of TUT's anechoic chamber with absorbers on the walls and floor is shown in figure 3.2.

Figure 3.2 View of walls and floor of TUT's anechoic chamber

Ferrite tile model FT-100 [38] has been installed on the inner walls and ceiling of the anechoic chamber. This structure combines precision machined ferrite tile with a tuned dielectric backing layer to provide high performance. For compatibility with radiated immunity testing standard IEC 61000-4-3, ferrite model FT-100c has been employed at the floor and covered with a special grade carpet surface. It offers a power handling of 1000 V/m and 16 dB absorption over the frequency range of 30 MHz to 1 GHz [38]. Figure 3.3 represents the ferrite tiles pasted on the inner walls and ceiling of the chamber under study.

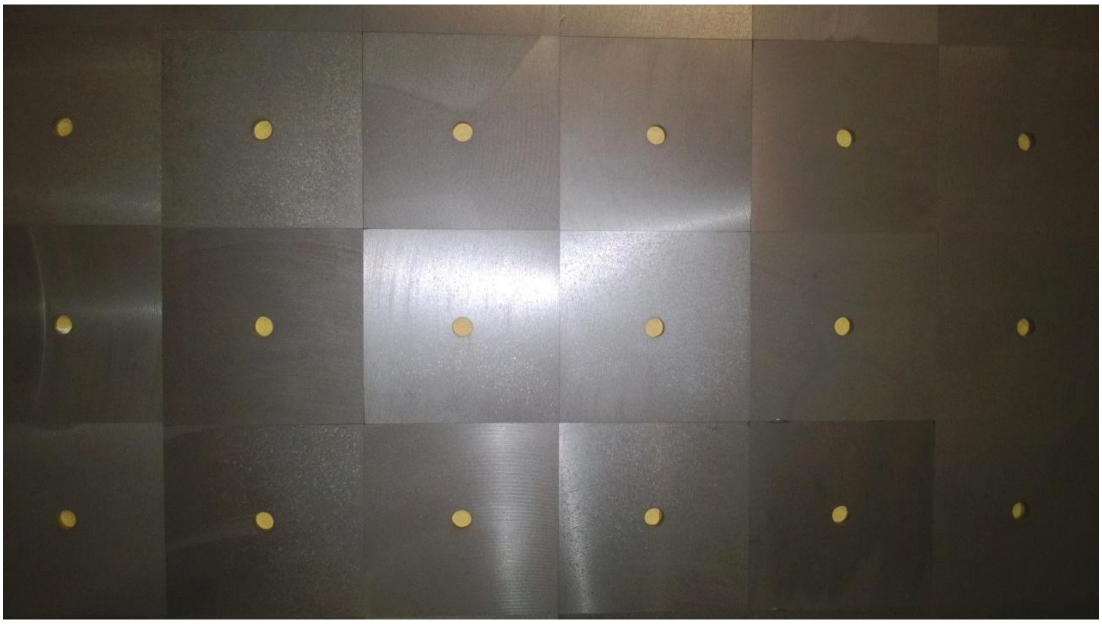


Figure 3.3 ferrite tiles lined on the inner walls of TUT's chamber

Usually, FS-400 broadband high performance hybrid polyurethane dielectric microwave absorbers which have been lined on the inner walls and ceiling of the chamber are used in space saver and 3 m chambers. The polystyrene (aka Styrofoam) put on the absorbers produces an even and consistent density of carbon throughout the absorber dimension. It also improves the absorption performance of the absorbers. In general, hybrid absorbers FS–400 offer good performance from 30 MHz to 18 GHz with a maximum power handling of 200 V/m. FS–400 is fire retardant and meets all the tests defined by different flammability testing standards [34] [38].

3.5. Shielding effectiveness of the chamber

The capability of a shield to suppress unwanted electric/magnetic fields or plane waves is called shielding effectiveness (SE) of the shield. In measurement perspective shielding effectiveness is the ratio of the signal strength received without shield to the signal received with shield [39]. SE is also considered to be a barrier to radiated EM fields and it describes the effectiveness of metallic enclosures [40]. Common materials deployed to make shields are stainless steel, copper, silver, aluminum and nickel. The main objective of SE measurements is to determine insertion loss of a shield and usually the result is given in decibels. In case of electric fields the formula is given in (3.1)

$$\mathrm{SE} = 20 \log\left(\frac{E_R}{E_L}\right) = \mathrm{E}_R - \mathrm{E}_L \tag{3.1}$$

where E_R is the reference electric field and E_L is the electric field measured with load (shield). SE can also be calculated by power measurements as shown in (3.2)

$$\mathrm{SE} = 10\log\left(\frac{P_R}{P_L}\right)\ \mathrm{dB} \tag{3.2}$$

where P_R is the reference power and P_L represents the power measured with load (shield) [41].

The procedures for SE measurements have been described in IEEE 299 [42]. At first test antennas should be separated from each other by a measured distance and a reference measurement is performed. To conduct this reference measurement one antenna is made transmitter that transmits a specific level at a certain frequency and other antenna is used as receiver that measures the strength of the received signal. Similar measurement is done with one antenna inside the chamber at the same distance. The difference of both signal strengths in decibels is known as SE and this procedure is repeated for the entire operating frequency range of the chamber [42].

4. DEVELOPMENT OF RADIATED EMISSION TEST SETUP

Radiated emissions emanating from a device may have any polarization. Usually RE measurements are performed with horizontal and vertical polarizations of test antennas. These emissions can be measured in the near or far field, but normally measured in far field. In general, the levels of radiated disturbances are quite low and therefore measured in dBµV/m. The limits for radiated emissions given in CISPR standards are also in dBµV/m. If the radiated emissions cross the limits defined by applicable testing standards, the equipment is declared as fail and is not suitable to operate in an environment where other electronic devices are also being used. Otherwise it will interfere with nearby equipments.

The reference test site to conduct radiated emission testing recommended by CISPR standards is open area test site (OATS). However, there are several disadvantages of performing RE measurements in OATS. For instance, OATS needs a very large RF transparent and waterproof enclosure. In addition, climatic variations and ambient signals in the air also create problems during testing. The alternate solution of these problems is to perform testing in a shielded enclosure. These enclosures have magnetic and dielectric absorbers lined on the walls, ceilings and floors that eliminate the weather and ambient problems [43].

4.1. Agilent VEE software

Agilent VEE is a graphical programming language that is optimized for test and measurement applications – especially programs with user interfaces. Agilent VEE gives the operators an opportunity to control test equipment through general purpose interface bus (GPIB) and serial interface [44]. It is commonly used to develop programs for a variety of automatic test and measurement applications. A lot of built in custom made objects for different measurement instruments are available in the library of VEE. These objects offer a platform to write GPIB commands to control the test equipment automatically so that specific tasks could be accomplished. Due to unavailability of professional testing software in EMC lab of TUT, Agilent VEE software was selected to develop programs for RE and RI tests. Agilent VEE was chosen to develop above mentioned programs because a lot of work had already been done in it. Earlier work [7] includes the development of antenna radiation pattern characterization and some programs for radiated emission measurements. Moreover, VEE is user friendly, easy to understand, has many useful features and is readily available in TUT's EMC lab. Employing some other object oriented software, like Lab-view, would have required additional work and was therefore discarded.

4.2. Spectrum analyzer

A spectrum analyzer is a test instrument that is commonly used for emission measurements. The adjustable parameters of a spectrum analyzer are start/stop frequency, RBW, video bandwidth (VBW), sweep time and detector(s). Mostly spectrum analyzers lock RBW, VBW and sweep time together to avoid violations of critical timing requirements [45].

Spectrum analyzers facilitate some useful features such as versatility, familiarity and fast measurements; therefore they are commonly utilized for emission measurements. Although modern spectrum analyzers meet most of the CISPR requirements, however spectrum analyzers also have some limitations due to which test engineers make use of EMI test receivers. A common problem with spectrum analyzers is that the measurements cannot be completed in one frequency span. The reason is the limitation of maximum measurement points that spectrum analyzers can handle for a specific span [45].

This problem is solved by sub-ranging the span. There is a rule of thumb for calculating the size of the frequency span. For example HP 8593A facilitates 401 measurement points for a specific measurement span. The size of maximum sub-range can be calculated as follows:

$$\frac{1}{2}RBW = \max step\ size$$

$$\text{Maximum sub-range} = \text{Step size} * \text{number of points} \qquad (4.1)$$

$$120\ \text{kHz}/2\ =\ 60\ \text{KHz},$$

$$60\ \text{kHz} * 401 = 24\ \text{MHz}$$

The numerical value (120 kHz) is particularly mentioned in CISPR 22 for a measurement receiver to conduct RE test from 30 MHz to 1 GHz; therefore it has been utilized in (4.1). Splitting the frequency range into sub-ranges has been done to obtain the optimum frequency span. In addition, there are certain other issues related to spectrum analyzers especially with old spectrum analyzers that limit their usability. For example some old spectrum analyzers do not have quasi peak and average detectors. Many old models do not provide RBW required by CISPR standards. Other limitations of spectrum analyzers could be, setting of dwell time for CISPR detectors, availability of preselectors and overloading [45].

The spectrum analyzer HP 8593A available in TUT's EMC lab was utilized to develop RE testing program in Agilent VEE because it fulfilled most of the required features of CISPR standards. The frequency range of that spectrum analyzer was 9 kHz – 22 GHz with a maximum input level of +30 dBm [46]. The availability of GPIB card installed in it provided the user a facility to interact through GPIB interface. The necessary GPIB commands were available in the operating manual of the instrument.

4.3. Agilent VEE program with spectrum analyzer

The flow chart of figure 4.1 shows the operation of RE test program.

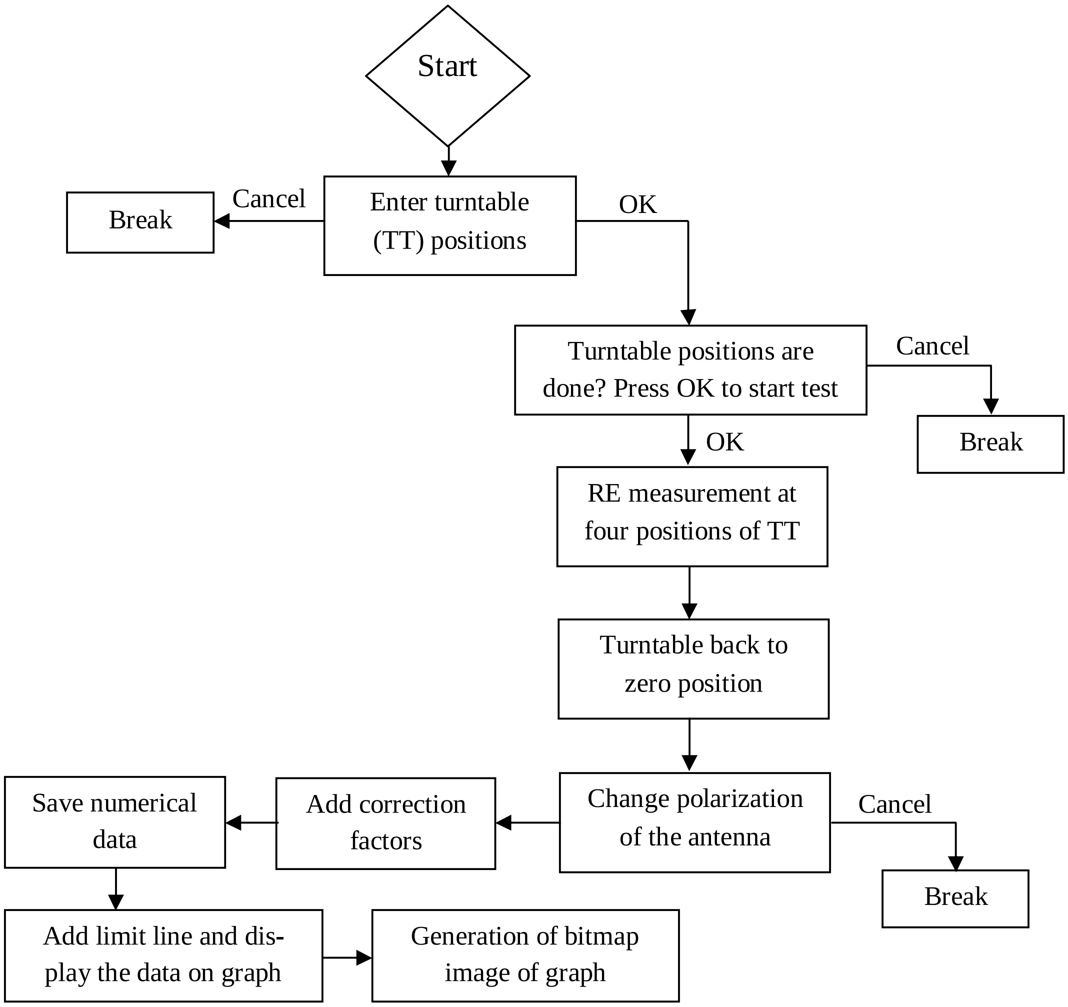


Figure 4.1 flow chart of RE test

4.3.1. Working of the program

The working principle of RE test program is very simple. As depicted in figure 4.1 when the start button is pressed, the program asks the user to enter four turntable positions at which the emission data is needed to be captured. Then measurement receiver executes a scan from 30 MHz to 1 GHz at all the given positions of turntable. When the scan is complete, the program displays a message to change the polarization of antenna and in the meanwhile turntable returns to zero degree position. After that correction factors and limit line are incorporated with the measured data and the result is displayed on the graph. As the data is displayed on the graph, the program generates an image of the graph at a specified location.

4.3.2. Prominent features of the program

The program developed in VEE for radiated emission test with spectrum analyzer exhibits most of the features mentioned in CISPR standards. The settings of the spectrum analyzer outlined in CISPR standards for RE test have been successfully implemented in the program. The movement of turntable is controlled with the help of device controller EMCO 2090 through GPIB interface to capture emissions of EUT from four directions.

The program facilitates the operator to save emission data both in numerical as well as in graphical form. The provision of displaying the applicable limit line on the graph is also available. A very important and interesting characteristic of this program is that a bitmap image of the graph is generated and saved at a specified location automatically. The generation of image is helpful for comparison purposes especially when the measurements need to be repeated and analyzed for a specific EUT.

Another property of this program is its flexibility because it provides the operator a choice to enter the positions for turntable movement. The operator is asked to enter four turntable positions at the start of the test. The display of ambient noise of the chamber with EUT inoperative is also facilitated in the same graph so that a comparison between reference noise and actual emission spectrum of EUT can be done. To make the measurements easy the frequency range of 30 MHz – 1 GHz has been splitted into smaller sub-ranges so that amplitude inaccuracies can be minimized.

4.4. EMI test receiver ESPC

An EMI test receiver is a test instrument for emission measurements with reference to CISPR standards. It consists of most of the needed features to perform emission testing in contrast with a general purpose spectrum analyzer. In case of test receivers the user can set start/stop frequency, RBW, detector(s), dwell time and step size. Furthermore, preselectors and automatic attenuators are available in test receivers to run tests without operator intervention [45].

In comparison with spectrum analyzer, a test receiver provides many tens of thousands of measurement points to avoid the necessity of sub-ranging the span. Moreover, much improved accuracy level can be achieved by making measurements with test receivers. The common problem with a test receiver is that it is slower than a spectrum analyzer so measurements take longer time [45].

The RE testing program has also been implemented with EMI test receiver ESPC available in EMC lab of TUT. The frequency range of this instrument is 9 KHz – 2.5 GHz and it meets all the requirements of commercial EMI testing standards such as CISPR, EN, ETS, FCC and ANSI C63.4. Integrated preselector, automatic overload detection and power sourcing from internal battery are tremendous features of ESPC. Automatic setting of attenuation, selection of required RBW, detectors and measurement time are key features of this device [47].

ESPC provides two operating modes, low noise (for low noise measurements) and low distortion (for low distortion measurements). In low distortion mode the Intermediate Frequency (IF) gain of the receiver is set in such a way that the noise indication is always below the zero scale deflection. As a result IF gain becomes the function of selected detector and IF bandwidth. In case of low noise mode the IF gain is 10 dB lower than low distortion mode. That is why signal to noise ratio (SNR) within permissible meter range is 10 dB higher than the low distortion mode. The low distortion mode is useful for measurements where low level signals are present in the vicinity of strong interference signals. Due to this feature EMI measurements are performed in this mode of ESPC [47].

The accuracy of EMI test receiver is excellent since its typical error is 1 dB in the amplitude levels of emission data. The operator has an opportunity to enter and call transducer factors, enter limit lines specified by different testing standards, generate a test report, print/plot the test results on a printer/plotter. To control ESPC remotely a GPIB interface with all the necessary commands have also been described in the operating manual [47].

4.5. Agilent VEE program with EMI test receiver

In general Agilent VEE program for RE test developed for EMI test receiver is quite similar to that one developed for spectrum analyzer. Despite of some additional objects, minor changes in user objects and functions; the operation of the program as a whole is exactly the same. The scanning feature of the test receiver has been utilized to develop RE test program that facilitates maximum 200 points for a specific frequency span. The frequency range of 30 MHz – 1 GHz is splitted into sub-ranges because of the implementation of RE test with scanning feature of test receiver. The scanning feature and sub-ranging has made test completion time quite long because scanning itself is a very slow process.

ESPC sends data at its output buffers in many formats like scalar, Real64 array or binary block. The format used to fetch data from this instrument in RE program is Real64 array. In this format ESPC returns frequency and amplitude values with a zero at the start of each data set. The data acquired from test receiver is in the form of a set of points (zero, frequency, amplitude…zero, frequency, amplitude) that are stored in an array as shown below:

0, 30 MHz, 30.4… 0, 30.5 MHz, 29.3

The data received looks like data junks with each junk starting from zero. In order to store 200 data points in numerical form, an array of 604 size is required to be defined. This is the main problem with this instrument when its scanning feature is utilized for RE measurements. The scanning in test receivers is an alternate of sweep in spectrum analyzers. Unfortunately GPIB commands in ESPC's operating manual are available either for single point measurements or for scanning feature. Due to excess number of points data saved in numerical form gets very long. To segregate frequency and levels a MATLAB object is employed in this program so that data can be displayed on the graph. The MATLAB object intended to pick up frequency data from this array reads every second element of the array and sends the values to a graphical display. Similarly MATLAB object defined to collect level's data reads every third element of the array.The test results shown in figures 4.4 and 4.6 express radiated emission graphs acquired with ESPC.

4.6. Test equipment utilized for sample testing

The equipment list used for radiated emission testing of sample EUT is given below:

a. Spectrum analyzer (HP 8593A) and EMI test receiver (ESPC)
b. Preamplifier (Sonoma instrument 310)
c. Antennas (Bilog CBL 6111C, from 30 MHz to 1 GHz)
d. Turntable EuroPro 2088
e. Antenna mast (Utilized for a fixed position of antenna)
f. Device controller (EMCO 2090)
g. RF cables

4.7. Test setup and procedure

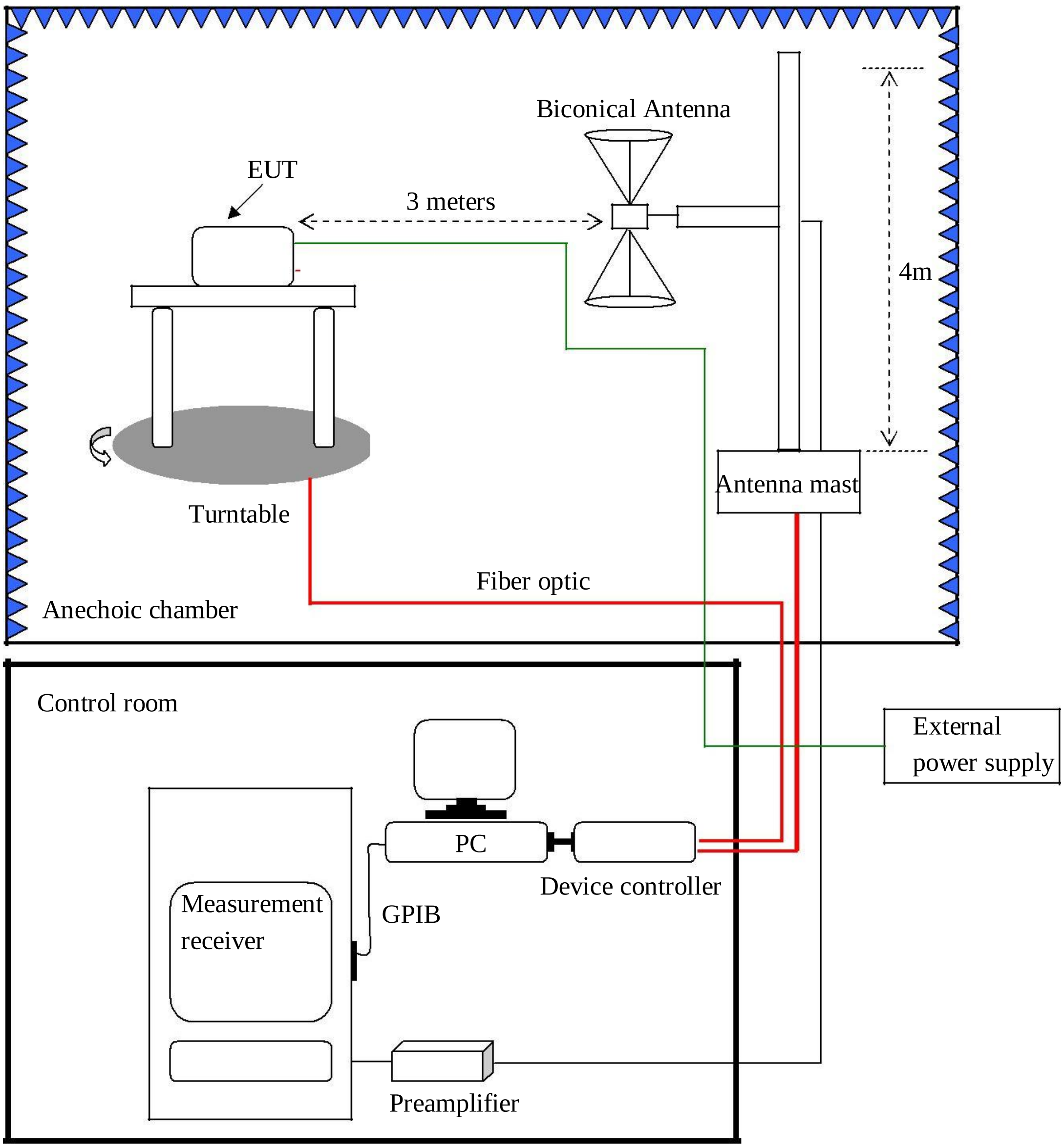


Figure 4.2 Radiated emission test setup [5]

A schematic diagram of test setup of RE test has been illustrated in figure 4.2. Ideally the antenna should be mounted on an antenna mast so that it can be moved to capture the emission spectrum of EUT at different elevations. CISPR 22 recommends that radiated emissions should be captured at various heights of antenna (from 100 cm to 400 cm). As the antenna mast lying in EMC lab's anechoic chamber does not provide automatic antenna height adjustment, radiated emission measurements are exercised only at a fixed height of the antenna. In test setup depicted in figure 4.2 a computer with all the accessories (CPU, monitor, keyboard and mouse) is used as EUT.

It is also important to mention here that the biconical antenna shown in figure 4.2 is replaced by a bilog antenna because it covers the entire frequency range of RE test 30 MHz-1 GHz alone. Therefore, there is no need to change the antennas to complete the test. All the auxiliary equipment and external (additional) power supplies needed to operate the EUT should be kept outside of the anechoic chamber during RE test.

Radiated emissions are measured according to the procedures summarized in CISPR 22. Test procedure with reference to test setup shown in Figure 4.2 is described below. The measurements are assumed to be performed in an anechoic chamber at a distance of 3 meters whereas measurement results for both polarizations of bilog antenna as well as pictures of test setups are shown in section 4.8.

a) CISPR 22 recommends an ambient measurement with the EUT inoperative before performing actual RE test. This ambient noise should be at least 6 dB below the applicable test limit. The EUT to be tested as table top equipment should be placed on a wooden table, 0.8 meter above the ground plane. The wooden table is in turn placed on a turn-table to measure radiated emissions at different angular positions. [4].

b) Generally radiated emissions are measured from all (four) sides of the EUT. The turntable is controlled by device controller EMCO 2090 with the help of fiber optic interface. Rotation is important so that the direction of maximum radiation can be determined for each frequency [4]. The turn-table is rotated from 0 to 270 degrees clockwise with a step size of 90 degrees to measure the emissions from all (four) sides. As mentioned in section 4.2, the user can set any angular position for the turntable, therefore above mentioned positions are not fixed.

c) Ideally the height of the antenna is varied from 120 cm to 360 cm with a step size of 120 cm to measure radiated emissions at different heights in the elevation plane. The purpose of varying the height is to determine the maximum radiation height of the EUT for each emission frequency [4]. Usually an antenna mast is used to accomplish this task. Due to unavailability of antenna movement mechanism it is not possible to vary the height of antenna during emission measurements of sample EUT. Therefore, emission data is captured at a fixed height of 115.5 cm. The height less than 120 cm was used in the tests due to availability of a suitable stand at the lab.

d) Measurements are performed with bilog antenna in both vertical and horizontal polarizations using peak detector with spectrum analyzer in “MAX HOLD” mode [4]. In this mode spectrum analyzer holds the maximum captured level at a specific height of tower and angular position of turntable. For example spectrum analyzer detects a peak of 25 dBμV/m at 50 MHz at 0 degree position of turntable. Then turntable moves to 90 degrees and if spectrum analyzer finds a signal level of 27 dBμV/m at the same frequency but at this new position, it will hold this level and discard the previous one.

e) Cables are arranged to produce maximum emissions. About 1m of interconnecting cables should be exposed to antenna during RE testing [4].

f) In practice the emission spectra captured with peak detector is compared with the applicable limit. If the emission levels are below the limit line then no need to perform quasi peak measurements. Only peak values will be reported graphically. If emissions at one or more frequencies touch or cross the limit line then quasi peak measurements should be performed. After quasi peak measurements if the situation stays the same then the EUT is declared as fail [4].

4.8. Test conditions

Certain measurement conditions described in CISPR 22 have been summarized below:

a) A test site should permit disturbances from the EUT to be distinguished from ambient noise. The suitability of the test site is determined by measuring ambient noise with the EUT inoperative. Ambient noise should be at least 6 dB below the test limit applicable to a specific EUT [4].

b) If at a certain frequency band the ambient noise is not 6 dB below the applicable limit then the compliance of EUT will be tested by calculating a new limit with a close distance measurement. The formula to calculate new limit line at a shorter distance is given in (2.1) and calculation method has been described in section 2.4.

c) If the emission spectra of EUT combined with ambient noise do not exceed the limit then the ambient noise is not required to be 6 dB below the applicable limit [4].

d) The EUT will be tested as table top equipment or floor standing equipment; it is decided in mutual discussion of the client and testing agency based on actual use of the EUT [4].

e) The type and length of the interconnecting cables should match with the individual equipment requirements. If the length can be varied then it must be chosen to produce maximum disturbances.

f) Extra length of cables should be bundled with 30 cm to 40 cm in length [4].

4.9. Test results

Radiated Emission testing has been performed on a sample EUT and test results in graphical form have been given on following pages. The distance between EUT and antenna is 3 m and measurements are conducted with both polarizations of the antenna. The correction factor is a single value at each frequency point and has been calculated as follows:

Correction Factors for Radiated Emission Testing.

Corr_Factor = [Antenna Factor +Cable loss] – Gain of Pre-amplifier

Numerical data: The format of the data saved in numerical form is a one dimensional array of Real 64. After the completion of a measurement, the program asks the operator to select the file name in which the numerical data can be saved. Alternative method to save this data automatically is to place a text constant object in the program in which the complete path of the file is written. The ambient data; that is actually amplitude levels, is saved in numerical form in a file after ambient measurements. When a measurement is completed this data is automatically displayed on the graph with the help of a text constant object that consists of path of that file. Similarly correction factor and limit line data saved in corresponding files are incorporated automatically when RE test is completed.

Graphical data: The test results presented in following figures are plotted after incorporating the correction factors data in measured emission data. A reference measurement is performed to display ambient noise of the chamber on the graphs prior to actual radiated emission measurements. The emission spectrum in magenta color belongs to ambient noise whereas the emission spectrum in yellow color is the radiation data of EUT. The EUT is a computer (see figure 4.9) and it has been tested with two instruments as measurement receivers. First the emission spectrum of the EUT is captured with spectrum analyzer in both polarizations of bilog antenna. Then the same process is repeated with EMI test receiver.

The results with both measurement receivers have been shown in separate graphs. Figures 4.3 and 4.5 show the radiated emissions captured with spectrum analyzer whereas figure 4.4 and 4.6 represent radiated emissions taken with EMI test receiver. Figures 4.7 and 4.8 show bilog antenna utilized for RE measurements in horizontal and vertical polarizations respectively. Figure 4.9 denotes the sample EUT on which RE test has been performed. Measurement instruments (Spectrum analyzer and EMI test receiver) employed for sample RE test are given in figures 4.10 and 4.11 respectively. A limit line of class B ITE given in CISPR 22 is also added to these graphs for analysis and comparison purposes.

The interesting thing with these test results is that radiated disturbances generated by this specific EUT are crossing the limit line at certain frequencies. However, the objective of these measurements is to give the reader an idea of performing an RE test rather than investigating the reason of emissions going beyond the limit. Another thing to be noted is the difference between amplitude variations of noise floor of both measurement receivers. Spectrum analyzer's noise floor presents higher variations in the amplitude of noise floor than test receiver's noise floor.

The reason is the difference between reference level settings of both instruments. Spectrum analyzer's reference level can be remotely adjusted because GPIB commands are available in its operating manual for this purpose. However, test receiver's operating manual does not provide any GPIB command to change the reference level. Therefore, ESPC uses factory set (default) settings of reference level due to which amplitude variations in noise floor are different than spectrum analyzer. The soft setting of reference level according to requirements is the advantage of HP 8593A over ESPC.

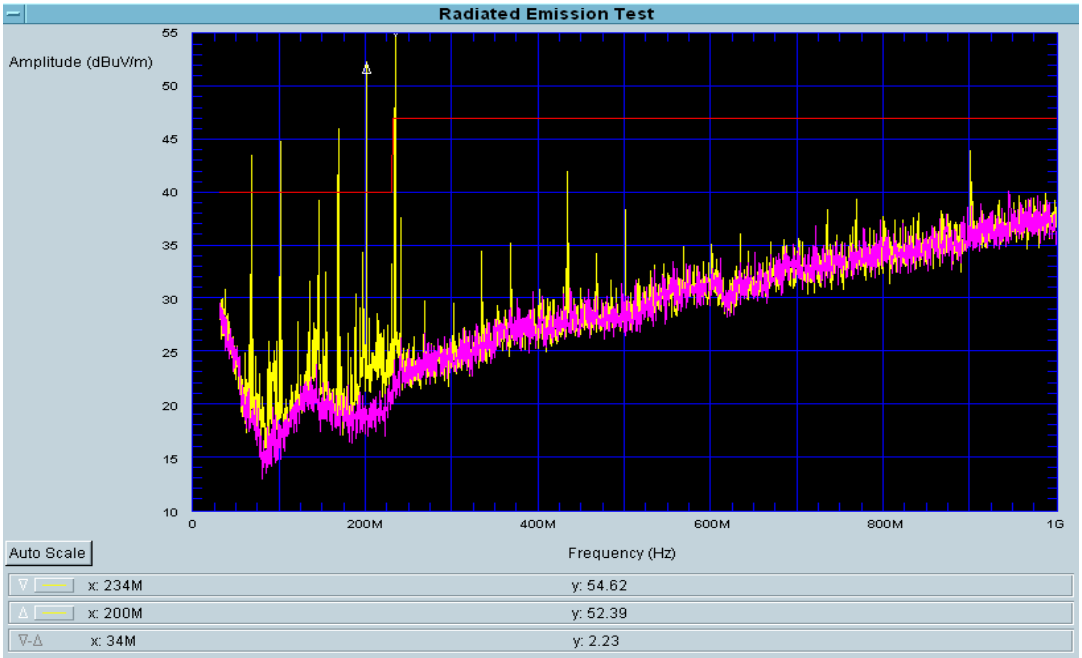


Figure 4.3 Radiated emissions in horizontal polarization – Spectrum analyzer

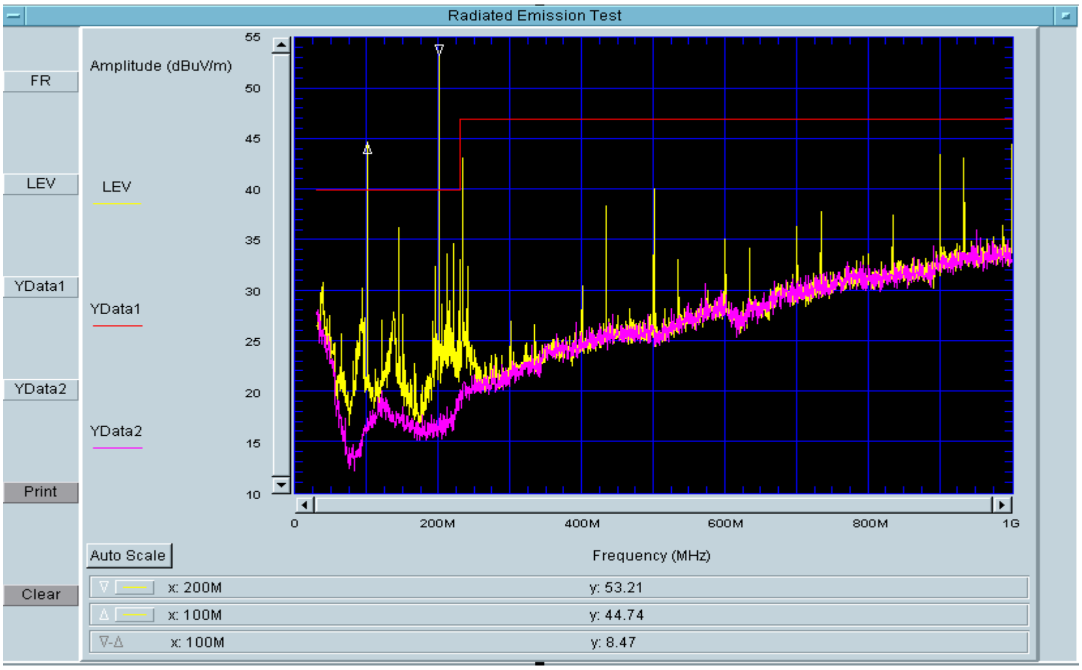


Figure 4.4 Radiated emissions in horizontal polarization – EMI test receiver

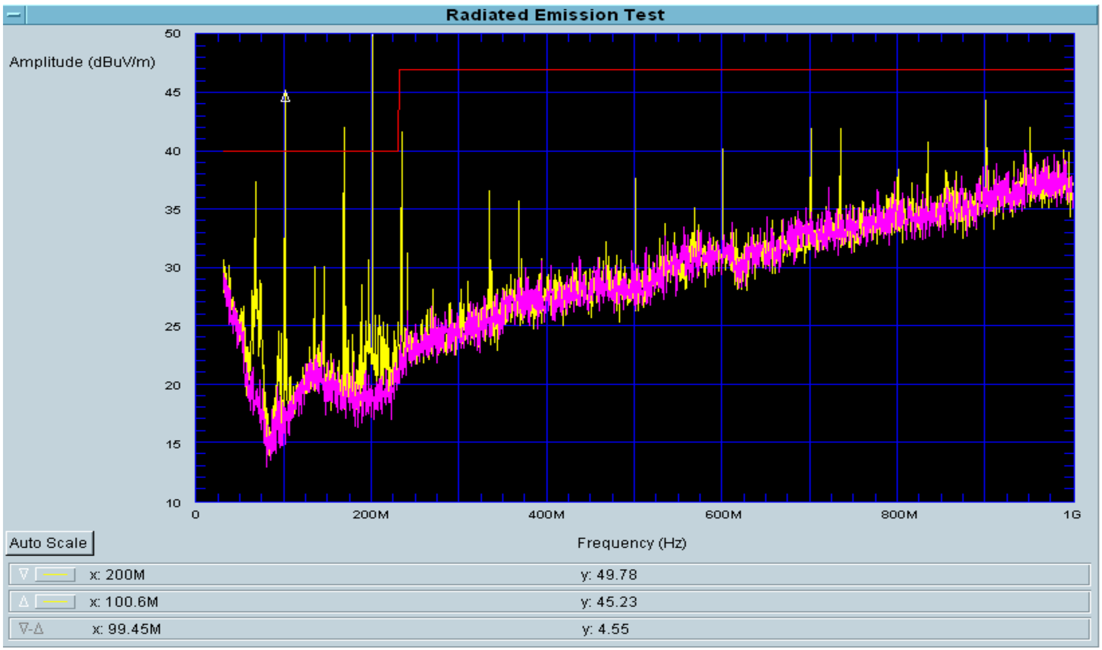


Figure 4.5 Radiated emissions in vertical polarization – Spectrum Analyzer

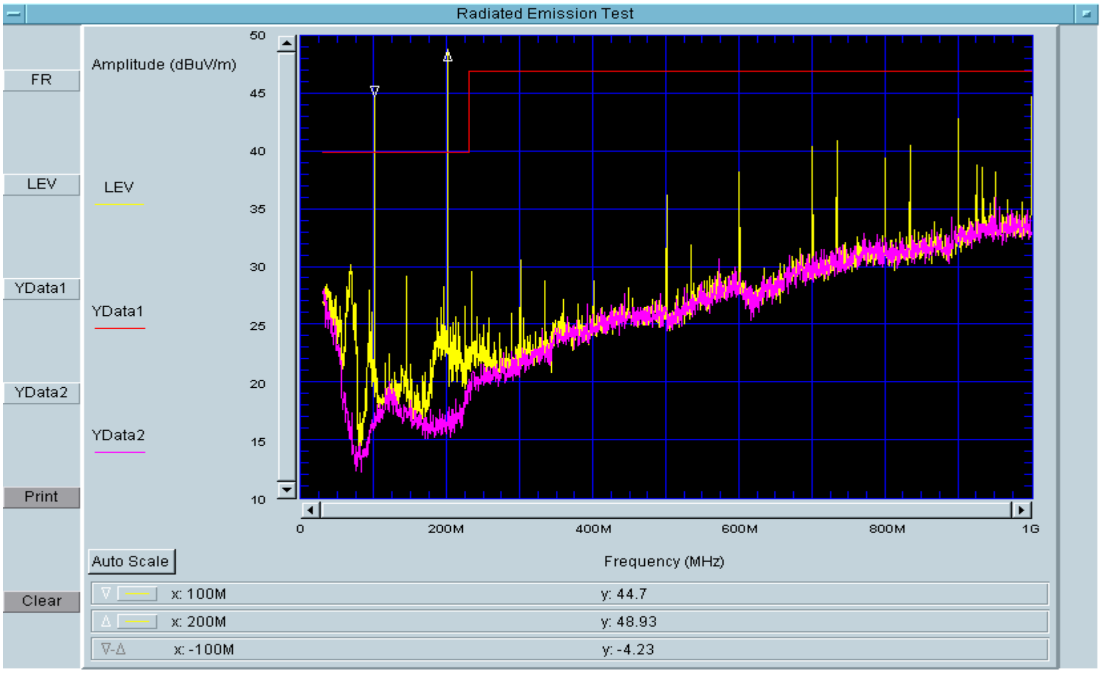


Figure 4.6 Radiated emissions in vertical polarization – EMI test receiver

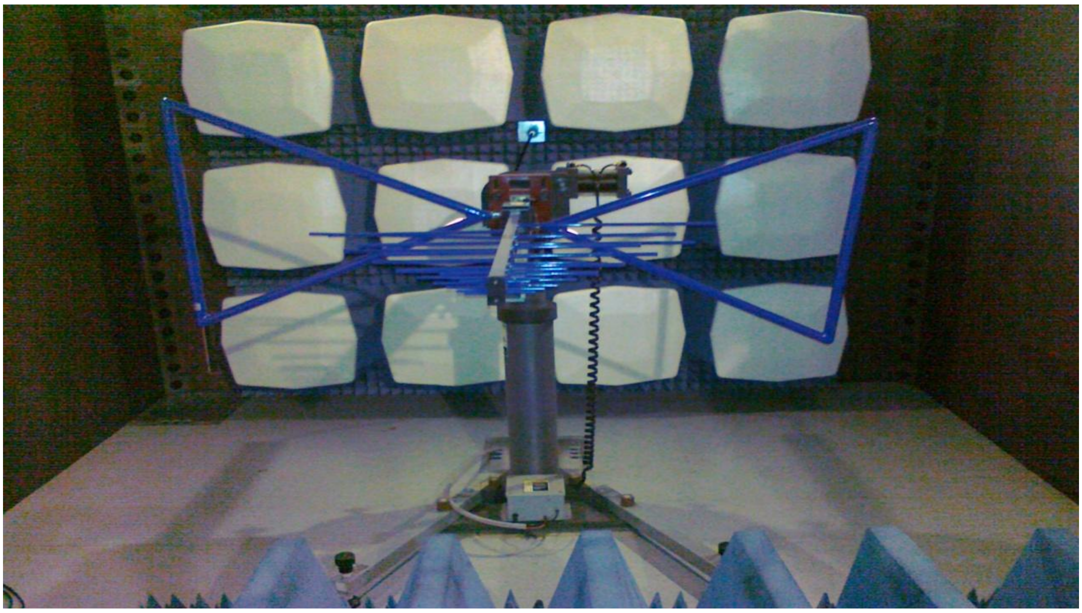


Figure 4.7 Test antenna (bilog CBL 6111C) in horizontal polarization

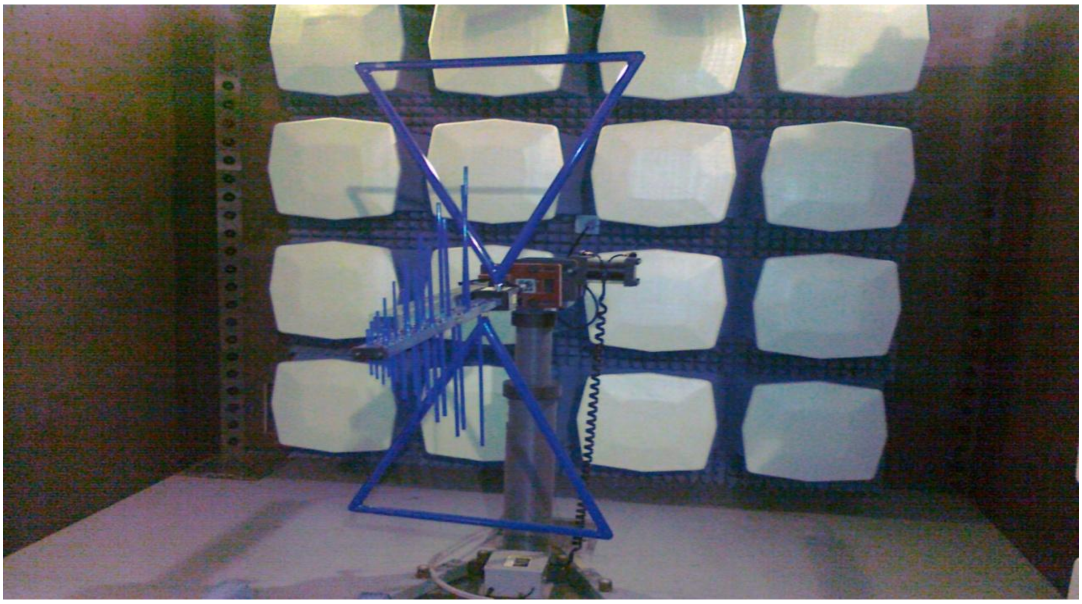


Figure 4.8 Test antenna (bilog CBL 6111C) in vertical polarization

Figure 4.9 Equipment under test (computer) for radiated emission test

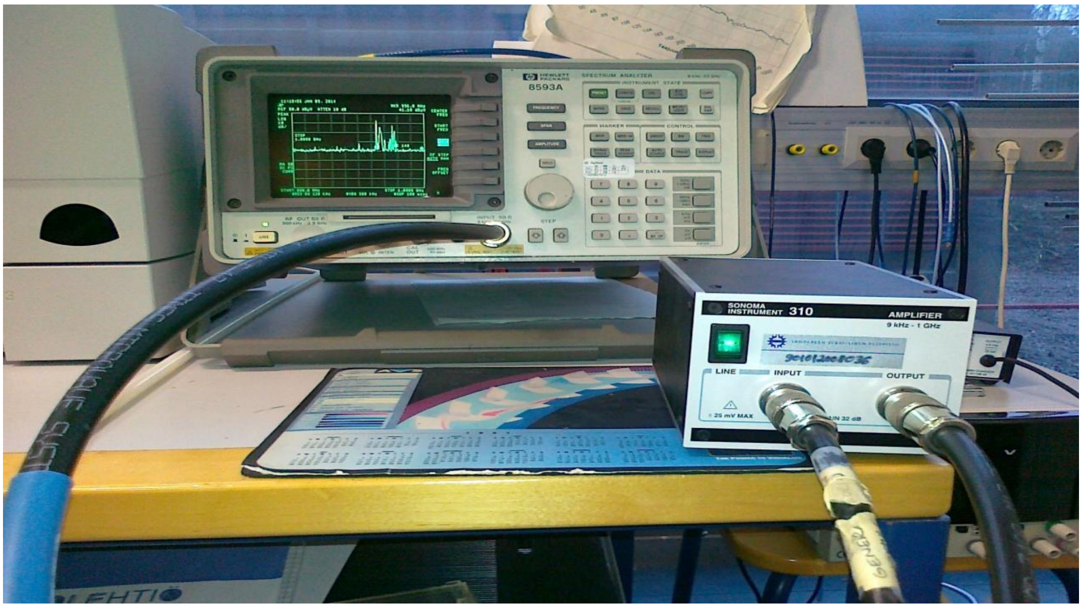


Figure 4.10 Spectrum analyzer as measurement receiver and preamplifier

Figure 4.11 EMI test receiver as measurement receiver and preamplifier

5. DEVELOPMENT OF RADIATED IMMUNITY TEST SETUP

The development of radiated immunity test consists of test equipment required to conduct the test, test setup, procedure and test sites where this test is actually performed. The arrangement of EUT, reference conditions which refer to climatic and electromagnetic conditions and test sites where the test is recommended to be executed all are given in related test standards for certain EUTs. For instance, in case of ITE the arrangement of EUTs, laboratory reference conditions, test equipment, setup and procedure are described in detail in IEC 61000-4-3.

The reference test site for RI test is OATS but it is difficult to achieve required reference conditions in OATS due to noise generated by mobile and other wireless communications. That is why RI test is usually performed in semi-anechoic and reverberation chambers. Mostly semi-anechoic chambers are used to execute RI tests because these chambers provide controlled climatic and electromagnetic conditions [6]. The required test equipment has already been explained in section 2.6. Therefore, test setup, procedure and test programs developed to conduct RI test will be discussed in chapter 5.

RI test is conducted in two phases. In first phase calibration of the electric field is performed and in second phase actual test is run. Therefore, two independent test programs have been developed for this particular test.

5.1. Test setup

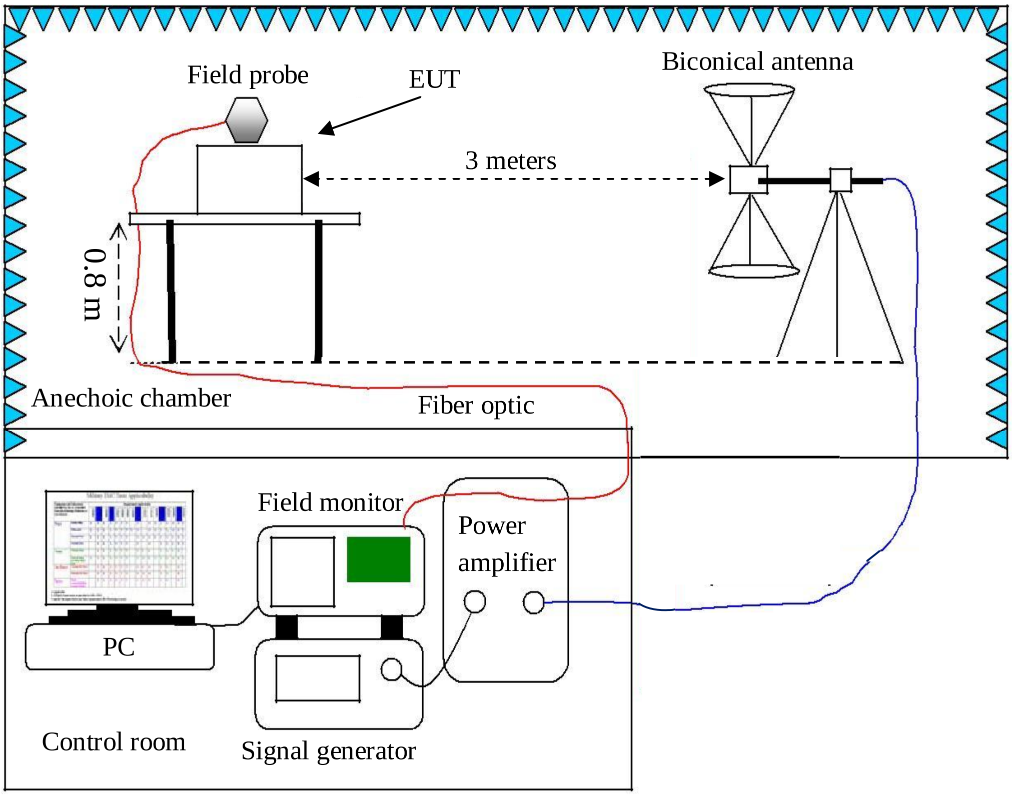


Figure 5.1 General test setup of radiated immunity test [5]

Figure 5.1 demonstrates the general test setup for RI test. During calibration EUT is picked out from the chamber whereas in actual test run field probe is not placed along with the EUT. However, in certain conditions both exist together especially when field monitoring is also required during the execution of test. Generally, the field generating antenna is mounted on a tripod stand at 3 meters distance whereas the EUT is placed on a wooden table that is 0.8 meters high above the ground plane. The sides of EUT are changed with the help of a turntable and device controller to apply electric field from various azimuths. If the EUT is put on a turntable then changing its orientations can be accomplished automatically. This is to apply electric field to all sides of EUT as mentioned in IEC 61000-4-3. The signal generator, power amplifier and field monitoring system lie in control room as shown in figure 5.1. A field monitor can be an independent unit or an integral part of a computer as software.

5.2. Test procedure of RI test

Test procedure of RI test is divided into two parts. In first part the calibration of electric field is performed over the entire frequency range of the test and in second part the actual test is run. Calibration is carried out in continuous wave (CW) mode whereas 80 % amplitude modulated (AM) wave having 1 kHz frequency is added to the carrier when actual test is run. During calibration process signal generator levels required to achieve the desired electric field strengths over the whole frequency range are saved in a file. Usually the calibration is performed at a test level of 1.8 times the desired field strength. The purpose of running the calibration at 1.8 times the original test level is to verify that the power amplifier is capable of reaching the required field when 1 kHz sine wave of 80 % AM will be added to the carrier [23].

5.2.1. Calibration of the field

The calibration process has been briefly described in immunity test standard IEC 61000-4-3. The main objective of the field calibration is to make sure the validity of test results and uniformity of field over the test sample. The concept of uniform field area (UFA) is utilized in IEC 61000-4-3 for field calibration that is a hypothetical vertical plane of field with acceptable field variations [21]. This field calibration is considered to be valid for all EUTs whose faces could be fully covered by UFA. The calibration is carried out without EUT and is valid as long as the test setup remains the same. Therefore, placement of field generating antennas, additional absorbers on the floor, location of field probe, cables and test distance needs to be carefully documented. The reason is that even small displacements may result large variations in field strength [21].

For the calibration of the field, isotropic electric field probe is placed on a wooden table 0.8 m high above the ground plane as shown in figure 5.1. The field generating antenna is positioned 3 m away from the probe so that antenna's beam could cover the UFA. The size of the UFA ranges from 0.5 m * 0.5 m to 1.5 m * 1.5 m but normally 1.5 m * 1.5 m size is used for 16 point calibration so that interfacing cables of EUT could also be illuminated. However, if the size of the EUT is small then smaller UFA can also be implemented [21].

Additional absorbers are recommended to be put on the floor in order to avoid reflections from ground plane. The UFA is subdivided into smaller grids that have a spacing of 0.5 m from each other. The field is said to be uniform at each frequency if its magnitude at the grid points is within $^{+6}_{-0}$dB of reference field value for at least 75 % of grid points (12 out of 16). This 6 dB tolerance is considered to be acceptable up to 1 GHz in practical test facilities. The method of calibration is described below [21].

a. First of all position the electric field probe at one of 16 grid points and set the signal generator's frequency to 80 MHz.
b. Next adjust the forward power applied to field generating antenna so that the field strength read by field sensor reaches to the required strength E_c, where E_c is the power of carrier. Record the forward power of the signal generator.
c. After that increase the frequency by a maximum of 1 % of previous frequency and repeat step b.
d. Repeat steps b and c until the upper frequency limit (1 GHz) of the test is reached.

e. Then steps from b to c are repeated for all the remaining grid points and the levels of signal generator are documented. At each frequency sort the 16 forward power levels into ascending order.
f. Select the highest value and check if at least the 11 values below it are within the specified tolerance (-6 dB to +0 dB).
g. In case 11 readings are not within this tolerance then go back, pick the next lower value and repeat step f.
h. The procedure is stopped if at least 12 readings are found within this tolerance and the levels of forward power are saved.
i. This entire procedure is exercised at both horizontal and vertical polarizations of antennas [21].

Figure 5.2 illustrates 16 point calibration method with UFA dimensions.

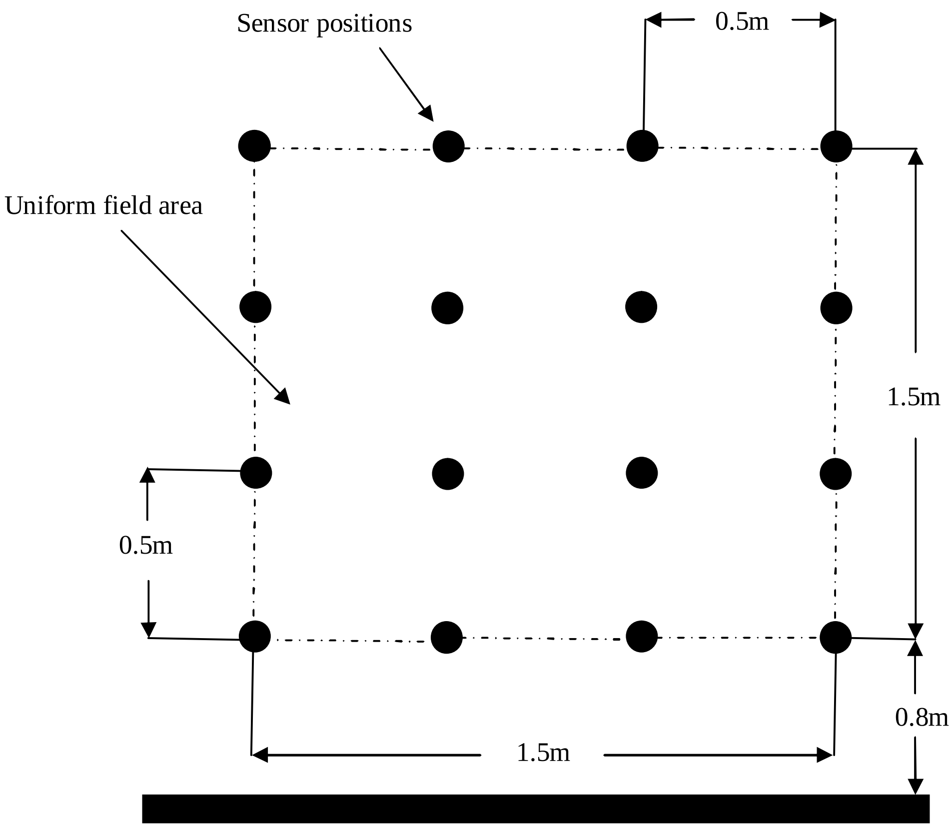


Figure 5.2 Illustration of the uniform field area (UFA)

5.2.2. Execution of the test

The test is performed by applying the signal generator levels saved during calibration but with amplitude modulated wave of 1 kHz with 80 % modulation depth. The dwell time of the carrier of AM signal should not be less than the response time of EUT, however in any case dwell time should be at least 0.5s. The field generating antennas should face each side (four azimuths) of the EUT during the execution of RI test. The test is applied for both polarizations of the antennas and the performance of EUT is carefully monitored. Any functional degradation needs to be documented in test report [21].

5.3. Agilent VEE programs for radiated immunity test

The automatic execution of RI test is accomplished by two independent Agilent programs. The programs for calibration process and to run actual test both include all the features and specifications documented in IEC 61000-4-3. The detailed description is presented in following sections.

5.3.1. VEE program for radiated immunity calibration

Working principle and prominent features of calibration program developed for RI test are given below:

Operation of the calibration program: Figure 5.3 denotes the flow chart to understand the working principle of the RI calibration program. The working of the program is very simple. Start and stop frequencies of the test, maximum and minimum power levels of signal generator, acceptable tolerance to achieve the required electric field and step size of frequency increment, all have been implemented in the panel view. The operator can change these parameters depending upon the requirements. The program sends a command to the signal generator SMR 20 to transmit the minimum level set in panel view at the start frequency (80 MHz) of the test. Signal generator feeds that level to the power amplifier and power amplifier applies it to a field generating antenna. As a result the signal is radiated into the air as electromagnetic field.

This electromagnetic field is sensed by field probe that converts it into optical signal and sends to the modem. The modem converts that signal back to electrical form and forwards it on the Universal Serial Bus (USB) port of the computer. After a little processing the signal is displayed in Agilent VEE in numerical form that is actually electric field with a unit of V/m. The program compares this electric field value with a reference. If the value is less than reference then program increases signal generator's level by a defined step size and the comparison process is done again. The program continues to compare the electric field value with the reference and keeps on increasing the signal generator's level until the electric field read by field probe reaches the reference field value.

The present settings of required parameters available in RI program's panel view cannot be considered as default settings. These settings have been used to check the operation of the program. It can be assumed as a demonstration of RI test because due to the absence of power amplifier, real RI testing is not possible since required electric field cannot be generated. Therefore, all the parameter settings described on following pages are just examples; however operator can change these settings later on according to requirements.

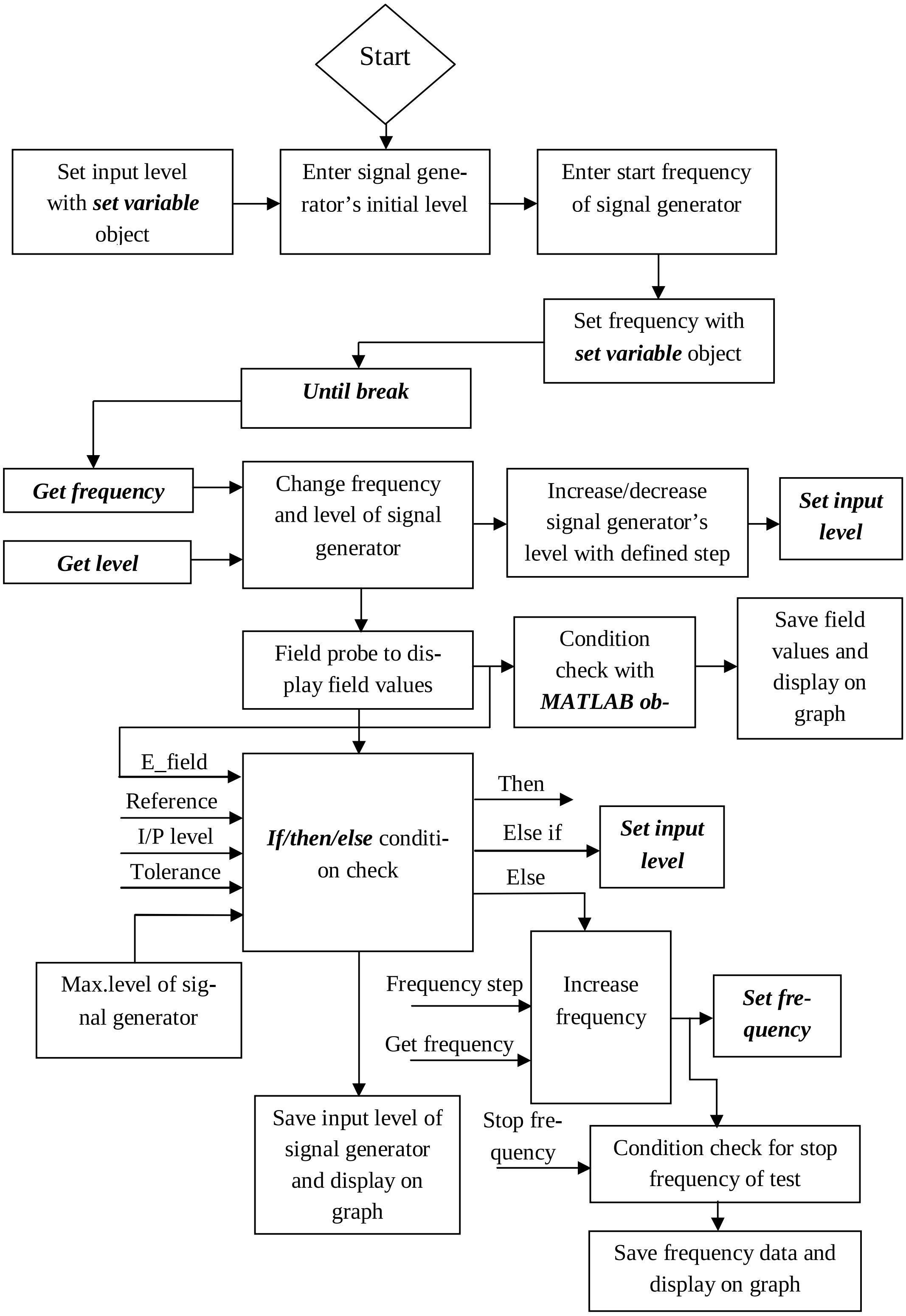


Figure 5.3 Flow chart of program for RI calibration

As acquiring the electric field value exactly equal to reference is not possible so normally a tolerance is set to obtain the electric field values closer to reference. In this case ±0.5 dB is set as tolerance but it can be changed in panel view. If for example, the calibration for a reference field of 3 V/m is being performed, the program will save electric field values between 2.5 V/m and 3.5 V/m with ±0.5 dB tolerance. When the required electric field value is attained the program saves the corresponding signal generator's level and increases the frequency of the signal generator by a specified step. Presently defined step size for the frequency is 1 % of the previous frequency but the operator can change it from the panel view. The whole data of calibration including signal generator levels, frequency points and electric field values are saved in associated data files and displayed on graphs for analysis purposes.

5.3.2. C++ code to access DLL file

To read the electric field values from the probe, via the USB, the DLL provided by the probe manufacturer is used. However, it could not be invoked directly from VEE program (because of reference parameters which are not fully supported in VEE). In order to circumvent this problem, a custom DLL file is created in C++, which exposed simple functions to connect to the probe, obtain electric field values, fetch battery level information of the probe, and disconnect from the probe. The functions exposed by the custom DLL, provide desired information through return values and these are invoked from VEE program. This custom DLL in turn calls the functionality provided by original probe DLL (ets_probe.dll) to complete the actual task.

5.3.3. VEE program to run radiated immunity test

This small program developed separately is intended to apply the calibrated levels on the EUT. The necessary requirements mentioned in IEC 61000-4-3 have been implemented in the program successfully.

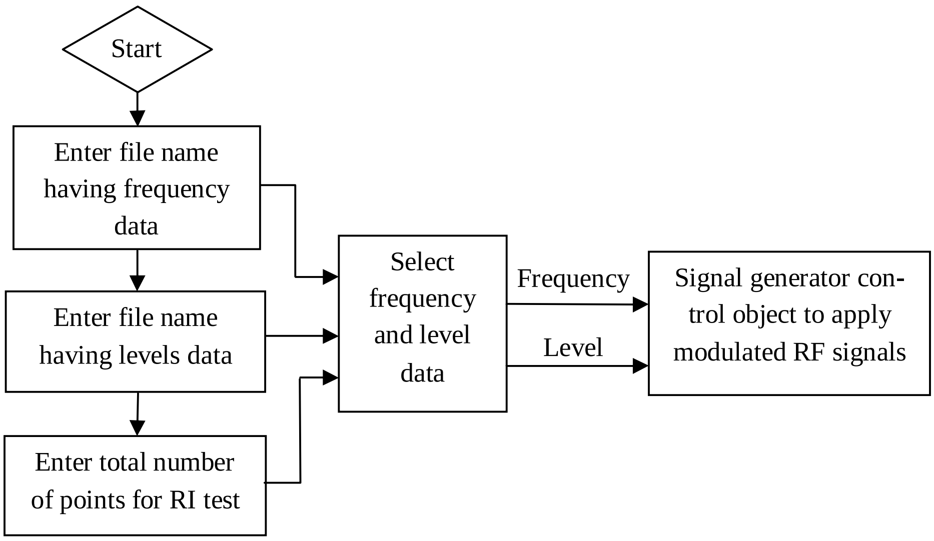


Figure 5.4 flow chart of program for RI test run

Figure 5.4 demonstrates the flow diagram of the program to run RI test. The working principle of this program can be understood with the help of figure 5.4. The files containing signal generator levels and their corresponding frequency points are loaded into the program and executed after implementing amplitude modulation with 1 kHz sine wave having 80 % modulation index. In order to execute the actual RI test the operator must enter the total number of frequency points/levels equal to the upper limit of the "for range" object. In case these points do not match, the test cannot be run.

The dwell time should be set very carefully so that the response of the EUT could be monitored properly. Dwell time at each frequency point should match with the response time of the EUT. To load the signal generator levels and frequency points into the program, two methods can be adopted. One option is to select it manually from the computer where it is saved during calibration. The other choice is to enter the complete path of the file in text constant object. The latter choice is more convenient because it loads the data automatically into the program. That is why it has been implemented to facilitate the operator.

6. SUMMARY AND CONCLUSION

A deep study, analysis and recommendations have been suggested by this thesis work regarding the anechoic chamber and test equipment for RE and RI tests. In addition, testing programs to execute these tests meet most of the requirements mentioned in CISPR and IEC 61000-4-3 standards. However, some suggestions have been provided in conclusion to improve the effectiveness of both programs. A summary of the thesis along with a brief conclusion is portrayed in following sections.

6.1. Summary

The work done in this thesis was divided and completed in smaller parts due to various tasks. Literature study and development of radiated emission program was accomplished in first phase. Then two commercial EMC laboratories were visited as a preparation to find suitable test equipment and develop the radiated immunity testing program in Agilent VEE. Those visits were very useful to find and select the best suited test equipment for RI test. After that study of available anechoic chamber was completed that helped to know the feasibility of said chamber for RI test.

Based on the information gained through theoretical study and practical visits, the list of equipment that fulfilled the requirements of RI test was finalized. Antennas and signal generator to perform RI test were already available in EMC lab but electric field probe, electric field monitoring system and power amplifier were needed to be purchased. The recommended power amplifier could not be procured due to lack of funds for this thesis.

Next step was to develop RI testing program in Agilent VEE and to accomplish this task a dynamic link library (DLL) file was obtained from the manufacturer of the probe so that electric field could be displayed in VEE.

6.2. Conclusion

A number of challenges have been faced to achieve the required goals. The programs developed for RE and RI testing are quite professional, precise and easy to operate. Especially testing program for RI test consists of all the required fields in the panel view that need operator intervention prior to perform calibration and run actual test. RI program includes the features offered by professional EMI/EMC testing software available in market. An interesting and useful property of these programs is displaying the data in graphical form.

The numerical data, after implementing the correction factors as well as the limit line, both are displayed on the graph without operator intervention. In RI testing program two graphs have been implemented in the panel view. This is to display the calibration data as “electric field vs frequency” and “electric field vs. levels” for information and analysis purposes. If the recommended power amplifier can be purchased an electric field of 10 V/m can be generated for immunity testing in TUT’s EMC lab.

Despite of many useful features there are also some problems associated with these programs. For example the numerical data acquired for RE test contains 2005 points (due to sub-ranging) that is too long to handle for analysis purposes. The frequency range of RE test (30 MHz-1 GHz) has been divided into five sub-ranges. The first sub-range is from 30 - 200 MHz, the second sub-range is from 200 - 400 MHz, third sub-range is from 400 - 600 MHz and so on. In each sub-range spectrum analyzer saves 401 points and with five sub-ranges total number of data points become 2005 (401*5=2005). Similarly EMI test receiver’s program has 1940 data points. In RI program to run actual test, the soft control of dwell time of signal generator SMR 20 could not be implemented because corresponding GPIB commands are not available in equipment manual.

For further improvements a number of suggestions could be recommended for both programs. As an example in RE program total number of turntable positions is fixed at four. It can be made flexible so that if the radiations from a specific side of a EUT are required to be measured, the operator does not need to wait for the turntable to complete scan at all positions. Moreover, replacing the old test equipment, spectrum analyzer (HP 8593A) and EMI test receiver (ESPC) with latest models would reduce some limitations of RE programs. The soft control of dwell time of the signal generator SMR 20 in Agilent VEE for RI program will be useful because it will provide the operator a facility to run the test in accordance with the response time of different EUTs.

REFERENCES

[1] Bernhard Keiser. 1979. Principles of Electromagnetic Compatibility 4th edition, The University of Wisconsin - Madison, Artech house. 327p.

[2] http://en.wikipedia.org/wiki/Electromagnetic_compatibility, Electromagnetic compatibility (07.02.2014).

[3] http://www.ece.msstate.edu/~donohoe/ece3323emc.pdf, Electromagnetic compatibility, (03.02.2014).

[4] CISPR22. 2005-06. Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement.

[5] Muhammad Asif Khalil. EMI/EMC testing problem diagnosis and solutions. 2009. F8 markaz Islamabad, Pakistan, COMWAVE Institute of Science and Information Technology. Sarhad University of Science and Information Technology, Bachelor degree project. pp. 107.

[6] International Electrotechnical Commission standard, IEC 61000-4-3:2006, Electromagnetic Compatibility (EMC) Part 4-3: Testing and measurement techniques-radiated, radio-frequency, electromagnetic field immunity test.

[7] Mikko Keskilammi. Säteilevien emissioden EM-mittausjärjestelmä. Master’s thesis. Tampere 1999. Tampere University of Technology, Faculty of Computing and Electrical Engineering, Electronics department, 73p.

[8] Michel Mardiguian. 1988. Electromagnetic Control in Components and Devices. Vol.5, Interference control technologies. 492p.

[9] IEC. 1999. Electromagnetic compatibility – The role and contribution of IEC standards. Geneva, Switzerland, IEC.

[10] http://www.elliottlabs.com/services_emc_immunity.htm, EMC-immunity testing, (03.02.2014).

[11] CENELEC Electromagnetic compatibility testing standards (02.02.2014), http://www.cenelec.eu/dyn/www/f?p=104:110:4004963590300874::::FSP_PROJECT:20576.

[12] Ramesh, A. A.; Mahesh, G.; Das, S.K., Importance of receiver dwell time in emission measurements, Proceedings of the International Conference on Electromagnetic Interference and Compatibility '99. vol., no., pp.237-240, 6-8 Dec. 1999.

[13] http://www.electron.frba.utn.edu.ar/~jcecconi/Bibliografia/10%20-%20Mediciones%20de%20EMC/EMCTestingPart1.pdf, EMC testing, (04.02.2014).

[14] http://www.elmac.co.uk/pdfs/wtlf-ant.pdf, what to look for in an EMC antenna, (01.02.2014).

[15] EMCO, Equipment manual of Bilog antenna, EMCO, model CBL-6111C, 30 MHz-1 GHz.

[16] Edwin L. Bronaugh, Instrumentation and associated uncertainty for measuring EM1disturbances above 1 GHz, EMC. 2001 IEEE International Symposium on Electromagnetic Compatibility 2001, 2, 980-984 vol.2.

[17] http://www.sonoma-instrument.com/pdf/310ds.pdf, Specifications of preamplifier, (28.02.2014).

[18] A handy guide on RF immunity testing, (04.02.2014), http://www.adlerinstrumentos.es/imagenes_web/productos/04_RF_immunity_testing_e_3.pdf

[19] http://www.elmac.co.uk/pdfs/wtlf-amp.pdf, Application note: what to look for in an EMC amplifier, (30.01.2014).

[20] CISPR 16-2. Specifications for radio disturbances and immunity measuring apparatus and methods, Part 2: Methods for measurement of disturbances and immunity, IEC International Electrotechnical Commission, 1996.

[21] Vignesh Rajamani, Charles F. Bunting. On Radiated Susceptibility Testing of Highly Directive Devices. IEEE International Symposium on Electromagnetic Compatibility, 2010. Fort Lauderdale, FL, 25-30 Jul. 2010. pp. 153-158.

[22] http://www.ewerksinc.com/refdocs/EMC%20Antenna%20Fundamentals.pdf, EMC antenna fundamentals, (30.01.2014).

[23] http://www.tc-ieee-emc.org/documents/IEC4-3updateIEEE8-07-07.pdf, Amplifier

research: how to select correct EMC amplifier, (01.02.2014).

[24] http://www.arww-rfmicro.com/pdfs/appNotes/AppNote44-RF_Field_Probe_Selection.pdf, Application note: Field probe selection, (01.02.2014).

[25] http://www.arww-rfmicro.com/pdfs/appNotes/AppNote56.pdf, Application note: proper use of RF field probes, (01.02.2014).

[26] Rohde & Schwarz, Equipment manual of Signal generator, Rohd & Schwarz, Germany model SMR 20, 10 MHz-20 GHz.

[27] Specifications of RF power amplifiers, 20 MHz-1000 MHz, (25.02.2014). http://www.frankoniagroup.com/cms/fileadmin/user_upload/documents/Catalogues/Amplifiers/20MHz_1000MHz.pdf

[28] Electronic Testing system (ETS-Lindgren), ETS EMC test systems, Operating manual of electric field probe, model HI 6005.

[29] http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=57E52A987A68502F4E4F4F3DEF118F84?doi=10.1.1.32.5953&rep=rep1&type=pdf, Anechoic chamber (04.02.2014).

[30] http://en.wikipedia.org/wiki/Anechoic_chamber, Anechoic chamber, (11.12.2013).

[31] http://en.wikipedia.org/wiki/Electromagnetic_reverberation_chamber, Reverberation chambers (09.02.2014).

[32] http://www.elnamagnetics.com/wp-content/uploads/library/Fair-Rite-Documents/Ferrite_Tile_Absorbers_for_EMC_Test_Chamber_Applications.pdf, Ferrite tile absorbers for EMC chambers, (06.02.2014).

[33] Sung-Soo Kim, Dae-Hee Han. Microwave Absorbing Properties of Sintered Ni - Zn Ferrite. IEEE Transactions on magnetic, Vol. 30, No. 6, November 1994

[34] http://www.djmelectronics.com/rf-absorber.html, RF absorber types, (09.02.2014).

[35] Kefeng Liu, Analysis of the Effect of Ferrite Tile Gap on EMC Chamber Having Ferrite Absorber Walls, IEEE 1996 International Symposium on Electromagnetic Compatibility, 1996, Santa Clara, CA, 19 – 23 Aug 1996, pp. 156 -161.

[36] Christopher L. Holloway, Paul McKenna, Robert T. Johank, The Effects of Gaps in Ferrite Tiles on Both Absorber and Chamber Performance, IEEE International Sympo-

sium on Electromagnetic Compatibility, 1999, Seattle WA, 02 – 06 Aug 1999, Vol. 1, pp. 239 – 244.

[37] http://www.ets-lindgren.com/pdf/FS-400.pdf, Construction and specifications of microwave absorbers, model FS-400. (04.02.2014)

[38] Electronic Testing system (ETS-Lindgren), ETS EMC test systems, Operating manual of anechoic chamber, model Euroshield 98269.

[39] http://www.radioing.com/eengineer/glossary.html, eEngineer- glossary, Acronyms (29.12.2013).

[40] Brian J. Chromarty, Dr. Robert Paknys. Shielding Effectiveness Diagnostics using a Network Analyzer. IEEE International Symposium on Electromagnetic Compatibility, 2001. Montreal, Que, 13-17 Aug. 2001. pp. 719-722. Vol. 2.

[41] http://www.emcs.org/acstrial/newsletters/winter09/pp2.pdf, Vasquez, Horacio, Laura Espinoza, Karen Lozano, Heinrich Foltz, and Shuying Yang. "Simple device for electromagnetic interference shielding effectiveness measurement." EMC IEEE EMC Society Newsletter 220 (2009): 62-68. (04.02.2014).

[42] Hamming, L. 2002, Electromagnetic Anechoic Chambers: A Fundamental Design and Specification Guide, First edition, Wiley-IEE press, pp. 137-158.

[43] TDN Williams, A New Ferrite Grid Absorber for Screened Rooms, IEEE Colloquium on Radiated Emission Test Facilities, London, 02 Jun 1992, pp. 5/1 – 5/5.

[44] Robert Helsel. 1997. Visual Programming with HP VEE. Second Edition, Upper Saddle River, New Jersey, Prentice Hall PTR press. 300p.

[45] http://www.ieee.li/pdf/essay/receiver_v_sa.pdf, Application note: Test receiver vs Spectrum analzyer, (04.02.2014)

[46] http://www.sonoma.edu/esee/manuals/08590-90301.pdf, Equipment manual of HP 8590 series of spectrum analyzers, (02.02.2014).

[47] Rohde & Schwarz, Equipment operating manual EMI test receiver, Rohd & Schwarz, Germany model ESPC, 150 (9) kHz-1000 (2500) MHz.

Appendix A: Tentative schedule and work plan for thesis

The completion plan of the thesis was divided into small phases and is given in appendix A. Those phases were helpful to accomplish the assigned tasks and acquire desired results. Study of literature, testing standards CISPR 22, operating and programming manuals of spectrum analyzer (HP 8593A), EMI test receiver (ESPC), device controller (EMCO 2090), turntable (EuroPro 2088), bilog antenna (CBL 6111C), signal generator (SMR 20), learning the Agilent VEE software and the development of radiated emission testing program was done in first phase. Second phase consisted of visits of professional EMC labs (in Rauma and Espoo) to collect information about anechoic chambers, test equipment, testing software and procedures being used in those labs. The study of radiated immunity (RI) test standard IEC 61000-4-3, specifications of test equipment required for RI test, searching the suitable test equipment, fetching quotations from different manufacturers, recommending the test equipment with best specifications and testing of purchased equipment was completed in third phase. Next step was to study and analyze feasibility of the anechoic chamber of TUT's EMC for RI test. In this phase (phase 4) specifications and properties of microwave chamber, RF absorbers and ferrite tiles installed inside the chamber were thoroughly studied. The last phase (phase 5) contained the development of radiated immunity test program with all the required features specified in IEC 61000-4-3. The flow chart diagram in figure below depicts the stage wise completion of the thesis.

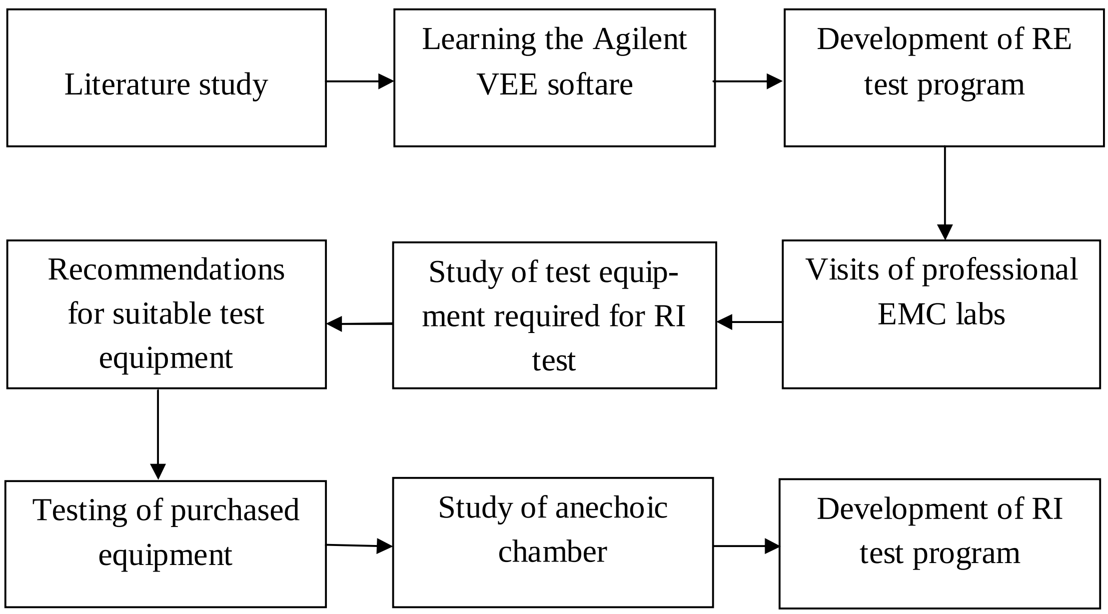


Figure A1 Thesis schedule and work plan

Appendix B: Description of Agilent VEE objects

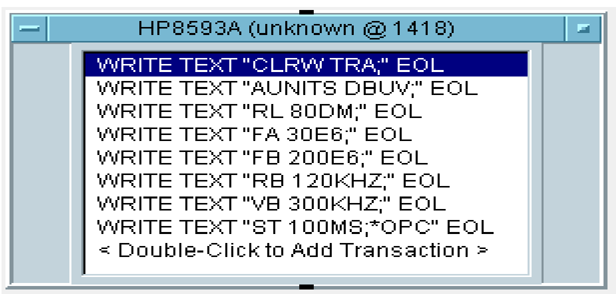
The function and role of Agilent VEE objects used in both (RE and RI) programs have been briefly summarized in appendix B. To help the reader understand a picture of each object has also been provided.

Instrument control objects

The instrument control objects used in RE and RI programs have been described briefly in this section. The same instrument control object has been utilized for RE test with spectrum analyzer and test receiver. However, GPIB commands for both instruments are different. These objects are present in VEE's library are ready to be used in program. They can be employed when the related test instruments are connected to the computer through GPIB interface and powered on. GPIB addresses for these instruments are set at the beginning and they stay the same for future usage. GPIB commands to perform specific operations are written in transaction fields of these objects.

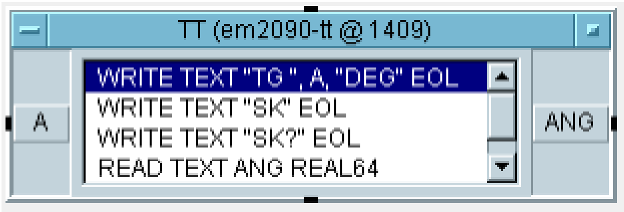
HP 8593A (unknown@1418)

This object is used to control the spectrum analyzer. The commands to set different parameters, for example frequency range, bandwidths, sweep time and amplitude units of the spectrum analyzer are written in transaction fields as shown in figure below. The same object is utilized to save the data acquired during measurements. The spectrum analyzer control object present in user object ”freqrange”, first clears the trace and then sets the frequency range defined in the command line. It also provides the amplitude values for the data to be displayed on X vs Y display and to be saved in a data file. In RE programs, first HP 8593A object is executed and after that turntable control object executes.



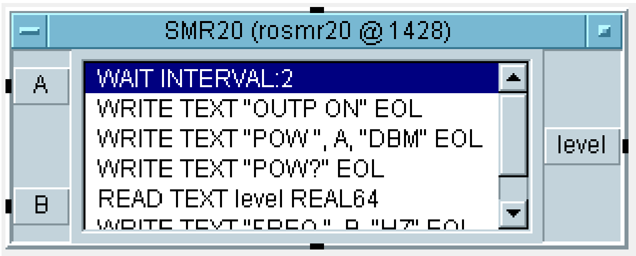
TT (em2090-tt@1409)

It is used to control the movement of turntable. To set the movement limits and step size, the commands are written in transaction fields as shown in figure below.



SMR 20 (rosmr20@1428)

An object that writes data to and reads data from an instrument (in this case a signal generator) using transaction statements.



User function (fullswp)

Five user objects that have been used for 30 MHz – 1 GHz frequency span can cover only one turntable position (one side of EUT) so they have been combined in a user function. This user function was named as fullswp and called four times to wrap left, right and back sides of the EUT. First user function scans from 30 MHz to 1 GHz in five frequency ranges as explained above and saves the emissions of EUT emitted from front side. Then the “TT EMCO 2090” object moves the turntable to next position. Second function scans EUT’s left side (90 deg.) and data is saved. In a similar way the remaining user functions perform the same task for the rest of EUT sides.

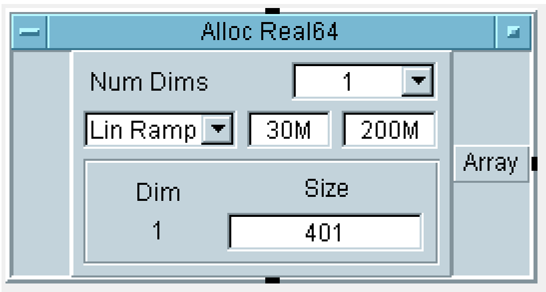
Agilent VEE program for RE test developed using spectrum analyzer HP 8593A contains one user function “fullswp”. There are five user objects inside this function that further consist of four sub objects. These sub-objects cover a specific frequency span for RE test along with necessary settings of spectrum analyzer’s parameters.

User objects

Three user objects have been defined at different locations in RE program with spectrum analyzer. One user object is inside the user function fullswp and two are at the input side of graphical display. The user object “corr_fact” contains three sub-objects and it is used to incorporate correction factors’ data into the emission data of EUT. This correction factors’ data is saved in an external file. Similarly second object “Limit_line” is used to incorporate limit line data on the graphical display. The third user object “freqrange” consists of “Allocate Array”, instrument control “HP 8593A”, “delay” and for “count” objects. It provides frequency points with the help of alloc array object and takes level values from spectrum analyzer control object so that both can be displayed on the graph.

Allocate array

“Alloc array” could be used to output the sub-ranges of frequency scans. The entire frequency range of 30 MHz – 1 GHz has been divided into smaller parts and each alloc array object has been used to define the sub-range for a particular frequency span. For example first alloc array object defines the sub-range of 30 MHz to 200 MHz.

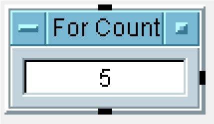


Delay

It adds delay for the next object to be executed. The object to be delayed is connected at the data/sequence output terminal of the delay object. The number written within this object defines the number of seconds of delay, therefore 5 means five seconds delay.

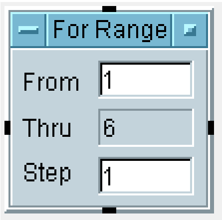
For count

This object repeats a certain task depending on the number written in it. It activates its data output pin for a specified number of times. A number 5 means that the data output pin will be activated 5 times.



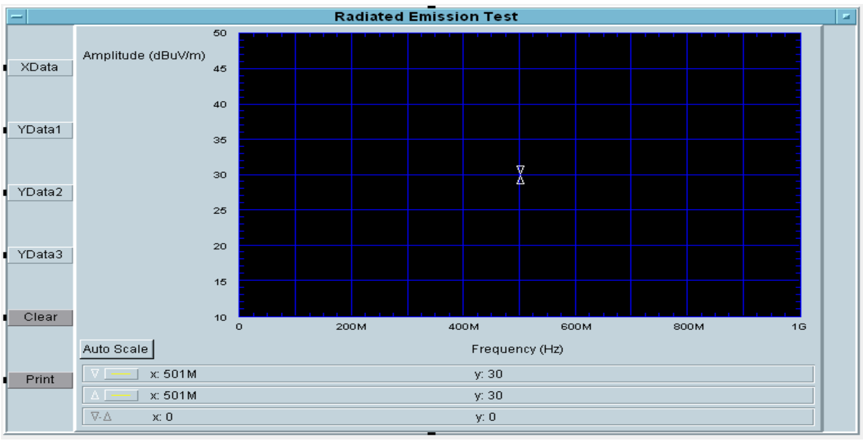
For range

For range object activates its data output pin for a specified number of times. It has three pins, from, through and step. Start value of data is given in from field, stop/end value is written in through field and a step size is entered in step field. For example For Range object given below activates its data output pin from 1 to 6 with a step size of 1. As “Thru” terminal has been controlled externally from a constant real64 object in RI program to run actual test, therefore in figure below its value seems to be fixed. It takes the numerical value written in constant real64 object as input that means the upper limit is defined by constant real64 object in RI program.



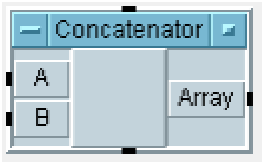
Display object (X Vs Y)

This object is exploited to display the radiated emission data and plot the amplitude as a function of frequency. The facility to set markers to the peak amplitudes has also been provided in the properties of X vs Y display. “Xdata” is connected to the junction that consists of frequency values and it displays frequency data in x axis. The “Ydata1” is used to display amplitude values of corresponding frequency points. The “Clear” button on the X vs Y display is utilized to clear data on graphical display. Additional buttons “Ydata2” and “Ydata3” take advantage of displaying limit line and ambient noise data on the same graph.



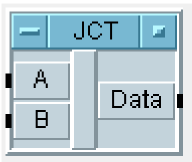
Concatenator

It concatenates (combines) the inputs at output. The data coming on all the inputs of this object is concatenated at output pin. Whatever is coming at inputs, concatenator logs it on output. Usually the output of concatenator is a one dimensional array. It is used to combine two or more data elements into the elements of one dimensional array. This object has been used in RE and RI programs to save and display the frequency and amplitude data.



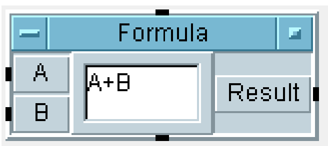
Junction

This object connects its activated data input to the data output pin. Whenever an input is activated (receives data), it is directly sent to the data output pin. Junction outputs the value from the most recent data input (one of multiple inputs) that is activated. It is usually used in feedback loop systems for data initialization because it transmits data passively. It is like wired OR to connect the data output pins of two or more objects to one data input pin of another object.



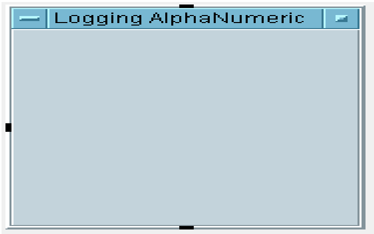
Formula

It performs the mathematical operation on inputs and produces the result at data output pin. The operation of this object depends on the operators used in the formula object and expressions are written in transaction field of formula object.



Logging alphanumeric display

This object is used to display a Scalar or one dimensional array (1D) of alphanumeric data. It logs the data input values and displays the result in alphanumeric form but does not overwrite the results. These values can be viewed and also saved in a data file.

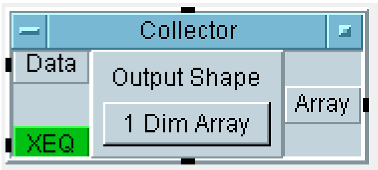


Alphanumeric display

Alphanumeric display object is used to display alphanumeric data. It accepts any of the data types as a single value, an Array of 1D or 2D.

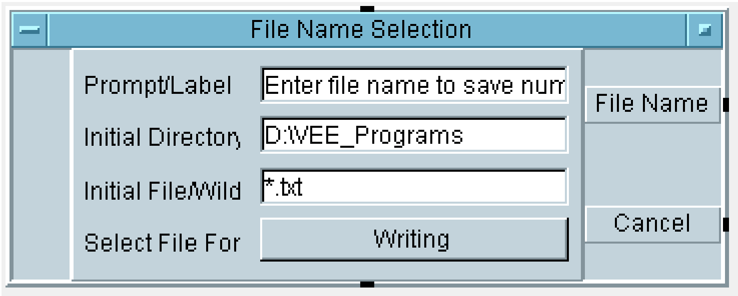
Collector

A collector is used to collect data available at its input pin. The data is sent to output pin when the sequence input pin is activated. The format of the data can be set as one dimensional or n+1 dimensional array but in RE programs one dimensional array format has been employed. It has one data input that receives the data and one sequence input that is activated when the data is required to be sent at the output/array terminal. The sequence input of the collector is connected at the sequence output terminal of the last “fullswp” user function. Therefore, collector’s data is sent at the output terminal after the execution of last “fullswp” user function. Unless the sequence input is activated, input data does not appear at output. The data output terminal “array” has been connected to data input terminal of the “To file” object that is utilized to save data into numerical form.



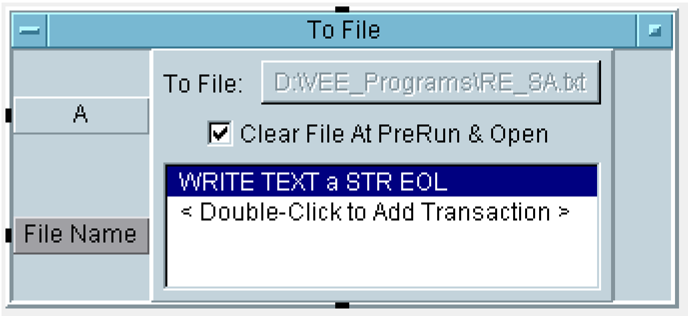
File name selection

This object is a dialog box and provides the operator a facility to select the name of the file in which the data is required to be saved in numerical form. When RE and RI programs are completed, “file name selection” object asks the operator to enter the name of the file to save numerical data. It is just like a message box object that is used to select file name.



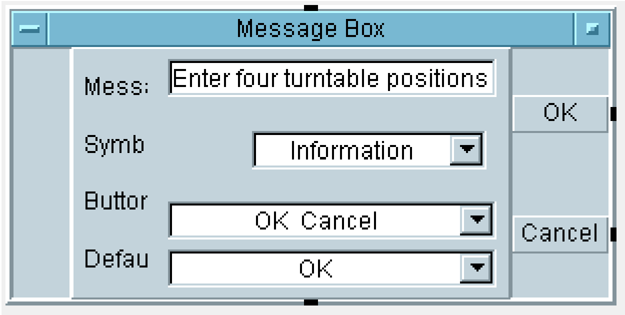
To file

“To file” object is utilized to save numerical data in a specified format. This object defines the format of data and save it on a previously selected location in numerical form.



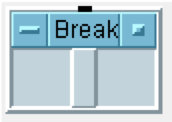
Message box

Message box object is used to display a message written in the transaction field. A lot of message boxes have been used in RE and RI programs to perform different tasks. For example one message box that is connected to the sequence output of the last “TT em2090-tt” object displays a message “Change the polarization of Antenna” at the end of the RE program. This object has two data outputs. One is ‘OK” and the other is ‘Cancel”. A “break” object has been connected to the OK output terminal in RE program which ends the program when OK button is pressed. The sequence output terminal of the message box is connected to the sequence input terminal of another user object called “corr_fact”. Following figure shows a message box object to enter the turntable positions for RE programs.



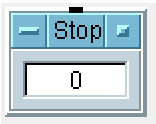
Break

The break object is used to terminate the execution of the program. The object after which the program is required to be terminated is connected to the sequence input of break object. It only has a sequence input pin.



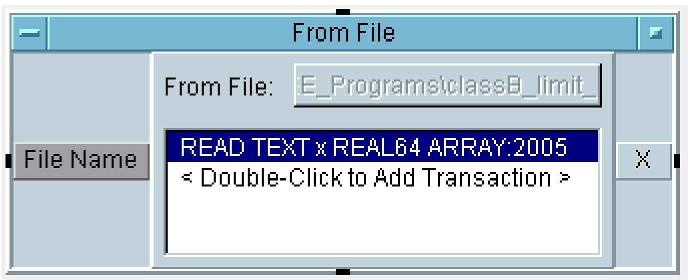
Stop

It is the object that stops the execution of a program.



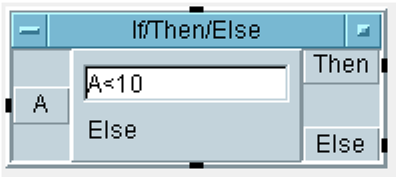
From file

"From file" object incorporates the data from a file into program. The format of data and number of points should match with the data being called with from file object. From file object has been used in RE and RI programs to display frequency, level and electric field data on the graphs. In RE programs limit line and correction factor data have also been incorporated and displayed on graph by from file object.



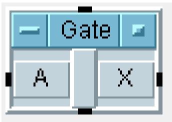
If/then/else

It is a conditional object that activates an output when the related input fulfills a condition specified in the transaction field. This object sends “1” at “then” output but “0” at “else” output. Therefore, to accomplish a specific task an object should be connected at proper output terminal of if/then/else object.



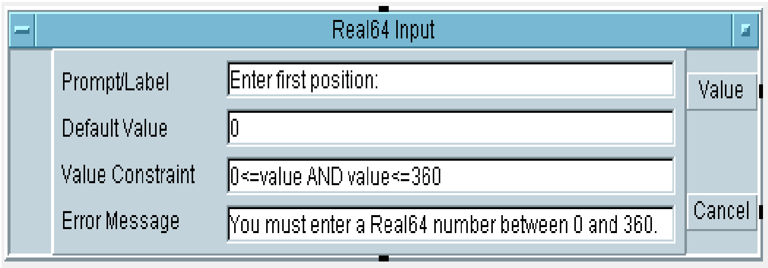
Gate

A gate object just transfers the data present at its data input terminal to the data output terminal when the sequence input terminal is activated. It is used in control loops.



Real64 Input

This object displays a pop up dialog box in which a real number is written as input. It has been used in RE programs to enter positions of the turntable.

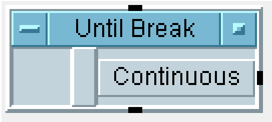


Constant

A text constant is an object that gives a constant string or one dimensional array as output whereas a real64 is a constant that outputs 8-byte real number. Both objects have been used in RE and RI programs.

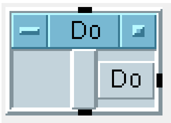
Until Break

Until break object is used to repeat the execution of a subthread until a break is encountered and it has been used in RI program to repeat the execution of the program. It is normally employed to start a set of operations until a break occurs.



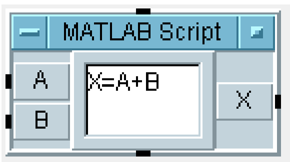
Do

A "Do" object creates a branch point to control the flow of execution of a thread. The object connected to the data ouput pin is activated before the object connected to the sequence output pin of this object. Therefore, it is used to define the order of an operation.



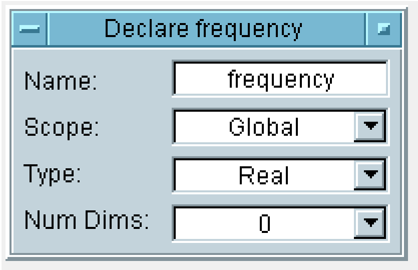
MATLAB Script

An object that calls the MATLAB script engine with operations specified by MATLAB script commands. It is utilized to pass the VEE data to the MATLAB script engine and to return from it. MATLAB commands for specific operations are written in its transaction field.



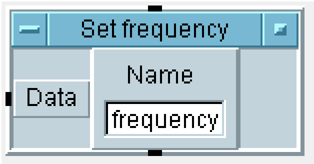
Declare Variable

An object that is utilized to declare programming variables is called Declare Variable. The variables can be declared to be used anywhere in the program as Global, Local to context and Local library. The variable declared as global can be used anywhere within the program. The type and shape of the data of a variable is set by declare variable object.



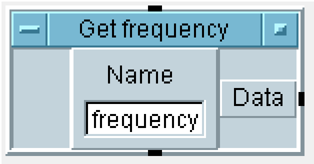
Set Variable

It is employed to set the data value of a variable. In RI program it has been used to set the frequency and level values of the signal generator. The levels of signal generator are changed during calibration to achieve the required electric field strength over the whole frequency range of the test.



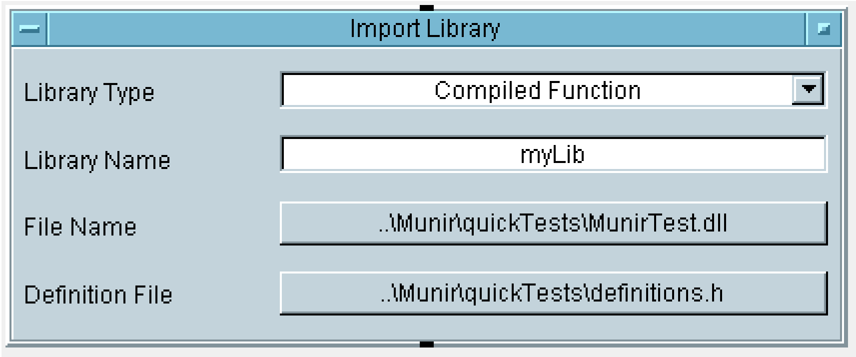
Get Variable

An object implemented to get the value of a variable that has already been set by “Set Variable” in the execution of the current program. The value of “Set Variable” is obtained with the help of Get Variable object.



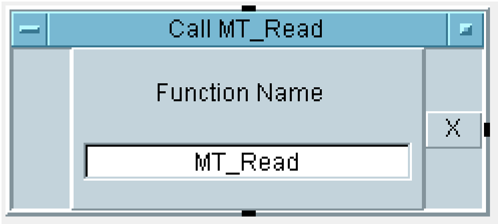
Import library

Import library loads a library of Userfunctions, compiled function definitions or remote functions into the program. This object is used to import a library of functions into the program. It has been used in RI program to display the data of electric field probe into VEE.



Call

An object that executes a previously defined function. A call object is used to call a function anywhere in the program. The function name is written in transaction field and this object calls it. For example in RI calibration program the object in following figure is used to call the function "MT_Read". This function in turn calls the "ReadFieldSynchronous" function from the manufacturer's library that reads electric field data of field probe.



Appendix C: Visits of professional EMC labs

The purpose of visiting professional EMC labs, the usefulness and learning outcomes of those visits has been briefly explained in this appendix.

Objectives of the visits

The primary objective of those visits was to see how the radiated immunity test especially its calibration was being performed in professional EMC labs in Finland. No doubt the test procedures for the calibration process and execution of RI test have been briefly described in IEC 61000-4-3 testing standard but the new thing for me was 16 point calibration for electric field data. Earlier, I never performed 16 point calibration for RI test.

The second and very important goal of those visits was to know what kind of devices were being tested there, how high the electric field levels were being applied on different EUTs and what was the upper frequency limit being currently employed for commercial EUTs. Third aim of visiting those labs was to get information about power amplifiers and testing software being used by in those labs for RI test. The discussions about different power amplifiers utilized for RI test and their specifications were very helpful in searching the best power amplifier and selecting the most suitable one in terms of specifications and price.

In addition, seeing practically the anechoic chambers, microwave absorbers, electric field probes and field monitoring systems of those labs was interesting and useful experience. Sharing of ideas about RE and RI tests, different types of EUTs, test equipment and procedures had been very beneficial for further improvements in EMI/EMC testing.

Visit of EMC lab of SGS

The EMC lab of SGS Company was visited in August 2012. The lab manager Mr. Ari Honkala showed his company’s anechoic chamber as well as test equipment used in different EMC tests. There were two anechoic chambers in SGS to perform EMI/EMC testing having dimensions of 10 m and 3 m. The selection of a specific chamber for EMC testing depended upon EUTs but normally 10 m chamber was being employed to perform EMC tests. It was a complete lab with capability to execute commercial EMC testing but no military devices were being tested there. They had antennas and power amplifiers to conduct radiated immunity testing up to 3 GHz. Radiated emission testing could be performed up to 18 GHz depending upon the operating frequency of the EUT. The commercial software EMC32 developed by Rohde and Schwarz was being used in SGS for EMI/EMC testing.

Due to confidential issues the demonstration of the calibration procedure for RI test could not be witnessed practically rather it was discussed theoretically in detail. Mr. Ari Honkala explained each and everything about the calibration procedure of RI test and also showed the test equipment and accessories used to execute the test. The discussion about test equipment, EUTs and testing procedures continued for one hour and later on had been helpful for developing the RI testing program.

Visit of EMC lab of SAMK

With the collaboration of Professor Teijo Nietola I visited EMC lab of SAMK in August 2012. He showed me the test equipment used in different EMC tests as well as anechoic chamber in use. I found that the anechoic chamber over there was almost the same as the chamber TUT's EMC lab. The discussion about test procedures, standards, equipment and testing software continued for about one hour and 30 minutes. The testing software being employed for EMI/EMC testing in SAMK was locally developed.

Professor Teijo Nietola mentioned that the EMC lab of SAMK had been operational for the last about 10 years and had a capability to cover almost all EMC test standards. They had test equipment for almost all EMC tests. For example they can perform

1. Radiated emission test, both for commercial and military equipment from 10 kHz to 3 GHz. They have facilities to conduct commercial testing according to CISPR 24 and military testing according to MIL-STD 461E and F standards.
2. They can perform radiated immunity test both for commercial and military equipment. They can test up to 3 GHz with an electric field level not more than 20V/m. From 80 MHz to 1 GHz the power amplifier used to generate electric field is of Amplifier Research but from 1 to 3 GHz Frankonia's power amplifier is being utilized.
3. For conducted emission test, they have test equipment to conduct the test according to the recommendations of CISPR 24.
4. For conducted immunity test they have a continuous wave simulator of EMTEST Switzerland that has been particularly designed for conducted immunity test. CWS has a built in signal generator and power amplifier. The test can be performed either through bulk current injection method or through coupling-decoupling networks (CDNs). EMTEST provides a complete package when it is purchased including CWS, CDN or current injection probe and software to conduct this test automatically.

Despite of above mentioned tests, they have test equipment required for following tests and these tests are being performed over there.

1. Electrical fast transient

2. Electrostatic discharge (ESD)
3. Surge immunity
4. High voltage dips
5. Damped oscillatory wave
6. Thermal shock
7. High temperature
8. Low temperature (cold)

Unfortunately, here again I could not witness the calibration procedure of radiated immunity test because no testing was going on in the lab on that day. Professor Nietola just showed me equipment and accessories used to conduct the 16 point calibration and explained the procedure verbally.

Comparison of both labs

Both labs used power amplifiers of Amplifier Research (AR), manufactured by RFI, Australia for radiated immunity testing. Same antennas were being used in both labs and the method of data acquisition of electric field from electric field probe was also similar. The difference was just in testing software. SGS used commercial testing software whereas SAMK used locally developed software.

The interesting thing was that both labs also had one power amplifier unit of Frankonia (Germany). Both labs covered most of the commercial EMC test standards. They had test equipment and facilities to test commercial products. The upper frequency for radiated immunity testing as well as the test equipment in both labs was similar. In addition, the lab in SAMK also performed military testing. As per electric field levels for radiated immunity testing are concerned both of them could generate a maximum level of 20 V/m.