APLICACIÓN DE PROCEDIMIENTOS DE CERTIFICACIÓN DE EQUIPOS ELECTRÓNICOS SEGÚN LAS NORMAS VIGENTES SOBRE COMPATIBILIDAD ELECTROMAGNÉTICA

ANGÉLICA MARÍA GARCÍA GUALDRÓN

UNIVERSIDAD INDUSTRIAL DE SANTANDER
FACULTAD DE INGENIERÍAS FÍSICO-MECÁNICAS
ESCUELA DE INGENIERÍA ELÉCTRICA, ELECTRÓNICA Y TELECOMUNICACIONES
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ANGÉLICA MARÍA GARCÍA GUALDRÓN

Trabajo de grado presentado como requisito para optar al título de
Ingeniera Electricista

DIRECTOR
Msc. ERNESTO AGUILERA BERMÚDEZ

TUTOR
Msc. JAIRO ROMERO

UNIVERSIDAD INDUSTRIAL DE SANTANDER
FACULTAD DE INGENIERÍAS FÍSICO - MECÁNICAS
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APPLICATION OF THE CERTIFICATION PROCEDURES FOR ELECTRONIC PRODUCTS ACCORDING TO THE INTERNATIONAL ELECTROMAGNETIC COMPATIBILITY STANDARDS

ANGÉLICA MARÍA GARCÍA GUALDRÓN

UNIVERSIDAD INDUSTRIAL DE SANTANDER
FACULTY OF PHISYCAL-MECANICAL ENGINEERING
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ANGÉLICA MARÍA GARCÍA GUALDRÓN

Undergraduate degree project presented as a requirement to be an Electrical Engineering

DIRECTOR
MSc. ERNESTO AGUILERA BERMÚDEZ

TUTOR
MSc. JAIRO ROMERO

UNIVERSIDAD INDUSTRIAL DE SANTANDER
FACULTY OF PHISYCAL-MECANICAL ENGINEERING
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AUTORA: **GARCÍA GUALDRÓN, Angélica María**.**

PALABRAS CLAVES: **Certificación, Compatibilidad Electromagnética, FCC, Comunidad Europea.**

DESCRIPCIÓN

La empresa Magenta Research, ubicada en la ciudad de New Milford, USA desarrolla productos electrónicos de transmisión de señales de audio, seriales y video a través de cable CAT5 y fibra óptica; estos productos son comercializados en diferentes países del mundo que exigen la certificación acorde a las normas vigentes de compatibilidad electromagnética.

La certificación en compatibilidad electromagnética es exigida por los Estados Unidos de América (USA) según las normas elaboradas por la Comisión Federal de Comunicaciones (FCC) y por los países que integran la Comunidad Europea según las normas creadas por el Comité Electrotécnico Internacional (IEC), estas normas regulan distintos fenómenos relacionados con compatibilidad electromagnética, tales como la emisión de energía por radiación o conducción, inmunidad a sobrepicos de tensión y a inducidos por ondas de radiofrecuencia.

Como resultado final de este proyecto de grado modalidad practica empresarial se creó un manual de laboratorio en donde se especifican de forma detallada los equipos utilizados en el laboratorio y los pasos a seguir en cada una de las pruebas que se le deben aplicar a cada uno de los equipos a certificar. En adición a esto, durante esta práctica se certificaron ocho productos de la empresa Magenta Research según las normas europeas y la norma americana.

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* Trabajo de grado

** Universidad Industrial de Santander (UIS); Facultad de Ingenierías Físico-Mecánicas, Escuela de Ingenierías Eléctrica, Electrónica y Telecomunicaciones (E3T); Programa de Ingeniería Eléctrica; Msc Ernesto Aguilera Bermúdez, Director de Proyecto; Msc Jairo Romero, Tutor.

UNIVERSIDAD INDUSTRIAL DE SANTANDER
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TITLE: **APPLICATION OF THE CERTIFICATION PROCEDURES FOR ELECTRONIC PRODUCTS ACCORDING TO THE INTERNATIONAL ELECTROMAGNETIC COMPATIBILITY STANDARDS.***

AUTOR: **GARCÍA GUALDRÓN, Angélica María****

KEY WORDS: **Certification, Electromagnetic Compatibility, FCC, European Community.**

DESCRIPTION

The company Magenta Research, localized in New Milford, USA develops electronic products to transmit audio, serial and video signals through CAT5 cable and optic fiber; these products are commercialized in different countries of the world that demands their certification according to the international electromagnetic standards.

The certification of electromagnetic compatibility is requested by the United States of America (USA) according to the standards developed by the Federal Communications Commission (FCC), also the countries members of the European Community demand the certification according to the standards created by the International Electrothecnical Committee (IEC). These standards establish the emissions limits for different phenomena related to electromagnetic compatibility, such as radiated emissions, conducted emissions, immunity to surges and immunity to conducted disturbances induced by radio-frequency waves.

The final result of this internship was a detail laboratory manual which contains all the information about the laboratory equipment used for the test, steps and details about each test procedure. In addition to this, eight products developed by Magenta Research were tested and certified during this internship.

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* Project Degree

** Industrial University of Santander (UIS); Faculty of Phisic-Mecanic Engineering, School of Electric and Electronic Engineering (E3T); Electrical Engineering; Msc Ernesto Aguilera Bermudez, Project Director; Msc. Jairo Romero, Tutor.

To:
My parents, my brother, my aunt Edilia and her husband

Thanks to:
Penny Kern, Bob Freedman, Magenta Research and Jairo Romero

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INTRODUCTION

For the last decades many old and new companies have appeared with new electronic products that make easier our daily life, like cellphones, video cameras, portable memories, personal computers, wireless technology, network equipment and other products.

Many of these products have certain electromagnetic properties that can produce some perturbations that interfere with other equipment causing several damages, like burning of microprocessors or integrated circuits. Then, these problems have become an issue for many companies in the world during the investigation, design and development process of the products. Improving the designs of the products to avoid these perturbations represent an important part in the design and development process; not only to guarantee the normal functioning of the product in a high contaminated environment, but to guarantee that no significant perturbations come out from the equipment to interfere with other products.

Also, this is a concern for the governments of many countries of the world, which in the last years had created their own electromagnetic compatibility standards to control the electronic products sold in their markets. These standards establish the certification process required for this type of products that has become stricter with every new version of the related standards.

This undergraduate degree project developed as an internship in the company Magenta Research located in New Milford, Connecticut, USA, allows the company to have access to the test procedures, test requirements, laboratory equipment, test facilities and other important information of the certification process required to certify its products. The information described in this book advice Magenta Research's engineers to develop a product capable to reject the perturbations which it is tested for; perturbations present in the environment where the product is going to be installed.

On the other hand, this internship represents a valuable source of information for the students of electrical engineering and electronic engineering to have an idea about the electromagnetic compatibility standards applicable to the products they are planning to develop in a further future. This information helps the student to understand the international requirements and parameters which the equipment has to follow in order to be well protected and non-offensive to other equipment. Also, it keeps them aware about the process that has to be followed in order to be allowed to sell electronic products in the different markets of the world.

This book describes. In general, the most important aspects of the certification process, such as the applicable standards and the relationship between them. Also, a brief description of the most important functions and futures of the measurement equipments required by the European community and the American entities in order to certify electronic products.

On chapter three you will find a short description of the phenomena related to the electromagnetic compatibility standards and the test procedures established by international standards and entities which the product has to be submitting in order to have the permission to be sold around the world.

Finally, a fourth chapter contains the final results and conclusions of this internship followed by an appendix with complements of chapters three and four, and the internship evaluation made by Magenta Research's supervisor, Robert Freedman.

1.1. OBJECTIVES

1.1.1. General objective

Analyze and apply the certification procedures established according to the international electromagnetic compatibility standards for some electronic products developed, manufactured and commercialized by Magenta Research.

1.1.2. Specific objetives

- Identify the international standards that specify the electromagnetic compatibility limits allowed for electronic products of video and audio signals that use CAT5 to transmit audio and video signals

- Identify the tests established according to the international EMC standards to measure the EMC levels and emissions from electronic products that transmit video and audio signals through CAT5.

- Perform, in a certified laboratory, the tests established by the international EMC standards to measure the EMC levels and emissions from electronic products that use CAT5 to transmit audio and video signals.

- Write an electromagnetic compatibility manual with the standards and procedures applicable to Magenta's products.

1.2. ELECTROMAGNETIC COMPATIBILITY STANDARDS

The increasing use of electric and electronic equipment during our daily life for the last years has helped to increase, in the same way, the problems present in the normal function of the equipment when they interfere with each other due to their electromagnetic properties.

The currents and voltages present in the equipments can produce electromagnetic energy that is transferred between electronic devices inside the equipment, between equipment connected to the same electric grid or between equipment placed close in distance one from the other; this electromagnetic energy transference is called electromagnetic interference (EMI).

All these phenomena is studied in a bigger field called electromagnetic compatibility (EMC), that according to the 2004/108/EC standard published by the European Community and available at: http://ec.europa.eu/enterprise/electr_equipment/emc/directiv/dir2004_108.htm, which “means the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment.” [1].

Three general aspects of electromagnetic compatibility are analyzed:

- The *electromagnetic emissions* characterize perturbations induced by an apparatus. These perturbations are usually emitted in radiated or conductive way, through the air or cables. The limits for these emissions are established in a few international standards to avoid high impact in humans and other electronic equipment.

- The *electromagnetic susceptibility* characterizes the disability of an apparatus or system to develop a satisfactory functioning inside an electromagnetic environment, having access to the perturbations present in conducted and radiated way.

    - The *electromagnetic immunity,* as an opposite of the electromagnetic susceptibility, is the ability of an apparatus or system to work in an electromagnetic environment without suffering significant alterations in its functions

Based in these three aspects, many countries in the world have developed their own compatibility standards to ensure the good quality of the products sold in their markets; some of those countries are Japan, Germany, Norway, Canada, USA and the European Community; but only two of them are mandatory to meet in order to be allowed to sell electric and electronic products around the world; these standards are the FCC Part 15 from the Federal Communications Commission of the United States of America and the EN55022 developed by CENELEC (European Committee for Electrotechnical Standardization). These standards specify the limits for radiated electromagnetic fields and conducted electric fields; also, the test equipment, the test procedures and the exceptions to the standards.

In addition to the EN55022, the European Community requires testing electronic products according to the IEC61000-3-2, IEC61000-3-3 and the immunity standards listed in EN55024; these standards are from IEC61000-4-2 to IEC61000-4-6 and IEC61000-4-11.

Also, these standards are related with other standards that specify the technical requirements for the measurement equipment, test procedures and test set up in order to make full compliance. The FCC Part 15 is related to the ANSIC63.17, ANSIC63.4 both created by the American National Standards Institute (ANSI) and available at the Institute of Electric and Electronic Engineers' (IEEE) standards data base, and the FCC/OET MP-2. And the European standards are related to the standards created by the International Special Committee on Radio Interference (CISPR); those standards are the CISPR11, CISPR16, CISPR22 and CISPR24. The relationship between standards is shown in figure 1.

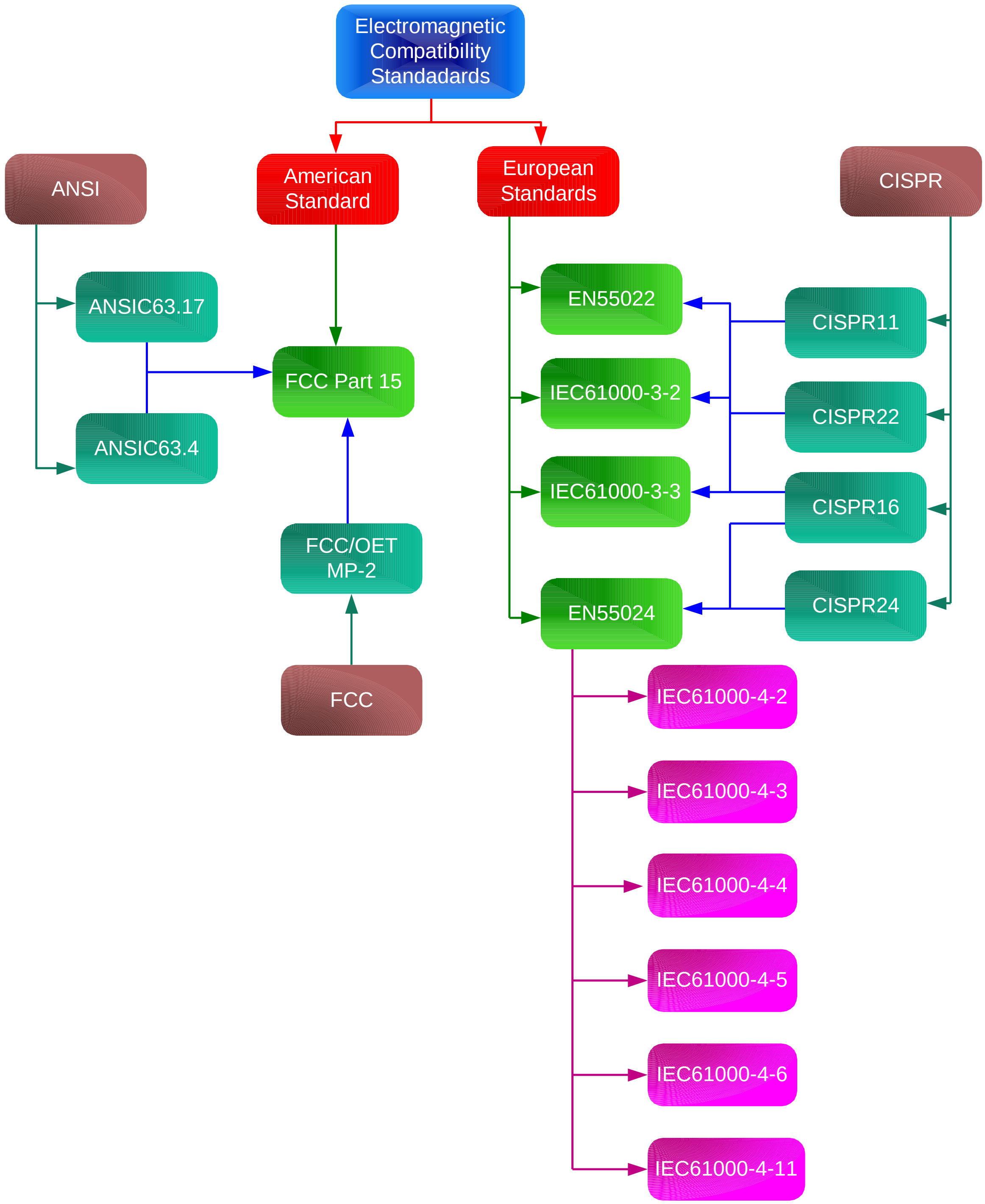


Figure 1 Relationship between EMC standards and tests procedures standards.

Once the equipment is fully tested for emissions and immunities, and passes all the tests; the manufacturer has the permission to mark the chassis of the product with the European Community seal and the FCC seal of approval.

Figure 2 European Community seal of approval

Figure 3 FCC seal of approval

Also, the Declarations of Conformity (DOCs) are created for every product as a proof of the tests and their results. These documents are public and for the customer access. See appendix B.

Two declarations of conformity have to be made for each product, one for the American standard and other for the European standards. The European Community and the FCC established the English language as the official language for these documents. In these documents have to be announced the company name, company address and telephone number, as well as the commercial name of the product, the serial number and the standards which the product was tested for.

Finally, at the end of these documents, must appear the creation date, seal of approval, internal reference number, the name and signature of the employee responsible of compliance.

2. EMC LABORATORY EQUIPMENT

A considerable amount of EMC lab equipment is available in the market to perform the tests presented in this book. But not all of them are officially approved.

All the EMC lab equipment, used to perform those tests, must comply with the CISPR standards and the ANSI standards listed in section 1.2 of this book. Also, the test equipment must be authorized or certify by international agencies; like NEMKO, Norwegian agency authorized by the European Community to certify processes and test equipment; and the FCC itself in order to make full compliance.

Also the test laboratory, where the product is going to be tested, must have the appropriate structure and electrical conditions according to these standards too, like protection against electrical shock and quick fires, insulations, equipment and cables in order to get the approval for testing and certification of electric and electronic equipment.

Another type of testing is the house testing, which is performed in the headquarters of the company and is not necessary to authorize the equipment and the test facilities. But these test results cannot be used as a proof of compliance.

Most of the EMC lab equipment used for full compliance of electronic products can be classified in four categories:

- Frequency domain analyzers.
- Transducers and Networks.
- Test facilities.
- Generators.

2.1. FREQUENCY DOMAIN ANALYZERS

Some analyzers examine the frequency domain in a visual manner while others investigate wave shape, phase, and other advanced characteristics of a transmitted signal.

Their functioning is based on the Fast Fourier Transform and gives different results depending on the window selected for the conversion; some of them measure in quasi-peak, some in average and others in both. Some scopes sold in the market have the Fast Fourier Transform as a feature, but do not have quasi-peak or average responding detectors required for proper emissions testing, so this features is used for house testing.

The most common analyzers used for the tests are the spectrum analyzer, the RF receiver, the flickermeter and harmonic analyzer.

2.1.1. Spectrum analyzer

A spectrum analyzer displays a spectral distribution of RF energy from a signal. The signal being measured is received from a transducer, such as an antenna or a probe.

This equipment is commonly used to measure the emissions from the equipment under test according to the American and the European standards. The process based on the Fast Fourier Transform (FFT) within the spectrum analyzer displays the spectral distribution of the measure signal. This signal is commonly received by a transducer such as closed-field probes, current probes, voltage probes, and antennas. The horizontal axis of the graphic displays in the screen gives the frequencies of the signal in Hertz (Hz); the vertical axis gives the amplitude of the frequencies and it is commonly given in decibels relative to one microvolt, dBμV, according to the units specified in the standards; an example of the spectrum analyzer's screen is shown in figure 4.

Figure 4 Picture taken to the screen of the spectrum analyzer

A spectrum analyzer is a complicated test and measurement tool. It is ideal for signal characterization, identification of unknown signals, harmonic and spurious measurements, signal monitoring, field strength measurements, and EMC precompliance or house testing.

The primary advantage of using a spectrum analyzer for development, diagnostic, and qualification verification is that it is much easier to correlate measured results from prequalification analysis with those of a formal EMC test. Making the frequency domain visible enhances the ability of a design and development engineer to understand what is happening inside the product.

Some important basic parameters have to be considered when choosing or selecting a spectrum analyzer; depending of the signal nature, maximum frequency to analyze, amplitude of the signal and the test to perform:

- *Frequency range*. The frequency range is the spectral distribution of frequencies that one desires to measure and analyze. The three primary areas related to frequency range are: start frequency, stop frequency and center frequency.

- *Span*. Frequency span is how small or large a desired frequency range is to be displayed on the screen in hertz on the horizontal scale.

- *Resolution bandwidth*. Resolution bandwidth is the passband of the internal filters that aids in distinguishing two signals that are very close together. A smaller resolution bandwidth means a better ability to "resolve" adjacent signals.

- *Dynamic range*. The dynamic range is a value that determines the lowest level signal that can be measured and is related to the internal noise floor of the analyzer. Signals being measured must be higher in amplitude than the minimal value capability of the analyzer in order to be a valid measurement. Ideally, is better to choose an instrument with the lowest noise floor possible.

- *Video bandwidth*. Video bandwidth refers to a monitor's ability to refresh the screen. High bandwidths allow more information to be painted across the display in a given amount of time, which translates into support for higher resolutions and higher refresh rates.

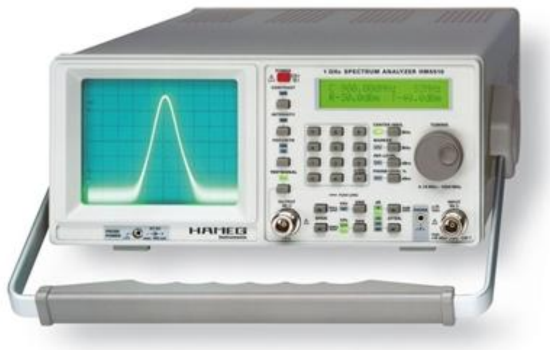


Figure 5 Example of a spectrum analyzer. Developed by Hameg, model HM5510

2.1.2. RF receivers

An alternative or complement to the spectrum analyzer is the measuring receiver. Receivers have been around since the early 1900s and were the first EMI measurement tool; they use the same Fast Fourier Transform theory and the same transducers as the spectrum analyzer.

The main difference between a receiver and spectrum analyzer is that the RF amplifier of receivers has a narrow bandwidth of operation, unlike spectrum analyzers which must be wide open to allow the signal through. The front-end RF amplifier within a receiver is tuned to a narrow bandwidth around a single frequency of interest becoming more acquired than the spectrum analyzer.

The RF receiver has the following basic functions and characteristics, most of them are important criterions to choose a proper receiver depending of the signal nature and the type of tests to perform:

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

Figure 6 Example of an EMI receiver. Developed by Schaffner, model SMR 4518

2.1.3. Flickermeter and harmonic analyzer

The measurement of the voltage fluctuations induced by the equipment under test according to IEC 61000-3-3 is made using a flickermeter, while the magnitude of the harmonics of the current according to IEC 61000-3-2 is measured by a harmonic analyzer.

The output of the flickermeter is given in units of flicker severity (Pst), a value of the maximum human being tolerance to changes of the intensity of the light. The flickermeter employs a series of electrical filters to model the response of the human eye and brain to those changes.

The flickermeter use the same Fast Fourier Transform theory to separate the waveform producing the voltage change from the continuous mains signal. The resulting waveform is compared with a pure sinusoidal wave to obtain the changes induce by the equipment under test to the AC mains.

A harmonic analyzer has a similar functioning as the flickermeter; but, its output is given in units of current instead of units of flicker severity. The incoming signal is process according to the Fast Fourier Transform and filter to display the amplitude of the harmonics of the current. Due to the similitude between the flickermeter and the harmonic analyzer, these are generally packaged together.

Some of important aspects of this equipment have to be taken in account in order to choose proper equipment, depending of the signal nature and measurement to perform:

- Measurement range.
- Accuracy.
- Test control.
- Safety and compliance.
- Frequency range.
- Voltage range
- Current range.

2.2. TRANSDUCERS AND NETWORKS

Many types of transducers are used for EMC tests, some of them to measure electromagnetic fields, currents and voltages; others are used to induce currents and voltages in cables. It is important to recognize that each type of transmission is different depending on the application or functional use.

2.2.1. Antennas

The antennas available in the market are great probes to measure and emit electromagnetic fields; but, only a portion of them are designed to be used for EMC.

Full-compliance testing for radiated emissions test requires antennas to be designed for use in the far field. Electromagnetic compatibility standards specify emission limits only for the far field, with some exceptions. The far field is generally defined as greater than one-sixth of a wavelength, though the near field–far field transition boundary is a factor of ±2 of this value. For 30 MHz, this distance is 1.7 m.

Between 30 MHz and 1 GHz dipoles are recommended. Dipoles have a limited frequency range that makes testing very time consuming. Since dipoles have a known calculable response, they are used as the standard transducer for radiated emission site calibration. However, some frequencies are not required to test with dipoles antennas. Some of the antennas used for EMC tests and their frequency range are listed in table 1.

Antenna	Range of frequency
Biconical	30 MHz – 300 MHz
Log-period	300 MHz – 1 GHz
Horn	1 GHz – 18 GHz

Table 1 Types of antennas and frequency range of measurement.

Before using antennas for troubleshooting EMI or for conformity tests, one must select an appropriate transducer. There are other types of antennas available for very specialized applications, not detailed here.

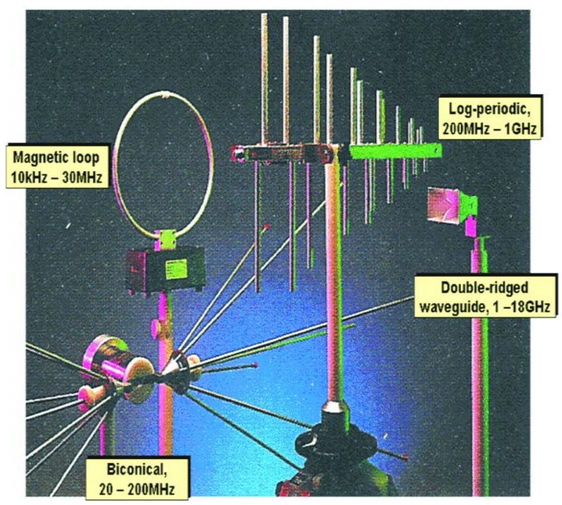


Figure 7 Types of antennas used for EMC tests. Excerpt of reference 2.

Another kind of antenna is the near field probe; this probe is not allowed to be used for electromagnetic fields measurements. However, they are very helpful when a level measured is above the limits and is required to identify, inside the circuitry, the source of the emission.

Figure 8 Example of near field probe set. Developed by RHODE&SCHWARZ, model HZ-11

Due to the 50 Ω internal termination of the spectrum analyzers and receivers, the antenna must be corrected for a 50 Ω output at a given field strength for each frequency. These corrections are called antenna factors and are provided by the antenna vendor. Frequently, these factors are given in dB/m versus frequency which allows one to make necessary corrections. A problem with antenna factors is that the antenna is usually calibrated at only a particular distance from a source transmitter. When using the antenna at a different test distance, the calibration chart from the vendor may be invalid for this particular test.

Consider the example 7.10 of [3], where a measure data is used to determine the antenna factor: "A known, incident, linearly polarized, uniform plane wave is incident on the antenna, and the electric field at the position of the antenna in the absence of the antenna is 60 dBμV/m. A 30 ft length of coaxial cable is used to connect the antenna to a 50 Ω spectrum analyzer. The spectrum analyzer measures 40 dBμV. Since the antenna factor relates the incident electric field to the voltage at the base of the antenna, we must relate the spectrum analyzer reading to the voltage at the base of the antenna. The coaxial cable has 4.5 dB/100 ft loss at the frequency of the incident wave, 100 MHz. Thus the cable loss of 1.35 dB must be added to the spectrum analyzer reading to give the voltage at the antenna terminals of 41.35 dBμV.

Therefore the antenna factor is:

$$AF_{dB} = 60\ dB\mu V/m\ - 41{,}35\ dB\mu V = 18{,}65\ dB\ \text{"}$$

2.2.2. Current and voltage probes

Many tests performed to certify electronic products use probes to measure current and voltages in cables, most of them clamps; due to cables are insulated by dielectric materials, like plastic and rubber, and is impossible to have direct contact with internal conductors to measure and insert currents and voltages, therefore clamps are the most used probes for EMC compliance.

A current clamp is a valuable tool for measuring and inserting current levels within transmission lines. These probes contain a magnetic core material that in the case of the measuring clamps, commonly known as current probes, detects the magnitude of magnetic flux present and delivers this field measurement to a receiver.

This probe is placed around a transmission line to measure various forms of conducted EMI. When placed around a cable, only common-mode EMI is observed as differential-mode currents cancel out. A Hall Effect sensor produces an output voltage in response to the magnetic field of the circuit being measured. A semiconductor circuit inside the probe is exposed to the magnetic field of the transmission line to be measured and an output voltage is generated in response to the field strength present; then an amplifier within the probe increases the internal voltage level to a measurable value and buffers it.

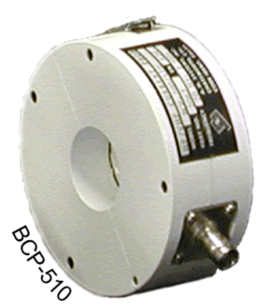


Figure 9 Example of current probe; developed by A.H. Systems, Inc.

On the other hand, the probes used for injection are commonly known as Bulk Current Injector (BCI). The BCI method is intended to simulate continuous-wave (CW) currents developed in electrical conductors of equipment during normal operation. These conductors include signal, control, and power circuits.

Bulk current injection uses RF transformers to inductively couple large amounts of RF currents into conductors linking parts of electronic systems. The injection probe acts as a multiple or single primary winding of a transformer and the transmission line or circuit under test acts as the secondary winding. Injection probes are used over a specific range of frequencies depending on design. Each probe is provided with an insertion loss curve plotted from the vendor.

The attenuation level of the injection probe is more stable throughout the frequency range of operation. When using the clamp, the cable sees simultaneously both electric and magnetic field coupling with a directional effect: The resulting power is sent to the equipment under test side with practically no power being sent toward the support equipment. This is an attractive method of measurement with high efficiency. This means that much less power from the RF amplifier is required, saving cost in instrumentation.

Figure 10 Examples of BCI; developed by A.H. Systems, Inc.

The design engineer should evaluate the effects of injected currents on the system or subsystem under development and the relative immunity level of different designs at the prototype stage of equipment development, saving significant redesign time and cost.

The most common voltage probes for EMC tests are the capacitive clamps. Their work is based in the same principle of the current probes; but, their physical structure allows measuring and inserting of voltage instead of current.

Figure 11 Example of capacitive clamp. Developed by Haefely, model IP 4A.

2.2.3.Networks

For EMC tests, two kinds of networks are needed; the Line Impedance Stabilization Network (LISN) and the Coupling-Decoupling Network (CDN).

A *Line Impedance Stabilization Network* (LISN), also known as an Artificial Mains Network (AMN), is a device inserted into the AC supply mains of a product to be tested. For a frequency range of interest, the network maintains specific load impedance defined by international standards. This impedance allows measurement of disturbance noise voltages present within the AC mains distribution system. This type of measurement is known as Line Conducted Interference (LCI).

Excessive RF noise from one device may cause harmful interference to other systems through the AC mains plug. This undesired noise is from switching energy developed within the unit. In addition, undesired RF energy from periodic switching circuits such as clocks or high-bandwidth components can inductive or capacitive couple into the power supply system through radiated or conductive means. Once undesired energy gets into a power supply, along with its own inherent switching noise, an excessive amount of harmful interference may be observed on the mains cable leaving the product.

In order to make tests repeatable between laboratories, the LISN/AMN is to be normalized to international standards and must be stable across a wide range of frequencies. Above 30 MHz the impedance is not defined as most regulatory compliance limits do not exceed this frequency limit.

CISPR 16 and CISPR 22 provide guidance on the design and specifications of a LISN. The value of impedance is the primary item of importance. The output for the measuring instrumentation input impedance is specified as a 50 μH inductor and a 5 Ω resistor. The remaining components are provided to decouple the incoming supply voltage.

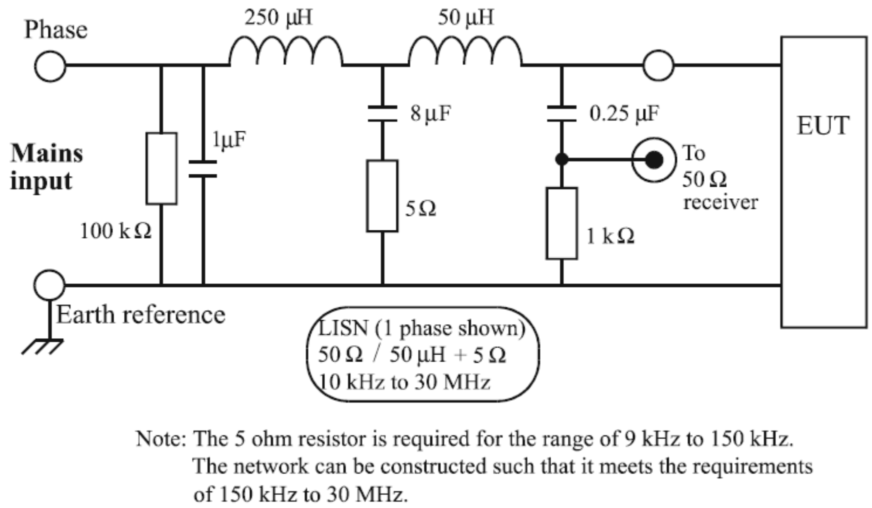


Figure 12 Schematic of a LISN for 1 phase, an excerpt of reference 4.

A high pass filter is commonly added between the LISN output and receiver, cutting off below 9 kHz. This high-pass filter prevents the receiver from being affected by high levels of harmonics present within the mains supply. This high-pass filter must be maintained at 50 Ω impedance and have a defined insertion loss, preferably 0 dB at all measured frequencies.

Coupling and Decoupling Networks work by measuring the common-mode current disturbance that may be present on a cable. The coupling network operates identical to the LISN with different values for components. For immunity tests (IEC 61000-4-6), decoupling networks are used to ensure that the disturbance signal does not significantly influence the support equipment (SE), but the highest levels of disturbance significantly affect the equipment under test (EUT) due to the high-pass filter within . This network is placed between the EUT and SE. Coupling and decoupling networks use less power from a power amplifier than bulk current injection (BCI). Most decoupling networks are inductive and use a high-impedance choke.

Figure 13 Example of CDN, developed by Shaffner.

Injection of the signal must be performed on unscreened cables, shielded cables, balanced cables, coaxial cables, and power mains. A CDN acts as a low-pass filter, preventing the susceptibility test signals from interfering with the support equipment. The disadvantage of having to test products using CDNs is that a number of different units must be used, according to the number of different interfaces that must be tested. For cables with more than two or four wire pairs, a CDN test is impractical.

2.3. TEST FACILITIES

Some tests have to be performed in specials facilities or chambers, the physical structure and designed make them perfect to developed tests for EMC compliance. Not all of them are specified in the CISPR standards but they are approved, tested and certified to be used to perform the tests due to the high precision and accuracy that they present during the tests.

Four kinds of chambers certified to perform full compliance are:

- Open Area Test Site (OATS).
- Anechoic Chamber.
- GTEM Cell.
- Shield Room.

2.3.1. Open area test site

According to the CISPR standards this is the facility where the radiated test should be done and is commonly call OATS. It provides the most direct and universally acceptable approach. An OATS requires a calibrated receive antenna, a proper ground plane, and quality coaxial cables and must be located a significant distance from metallic objects and high-ambient electromagnetic fields such as broadcast towers and power lines.

The test site shall be flat, free of overhead wires or electromagnetic conductive elements such as nails, screws and others, and hence it must be made of wood. Also, the test site should be away from reflecting structures; this includes the control room where the measurement equipment is located.

The form of the OATS is required to be an ellipse; and, the EUT and measurement antenna must be placed on the focus of this ellipse, as shown in figure 15. The major diameter of this ellipse is 20 m, twice the distance between the EUT and antenna. The minor diameter is 17.3 m. The distance between source and receiver antenna is usually 3 m, 10 m, or 30 m depending on the test specification used and physical size of the EUT.

Figure 14 Example of an OATS.

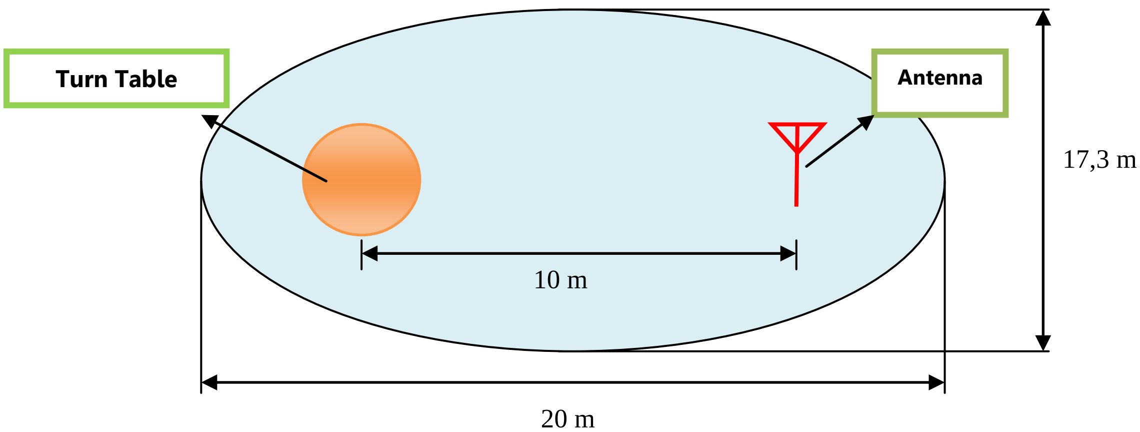


Figure 15 Dimensions of an OATS

All OATS must have a *Reflecting Ground Plane.* This plane is usually rectangular with a width twice the maximum test unit dimension and extending the plane 1 m beyond the perimeter of the test unit and 1 m beyond the measurement antenna on both sides. The ground plane must not have gaps or voids that are a significant fraction of a wavelength at 1 GHz. The recommended mesh size of a perforated metal ground plane is 30 mm. For installations on a paved area or rooftop, the metal ground plane should be the size of the ellipse.

Also an important element of OATS is the *Turntable.* The turntable must be able to support the weight of the EUT and accessory equipment; there are turntables in the market that can handle a large amount of weight. A turntable facilitates determination of direction of maximum radiation at each EUT emission frequency.

The primary disadvantage of using an OATS is the need to search the entire frequency spectrum for unintentional radiated emissions within an electromagnetic environment that may have ambient noise that far exceeds a propagated signal from the EUT being measured.

Other disadvantage, is the high cost of construction of an elliptic OATS; although, the international certification agencies allow the performance of conformity tests in rectangular OATS with the same dimensions.

2.3.2. Anechoic chamber

The anechoic chamber is the most common shielded facility in use. There are two types of chambers, anechoic and semianechoic. An anechoic chamber has shielding material on the floor and walls, the most common materials used for this shield are carbon and iron. This shield contains carbon-filled absorber cones, ferrite tiles, or a combination of both. On the other hand, a semianechoic facility (Figure 16) has the same shielding system on the walls as the anechoic chamber but the floor is a solid metal ground plane, simulating the effects of an OATS. The size of the absorbers should be suitable for the size of the EUT to be tested in order to achieve adequate control over the tolerance of the required field strength for radiated immunity tests.

Figure 16 Example of semianechoic chamber

The primary criterion for a chamber is the uniformity of the field strength that illuminates the EUT. Larger or smaller screened enclosures may be used if it can be demonstrated that the radiated field is not altered in such a way as to affect test results; therefore, no specifications of size or shape for this chamber or the absorbers are required. But, the chamber must be calibrated before any test to ensure the accuracy of the data.

The measurements made in the anechoic chamber are very similar and close with the ones made in the OATS, but anechoic chambers are more expensive than OATS and less effective at lower frequencies because the absorbers are less efficient.

2.3.3.GTEM Cell

The GTEM (Gigahertz Transverse Electromagnetic) cell is a small enclosure used in normal laboratory environments for radiated immunity tests. The most common unit looks like a pyramid lying on its side, an example of a GTEM cells is shown in figure 17.

Figure 17 Example of GTEM Cell.

The restriction on the frequency of the radiated field is made by tapering the transmission line continuously outward from the feed point to a termination system. This is made with a septum or an electromagnetic material that works similar as an antenna.

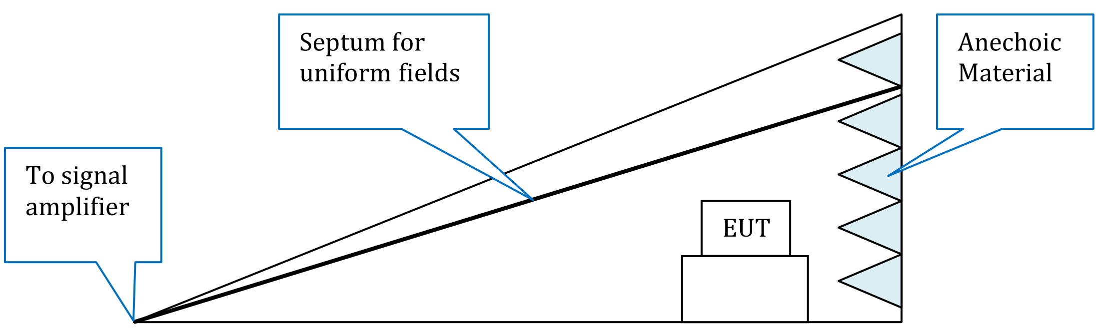


Figure 18 Internal elements of the GTEM Cell

The EUT is located on the rectangular end of the transmission line. A dielectric spacer is used to electrically isolate the EUT from the outer and inner conductors of the transmission line. The presence of a closed outer shell provides an effective shield to isolate electromagnetic fields. Also, anechoic cones are placed in the rectangular wall of the camber to prevent the reflection of the RF Waves and the distortion of the field.

Advantages of the GTEM Cells are: small size, low cost, and lack of need for a high power amplifier. This chamber can be located almost anywhere. In addition, no additional shielding is required to attenuate external radiated fields. One disadvantage is that a window is required if one is to view operation of the EUT, such as a video screen.

2.3.4. Shield room

A screen or shield room (Figure 19) is a facility that is used for diagnostic testing or debugging known EMI problems. In addition, this room can be used to perform conducted emission tests for regulatory compliance (EN55022 and FCC Part 15). Use of this room for radiated emission compliance is not permitted. This is because multiple reflections of RF waves are bouncing around the chamber, distorting the real signature profile of the EUT.

Figure 19 Example of Shield Room. Developed by ETS·LINDGREN.

Most screen/shield rooms are built from modular steel and wood sandwich panels welded or clamped together. Honeycomb assemblies provide ventilation. A screen room may contain a copper mesh screen for the walls of the room; this mesh not only allows for air ventilation but also provides a scenic view of the test laboratory. All electrical services that enter the chamber must be filtered; this includes AC mains, I/O, and lightning protection.

Lights must be incandescent as fluorescent bulbs emit broadband interference. The most critical part of a screen/shield room is the door assembly. A double-wiping action knife-edge gasket must contact the door frame on all four sides with beryllium copper finger strips.

A shield room isolates the EUT and support equipment from the external environment, which may cause erroneous operation or false readings. A removable bulkhead panel is generally provided to allow multiple cable assemblies to enter the room; depending on the application, certain interconnect cables will require filtering.

2.4. GENERATORS

There are many signals generators in the market than can be used for lab test, but not all of them are designed for EMC compliance, only a portion of those equipments are authorized or certified to be used in this field.

Some of those equipments are the EFT generator, Surge generator and the ESD gun. The operation of these equipments is based on the charging of an arrangement of capacitors that through a switching system are discharged according to a certain timing to obtain the signals specified in the standards.

(a)

(b)

(c)

Figure 20 Examples of generators. (a) EFT generator developed by Haefely: PEFT 4010, (b) Surge generator developed by Haefely: PIM 100, and (c) ESD gun developed by KeyTek: KeyTek MiniZap.

3. EMC STANDARDS, PHENOMENA AND TEST PROCEDURES

3.1. FCC PART 15

On May 4th of 2007, the Federal Communications Commission of the United States of America published the latest version of the FCC Part 15 standard. This standard was developed to limit the radiation of electromagnetic fields to the environment and the conduction of electric fields through the power cable to the electric grid from all the electric and electronic equipment being connected to the American power system, 120 V at 60 Hz. It is available at http://www.fcc.gov/oet/info/rules/part15/part15-5-4-07.pdf

The FCC part 15 standard is divided in 7 sections, Subparts:

- Subpart A: General.
- Subpart B: Unintentional Radiators.
- Subpart C: Intentional Radiators.
- Subpart D: Unlicensed Personal Communications Service Devices.
- Subpart E: Unlicensed National Information Infrastructure Devices.
- Subpart F: Ultra-Wideband Operation.
- Subpart G: Access Broadband Over Power Line (Access BPL).

In the Subpart A are all the definitions of the terms used in the standard, equipment under test classification, test conditions and restrictions, support equipment conditions and restrictions, and the information that should be given to the customer.

The products are classified in two categories, INTENTIONAL RADIATORS and UNINTENTIONAL RADIATORS. The intentional radiators work with antennas and wireless technology to transmit and receive data from their sources. On the other hand, the unintentional radiators do not work with any kind of antenna, they do not need wireless connections to transmit or receive data, but they radiate energy to the environment without purpose.

Also the FCC part 15 classifies the equipment under test in two classes depending on the purpose of the product; if the equipment was developed to be installed in a commercial environment, business environment or industrial environment without public access, then the equipment is class A; but the equipment is class B if it is meant to be used in a medical environment, commercial environment, business environment or even a residential environment and has to be manipulated by the public. Class B has the most demanding limits of both and is the most difficult class to reach.

Magenta's products are classified as unintentional radiators; then in Subpart B are the limits for the unintentional radiators class A and class B; these limits are for the electromagnetic fields radiations and for the conductance of electric fields through the AC power connector.

3.1.1. Terminal disturbance voltage emissions test

The conducted limits for both classes are specified in the section 15.107, this measurement has to be done with a LISN (Line Impedance Stabilization Network) with an impedance equal to 50Ω/50µH; every measurement has to be done between each power line and ground of the power terminal.

The limits for class A are:

Frequency (MHz)	Limits (dBµV)	
	Quasi-Peak	Average
0,15-0,5	79	66
0,5-30	73	60

Table 2 FCC terminal disturbance limits for class A

The limits for class B are:

Frequency (MHz)	Limits (dBµV)	
	Quasi-Peak	Average
0,15-0,5	66 to 56*	56 to 46*
0,5-5	56	46
5-30	60	50

*Decrease with the logarithm of the frequency.

Table 3 FCC terminal disturbance limits for class B

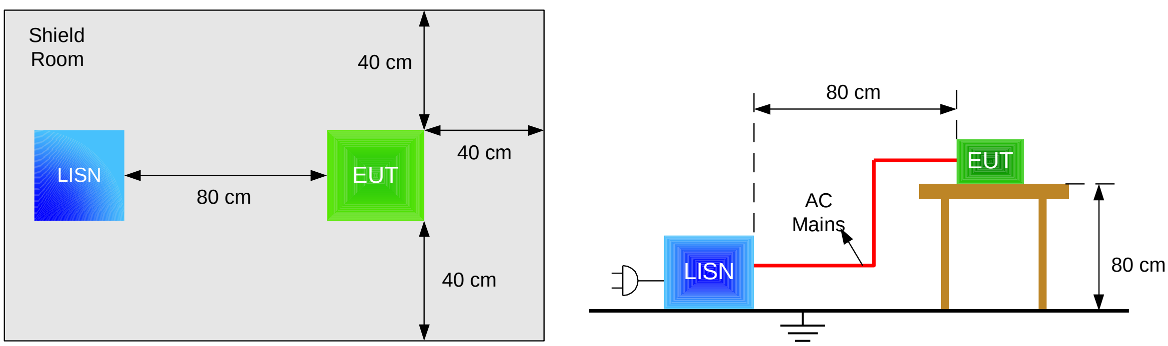
Test procedure for terminal disturbance voltage emission measurement

Equipment:

- ✓ One Shield Room
- ✓ One Spectrum Analyzer
- ✓ One RF Receive
- ✓ One LISN
- ✓ Equipment Under Test (EUT) and Support Equipment.

Procedure:

The EUT is placed on a table of 80 cm tall located at least at 40 cm from the walls of the shield room and 80 cm from the LISN as shown in figure 21. The LISN is energized with 120 V at 60 Hz; the EUT is plugged to the mains through the LISN.



(a) (b)

Figure 21 Location inside the shield room, (a) above view and (b) front view.

With a measurements tip connect the LISN to the spectrum analyzer; the LISN has a switch to measure the emissions in the three phases of the power cord of the equipment.

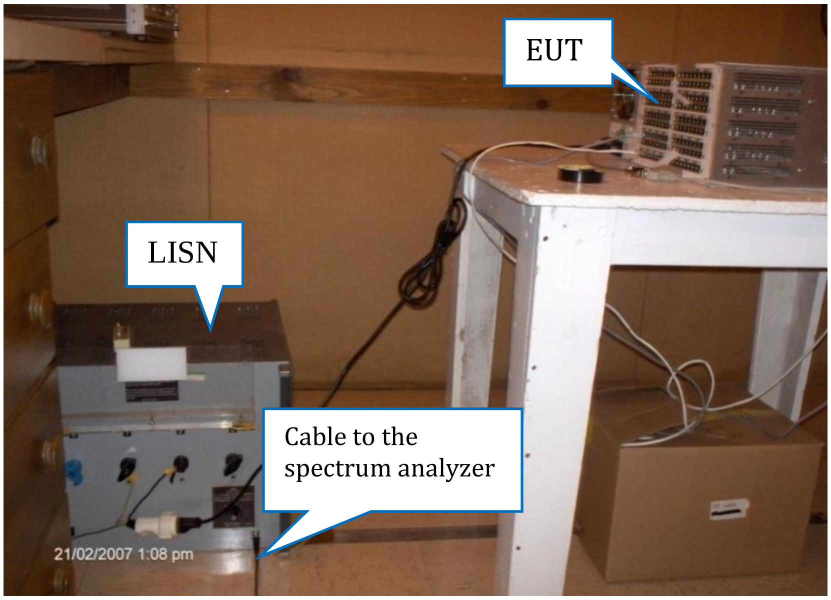


Figure 22 Picture taken to test set up. Source: Author.

Configure the spectrum analyzer to show the frequencies between 150 kHz and 30 MHz, identify the frequencies were the highest peaks appear.

Change the measurements tip from the spectrum analyzer to the RF Receiver and measure these frequencies again, the amplitude shown by the spectrum analyzer is similar to the amplitude shown by the RF Receiver.

In order to have the real emission level, sum this amplitude to the cable losses and keep it on the records. An example of the table of records is shown in appendix A.

Change the position of the switch of the LISN to other line to measure its emissions in the same range of frequencies.

Figure 23 Picture taken to the set up of the conducted emissions measurements. Source: Author.

3.1.2. Radiated emissions measurement

In the section 15.109 are the limits for the radiated emission for class A and Class B; the measurements for class A must be done with the antenna or electromagnetic fields receptor at 10 m and for class B must be done at 3 m.

The levels specified in the standard are in field strength units, μV/m , to make them comparable with the measurement shown in the spectrum analyzer, the following formula has to be taken in account, and E must be given in μV/m:

$$\mathbf{dB\mu V/m = 20\log_{10}(E) \quad ; \quad E \rightarrow \mu V/m}$$

The limits for class A at 10 m are:

Frequency MHz	Field strength μV/m	Decibels level dBμV/m
30-88	90	39
88-216	150	43,5
216-960	210	46,4
Above 960	300	49,5

Table 4 FCC limits for radiated emissions for class A

The limits for class B at 3 m are:

Frequency MHz	Field strength µV/m	Decibels level dBµV/m
30-88	100	40
88-216	150	43,5
216-960	200	46
Above 960	500	54

Table 5 FCC limits for radiated emissions for class B

Test procedure for radiated emission measurements

Equipment:

- ✓ One Open Area Test Site (OATS)
- ✓ One Biconical Antenna
- ✓ One Log-period Antenna
- ✓ One Double-Ridged Antenna
- ✓ One Spectrum Analyzer
- ✓ One RF Receiver
- ✓ 50 Ω Attenuator
- ✓ Equipment Under Test (EUT) and Support Equipment

Procedure

Install the EUT on a table of 80 cm of high on the center of the turn table that is inside the OATS; energize the EUT at 110V at 60 Hz. The support equipment must be installed on the floor of the OATS or on a table far from the EUT.

Place the Biconical antenna in vertical position to measure the frequencies between 30 MHz and 300 MHz at a distance of 10 m from the EUT for class A or 3 m from the EUT for class B and between 1 m and 4 m from the floor, as shown in figure 24 and figure 25. The support for the antenna must be made of an electromagnetic insulation material (figure 26).

Inside the OATS only can be the EUT, the support equipment and the antenna.

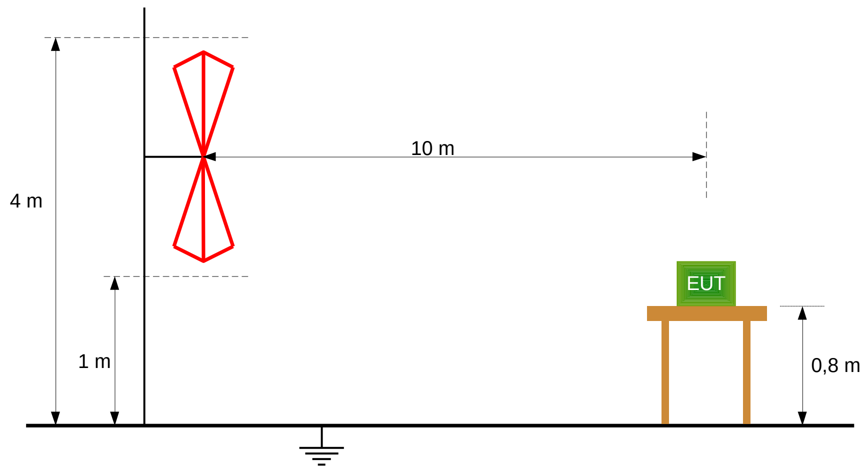


Figure 24 Diagram of distances for radiated emissions measurements.

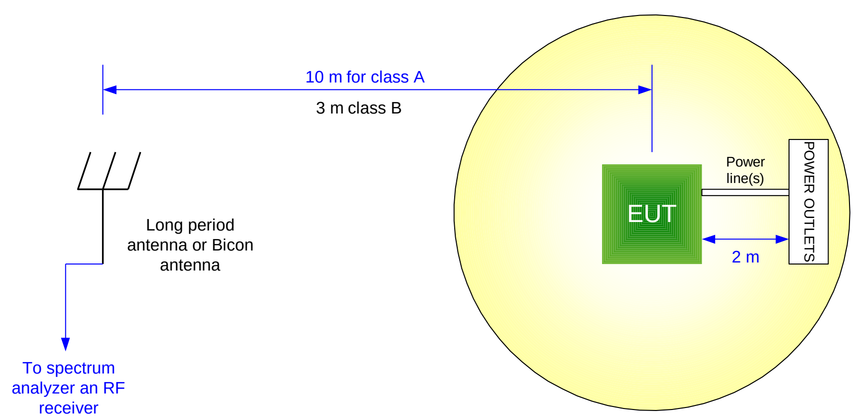


Figure 25 Connections diagram

Figure 26 Support for the antenna. Source: Author

Figure 27 Picture taken to the radiated emissions measurements inside the OATS. Source: Author.

Use a coaxial cable and the 50 Ω attenuator to connect the antenna to the spectrum analyzer; if the spectrum analyzer is installed outside the OATS in another building, then the coaxial cable has to be as short as possible and underground.

Once the setup is done, the spectrum analyzer has to be configured to view the frequencies between 30 MHz and 300 MHz, is recommended to use a small sweep step in the spectrum analyzer to view the frequencies and the amplitude as exact as possible. Remember that most of the spectrum analyzers show the amplitude in dB in the quasi-peak mode.

Check the frequencies shown by the spectrum analyzer and identify the frequencies with are highest peaks, connect the antenna to the RF receiver to identify if is an ambient signal or comes from the equipment itself; if the signal comes from the EUT, check again by rotating the turn table 360° slowly in order to identify the angle of the highest emission.

Note that the amplitude shown by the spectrum analyzer and the RF receiver must be similar. This amplitude has to be summed with the antenna factor and the cable losses. Keep these levels in a table as the example shown in appendix A.

When the measurement of the frequencies between 30 MHz and 300 MHz in the vertical position of the antenna is finished, rotate the antenna 90° to the horizontal position facing the EUT and check the range of frequencies again.

Change the Biconical antenna for the long-period antenna to measure the frequencies between 300 MHz and 1GHz and repeat the previous procedure.

Once again exchange the Log-period antenna with the Horn antenna and placed the antenna at 3 m (9 ft) from the EUT. Measure the frequencies between 1 GHz and 18 GHz, the limit for these frequencies is 59,5 dBµV/m.

3.2. EN55022: LIMITS AND METHODS OF MEASUREMENTS OF RADIO INTERFERENCE CHARACTERISTICS OF INFORMATION TECHNOLOGY EQUIPMENT.

The EN55022 standard is the European homologous of the American standard, FCC Part 15.

As the FCC Part 15, the EN55022 specifies the limits for the radiation of electromagnetic fields to the environment and the limits for the conduction of electric fields through the power cable to the electric grid for all the products attended to be connected to the European power system, 230 V at 50 Hz. All the electric and electronic products are classified according to the intention to radiate, unintentional radiators and intentional radiators; also according to the environment they are going to be install in, Class A: Industrial and commercial environment without public access and Class B: Industrial and commercial environment with public access, medical and residential environment.

The EN55022 not only limits the conduction through the power cable, also limits the conduction through the cables connected to the support equipment in the voltage and current wave. This type of conduction of electric fields is known as common-mode cables emissions.

3.2.1. Conductive limits, radiated limits and test procedures

Radiated limits at 10 m:

Frequency MHz	Class A	Class B
	Quasi-Peak (dBµV/m)	Quasi-Peak (dBµV/m)
30 - 230	40	30
230 - 1000	47	37

Table 6 EN55022 limits for radiated emissions.

The conducted limits through the AC mains according to the EN 55022 are the same limits establish by the American standard FCC part 15 (Tables 2 and 3). Also, the test procedures to measure the conductive emissions and the radiated emissions are the same as the test procedures specified for the FCC Part 15. The antenna used for the radiated emissions test must be place at 10 m from the EUT; this is regardless of the class of the EUT.

For both test procedures, the EUT has to be energized with 230 V at 50 Hz.

3.2.2. Limits for common-mode cable emissions and test procedure

Common-mode cable limits for class A:

Frequency MHz	Voltage limits dBµV		Current limits dBµA	
	Quasi-Peak	Average	Quasi-Peak	Average
0,15 - 0,5	97 - 87*	84 - 74*	53 - 43*	40 - 30*
0,5 – 30	87	74	43	30

*Decrease linearly with the logarithm of the frequency

Table 7 Common-mode limits for class A

Common-mode cable limits for class B:

Frequency MHz	Voltage limits dBμV		Current limits dBμA	
	Quasi-Peak	Average	Quasi-Peak	Average
0,15 - 0,5	84 - 74*	74 - 64*	40 -30*	30 - 20*
0,5 - 30	74	64	30	20

*Decrease linearly with the logarithm of the frequency

Table 8 Common-mode limits for class B

Test procedure for common-mode emissions measurement

Equipment:

- ✓ One Shield room
- ✓ One Spectrum Analyzer
- ✓ One RF Receiver
- ✓ One Capacitive Clamp
- ✓ One Current clamp
- ✓ One Ferrite
- ✓ One LISN
- ✓ Equipment Under Test (EUT) and Support Equipment.

Procedure

Install the EUT inside the shield room on a table or wood support of 40 cm tall, energize the LISN with 230 V at 50 Hz. The power supply of the EUT shall be connected to the mains through the LISN.

In a range of 30 cm to 70 cm of UTP cable measured from the EUT, place the current clamp and the capacitive clamp. Use the ferrite at the Support Equipment side to prevent the conduction of noise backwards into the EUT. See figure 28.

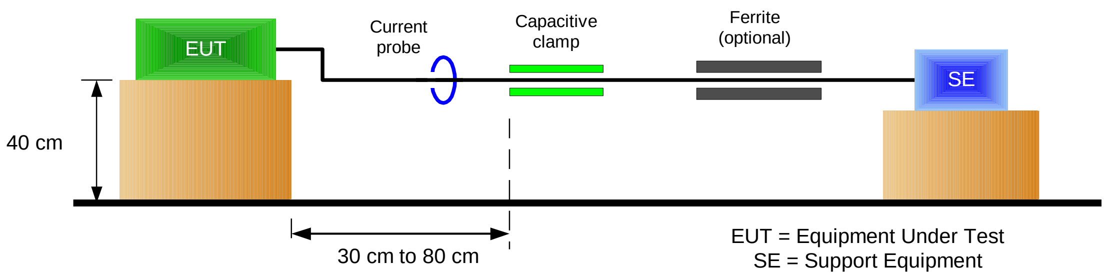


Figure 28 Location of the EUT, measurement equipment and support equipment.

With a tip, connect the current probe to the spectrum analyzer and check the frequencies between 150 kHz and 30 MHz; identify the frequencies with the highest emissions.

Connect the current probe to the RF receiver and check the same range of frequencies. The measurement shows by the spectrum analyzer and the RF receiver must be similar in frequency and amplitude. Sum the level shown by the RF receiver and the cable losses; keep this measure in a table as the one shown in appendix A.

Once the current is checked, connect the capacitive clamp to the spectrum analyzer and repeat the test in the same range of frequencies.

3.3. IEC61000-3-2: LIMITS FOR HARMONIC CURRENT EMISSIONS (EQUIPMENT INPUT CURRENT <= 16 A PER PHASE)

These days, the harmonics present in the voltage and current of the power system have become of great concern considering the problems they could cause to the equipment connected to the same power system.

All AC-DC power converters use a rectifier-capacitor to create a DC voltage level. This capacitor is, by itself, a “linear” load; but for the main supply seems to be a nonlinear load due to its discontinuous supply current and the non-sine wave, both rich in harmonics.

A particular problem with power converters is that they emit significant levels of triplen harmonics (3^{rd}, 9^{th}, 15^{th}, etc) causing heating of cables and transformers; also they add non-linearly in neutral conductors because there is no phase cancellation.

The harmonic current drawn from equipment's ac mains supply has no effect on the power consumption if it is measured in W (Watts); but will increase if it is measure in VA (Volt-Amperes). The ratio of equipment's consumption of W to its VA is known as PF (Power Factor), so if the equipment has a significant harmonics emission, it means that it has a lower PF. A PF of 1 means that the VA is equal to the W consumption and it looks like a pure resistance load.

The "Skin effect" has become a concern, in that large amounts of harmonics are present in the current drawn from the electric power system. The high frequency harmonics cause electrons flow toward the outer portion of a conductor; this reduce the ability of the conductor to carry current by reducing the cross sectional diameter of the conductor, thereby reducing the current capacity of the conductor and increasing the power losses by heating the conductor. The skin effect increases as the frequency and amplitude increases.

Also, the overcurrent protection devices like fuses, detect the actual heating effect of the conductor at lower levels of current than expected, due to the heating effect of the harmonics; reducing the operational life of the thermal control system.

Other problems less destructive, but not less important than skin effect, are telephone interference, distortion of the voltage wave form, lower DC voltage levels and others.
With the IEC 61000-3-2 standard, the European community establishes the harmonics emission limits where minimum effects are caused by them. All electronic equipment must fit in one of the four classes established in this standard, each of them with its own harmonic limits:

- ✓ Class A: Balance three phase equipment and everything else that do not fit into the others classes.

- ✓ Class B: Portable tools.

- ✓ Class C: Lighting equipment, including dimmers.
- ✓ Class D: Personal computers and TV receivers, with a specified power less than or equal to 600 W.

The limits for each class are:

	Class A	Class B	Class C	Class D
Harmonic order "n"	Maximum current (A)	Maximum current (A)	Maximum current (% of fundamental current) (A)	Maximum current (No more than class A)
2	1,08	1,62	2%	--
3	2,3	3,45	(30*pf)%	3,4 mA/W
4	0,3	0,645	--	--
5	1,14	1,71	10%	1,9 mA/W
6	0,30	0,45	--	--
7	0,77	1,155	7%	1 mA/W
8≤n≤40 (even)	0,23(8/n)	0,345(8/n)	--	--
9	0,40	0,60	5%	0,5 mA/W
11	0,33	0,495	3%	--
13	0,21	0,315	3%	0,35 mA/W
15≤n≤39 (odd)	0,15(15/n)	0,225(15/n)	3%	(3,85/n) mA/W

pf is the circuit power factor.

Table 9 IEC61000-3-2 limits. Excerpt of reference 5.

Measurement equipment and test procedure

Equipment

- ✓ One Shield Room
- ✓ One Harmonics Analyzer
- ✓ Equipment Under Test (EUT) and Support Equipment

Procedure

Install the EUT and the support equipment inside the shield room, as the customer would, on a ground plane; the EUT's AC power cable is connected to the analyzer through an adapter included with the analyzer, see the analyzer's manual.

Once the set up is done, identify the class of the equipment to perform the harmonic test and configure the analyzer to compare the harmonic's amplitude from the EUT with the limits according to the standard, see the analyzer's manual. Most of the analyzers do not have the limits in the memory and they have to be typed into the analyzer's configuration.

Once the analyzer starts the test, no intervention will be needed until the test is over. The results will be shown in the analyzer screen as well as the verdict of the test.

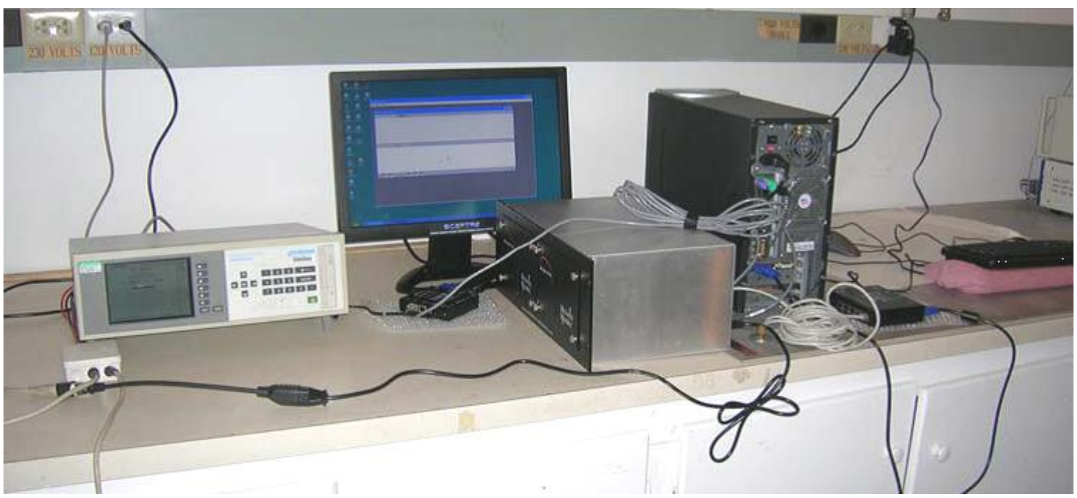
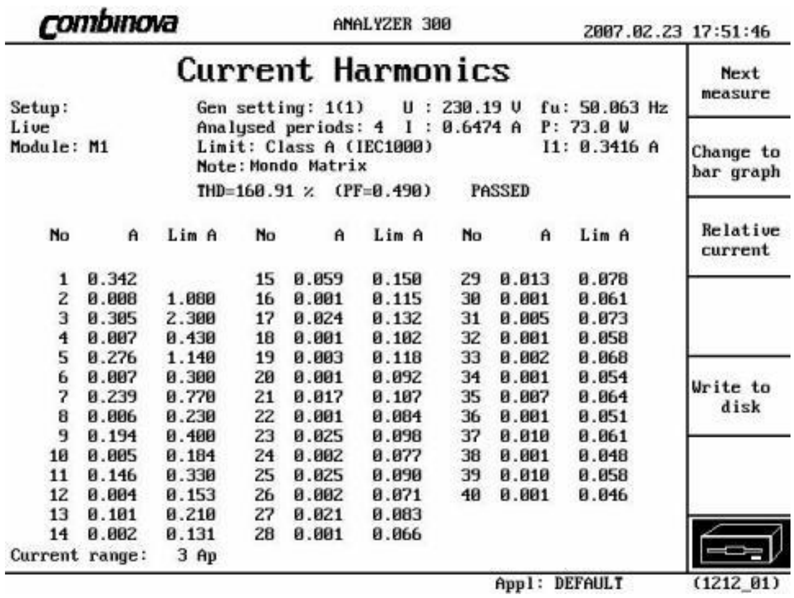
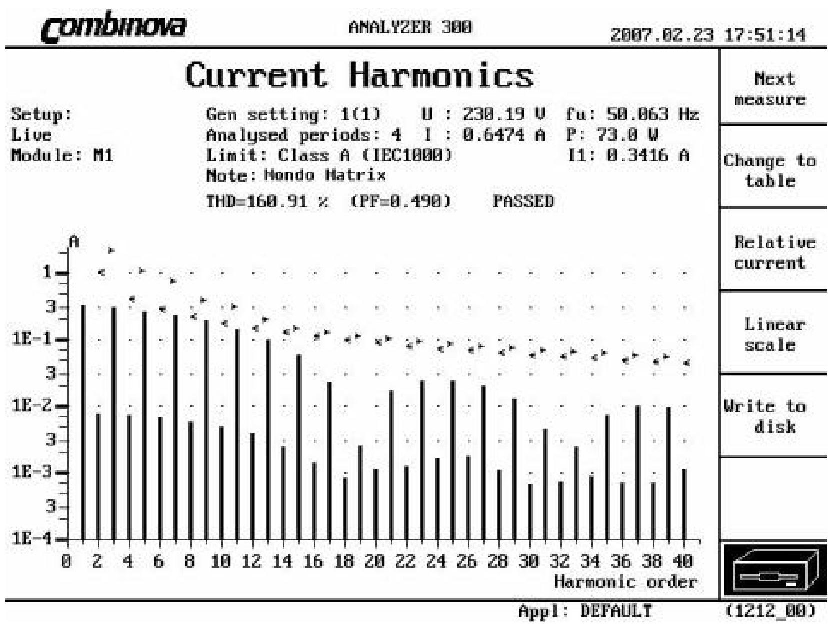


Figure 29 Set up for harmonic analysis. Source: Author.



No	A	Lim A	No	A	Lim A	No	A	Lim A
1	0.342		15	0.059	0.150	29	0.013	0.078
2	0.008	1.080	16	0.001	0.115	30	0.001	0.061
3	0.305	2.300	17	0.024	0.132	31	0.005	0.073
4	0.007	0.430	18	0.001	0.102	32	0.001	0.058
5	0.276	1.140	19	0.003	0.118	33	0.002	0.068
6	0.007	0.300	20	0.001	0.092	34	0.001	0.054
7	0.239	0.770	21	0.017	0.107	35	0.007	0.064
8	0.006	0.230	22	0.001	0.084	36	0.001	0.051
9	0.194	0.400	23	0.025	0.098	37	0.010	0.061
10	0.005	0.184	24	0.002	0.077	38	0.001	0.048
11	0.146	0.330	25	0.025	0.090	39	0.010	0.058
12	0.004	0.153	26	0.002	0.071	40	0.001	0.046
13	0.101	0.210	27	0.021	0.083			
14	0.002	0.131	28	0.001	0.066			

(a)



(b)

Figure 30 Example of harmonics test results, (a) table and (b) graph. Excerpt of reference 6.

3.4. IEC61000-3-3: LIMITATION OF VOLTAGE CHANGES, VOLTAGE FLUCTUATIONS AND FLICKER IN PUBLIC LOW-VOLTAGE SUPPLY SYSTEMS, FOR EQUIPMENT WITH RATED CURRENT <= 16 A PER PHASE AND NOT SUBJECT TO CONDITIONAL CONNECTION.

Voltage changes and voltage fluctuations are of great concern around the world. These changes or fluctuations are created by the switching of loads from the power distribution systems and affect the rms voltage value. If this value is greater than the tolerance of the power supply of the equipment, a flicker is observed in luminaries and can caused harm to those sensitive to flashing lights, like people who suffer from seizures.

Flicker is defines as the "impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time." [2].

The most concerning problem caused by flickers is related to humans, lighting flickers causes annoyance and possibly mental strain. The changes in the intensity of light that comes from a light bulb are annoying and stressful for people; a significant portion of humans are especially sensitive to these changes and can suffer of headaches, migraines and in the worst case can suffer epileptic seizures.

But not only the humans are affected by the flickers; when certain types of equipment such as TVs, power hi-fi systems or electric motors are switched on, a momentarily "blink" occurs in many lights that are connected to the same electrical network due to the high current induced by this equipment in the power system making the protection device to open, removing the power from numerous equipment causing lost production, wasted time and possibly increasing safety risk.

This standard limits the voltage variations generated across a reference load defined as follow:

- Relative changes in voltage characteristics, d_t .
- Maximum relative voltage change, d_{max} .
- Relative steady-state voltage change, d_c .
- Short-term flicker value, P_{st} .
- Long-term flicker value, P_{lt} .

To evaluate effects of voltage changes in the distribution network, the rms value is measure over successive half-periods of 10 ms each and the waveform obtained from this measure is called relative changes in voltage characteristics, d_t .

Two other characteristics are extracted from this graphic, the maximum relative voltage change, d_{max} , which is defined as the difference between the maximum and the minimum values of the voltage change characteristics; and the relative steady-state voltage change, d_c , which is the is the difference between two adjacent steady-state voltages separated by at least one change (steady-state is defined as persisting for at least 1 second).

Short-term flicker value and long-term flicker value

The level of sensitivity of the human brain to flickers is measure as the frequency of the voltage fluctuations; these fluctuations are processed over a period of a few minutes to take account of their frequency, the shape of the voltage change characteristics, and the cumulative irritating effect to repeated fluctuations.

This process gives two flicker values. The short-term flicker value is observed over a period of 10 minutes, to include the part of the operating cycle where the equipment under test produces the least favorable sequence of voltage changes and the long-term flicker value, is observed over a period of 2 hours. The specifications of how to calculate these values are in IEC 60868.

To make sure that all the electronic equipment does not produce flickers, this standard establishes the following limits:

- d_t is not allowed to exceed 3% for more than 200 ms.
- d_{max} is not allowed to exceed 4%.
- d_c is not allowed to exceed 3%.
- Short-term flicker is not allowed to exceed the value of 1.
- Long-term flicker is not allowed to exceed the value of 0,65.

NOTE: For manual switching equipment, the above limits are multiplied by 1,33 , the short-term flicker and long-term flicker are not applicable.

Measurement Equipment and Test Procedure.

Equipment

- ✓ One Shield Room
- ✓ One Flickermeter
- ✓ Ground plane
- ✓ Equipment Under Test and Support Equipment

Procedure

Install the EUT and the support equipment inside the shield room. The AC power cable of the EUT must be plugged to the flickermeter. See flickermeter's manual.

Configure the flickermeter to measure the EUT's voltage fluctuations and compare them with the limits establish in IEC 61000-3-3. Not all the flickermeters have the limits programmed in the configuration. Make sure to set the limits in the configuration process of the flickermeter. See flickermeter's manual.

The results of the test are shown in the screen of the flickermeter.

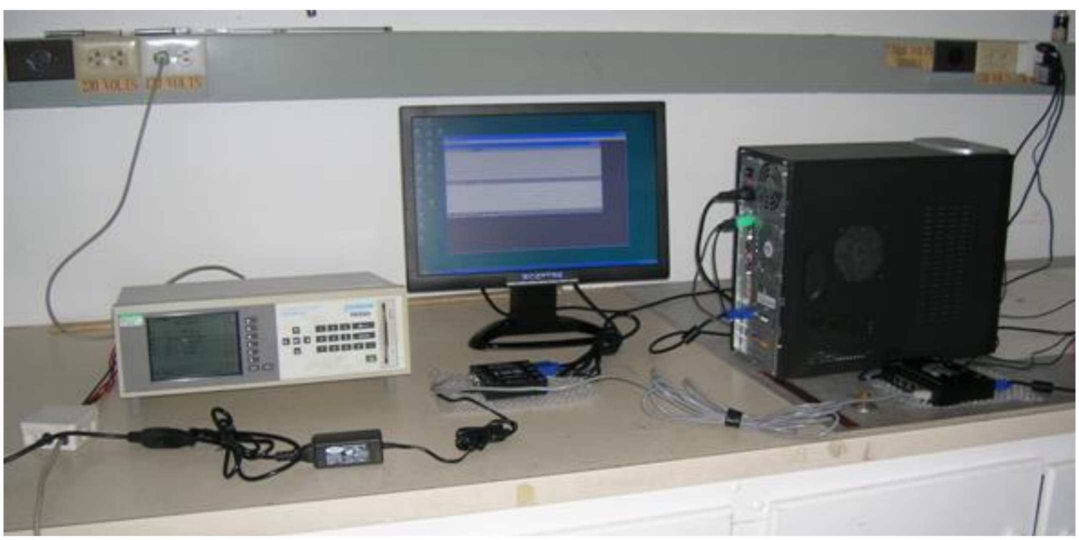
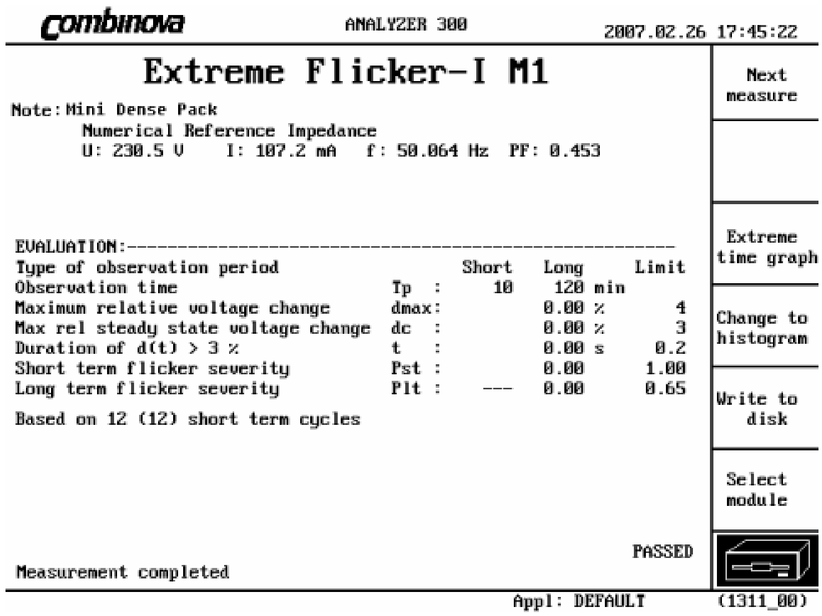


Figure 31 Picture taken of the set up for voltage fluctuations measurements. Source: Author.



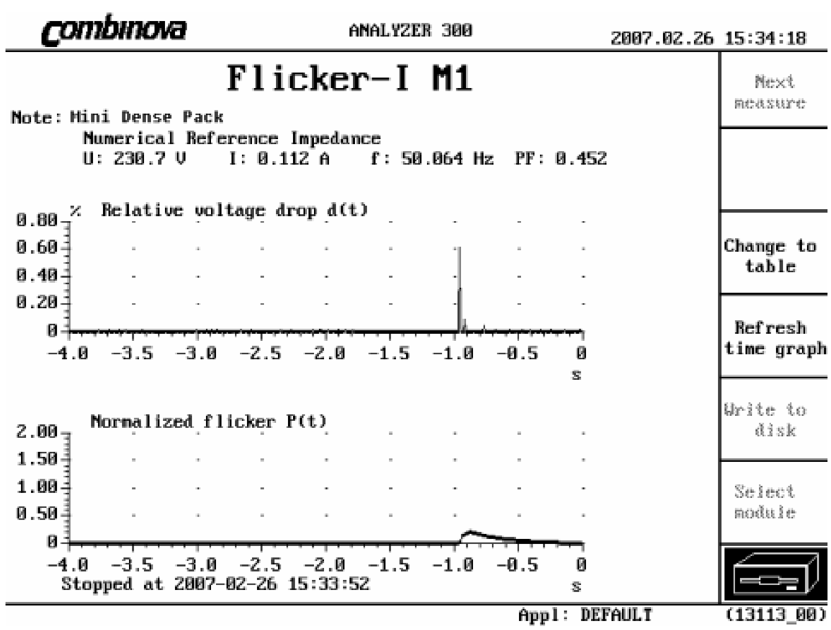


Figure 32 Example of flicker test results. Excerpt of reference 6.

3.5. ELECTROMAGNETIC IMMUNITY STANDARDS

Every electronic equipment attempted to be sold in Europe must meet the European immunity standards announced in EN 55024, these standards were developed by IEC (International Electrotechnical Commission) to guarantee the functioning of the products under common phenomena produced in the European electric system.

The immunity standards announced in EN 55024 correspond to the standard family IEC 61000-4; the standards applicable to Magenta's products are:

a) IEC 61000-4-2: Electrostatic Discharge Immunity Test.
b) IEC 61000-4-3: Radiated Radio Frequency Electromagnetic Field Immunity Test.
c) IEC 61000-4-4: Electrical Fast Transient/Burst Immunity Test.
d) IEC 61000-4-5: Surge Immunity Test.
e) IEC 61000-4-6: Immunity to conducted disturbances, induced by radio-frequency fields.
f) IEC 61000-4-11: Voltage Dips, Short Interruptions and Voltage Variations Immunity Tests

One of the biggest differences between limited standards and the immunity standards is the limits; the immunity standards evaluate the performance of the equipment with criterions instead of limits. These criterions are:

- Criterion A: The equipment is not affected during the test.

- Criterion B: The functions of the equipment are affected and present self recover.

- Criterion C: The functions of the equipment are affected and need the intervention of an operator to recover.

3.5.1. IEC 61000-4-2: Electrostatic discharge immunity test.

The electrostatic discharges are a common phenomena produced by contact between different types of materials, equipment, even nature and humans.

Static charges accumulate on an object or a person by rubbing its surface with other materials, this process is known as tribocharging. When similar materials rub their surfaces, one of them will steal electrons from the other, creating a separation of electrical charge between the two materials, as shown in figure 33.

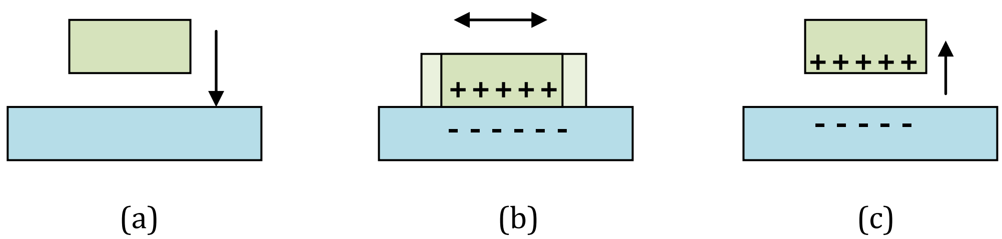


Figure 33 Tribocharging process. (a) Two materials are brought together, (b) contact and rubbing and (c) the two materials are separated and the charge imbalance between them remains.

When the objects are separated, the capacitance between them decreases and the voltage increase to keep the static charge according to Q=C*V.

Where the voltage is sufficient to break down the air between the two materials, by ionizing the air and making it highly conductive, a spark occurs as the separated charges attempt to equalize themselves.

But, not only the voltage present between the objects produces the spark, the ambient conditions also contribute to increase the possibilities of a spark. Humidity reduces the resistance of air, so separated static charges equalize more quickly as relative humidity increases. Also, low temperatures help to condense the air increasing the amount of ions present in the air, decreasing the resistance and allowing a perfect ambient for sparks.

The high current, high voltage and the minimum rise time of the discharge can cause considerable damage in the equipment if it does not have the appropriate insulation to change the path of the current. The currents associated with the discharge flow around shields and through conductors creating voltage drops that can interfere with the functions of the equipment when the electronics devices inside the equipment respond non-linearly to these currents.

Also, electromagnetic fields and sparks can occur inside the equipment when the insulation, commonly the air, is ionized and secondary fields with high amplitude are spread inside the equipment.

In order to know if the product is immune to the electrostatic discharges, this standard requires testing the equipment with a current waveform as shown in figure 34, the equipment has to be tested at different voltage levels, starting at +/-2000 V and finishing at +/-8000 V, the voltage has to change every 2000 V, positive and negative. The test includes 20 discharges for each voltage level, 10 positive and 10 negative; with 1 s of separation.

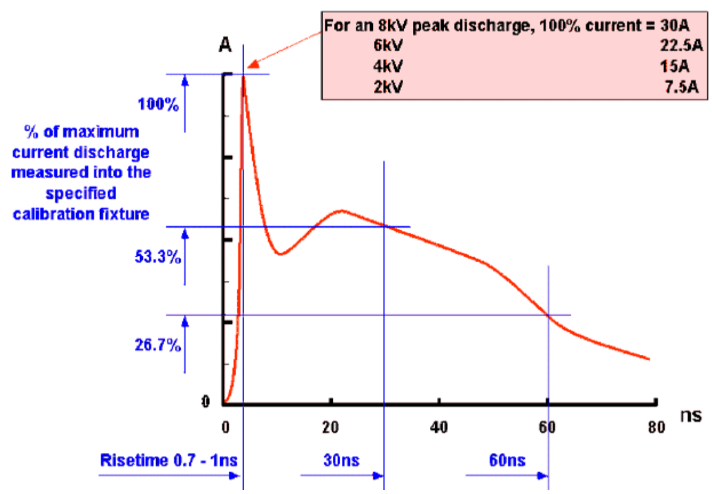


Figure 34 ESD current testing waveform. Excerpt from reference 7.

The test has two parts, direct discharge test and indirect discharge test. The discharges at the different voltage levels have to be made in both parts.

ESD immunity test procedure

Equipment:

- ✓ One support table
- ✓ Metallic Ground plane.
- ✓ Electrostatic Discharge simulator
- ✓ Metallic screen with plastic insulation
- ✓ Equipment under test (EUT) and support equipment.

Procedure

For this test is necessary to keep the temperature between 15°C and 35°C, the relativity humidity between 30% and 60% and the atmospheric pressure between 86 kPa and 106 kPa.

Install the EUT on the ground plane and place an insulation material, like cardboard, between the EUT and the ground plane.

The support equipment must be installed in another place instead of the bench or the table. Avoid contact between the support equipment and the electric ground plane.

This test has two parts, direct discharge and indirect discharge; in order to perform the test two inspections should be done:

- Identify all the connectors, inputs and outputs of the equipment and put numbers to each of them. Also put numbers to the sides of the equipment where are no connectors, continuing with the number list.

- Measure the high of the equipment.

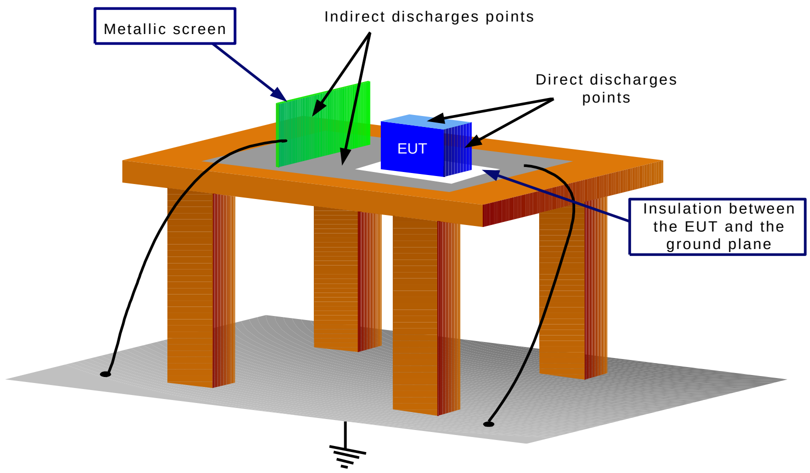


Figure 35 General test set up and discharge points

The indirect discharge part should be done at 10 cm from each side of the equipment in the ground plane, excluding the top and bottom sides. Make 20 discharges of ±2000 V separate by 1 s, 10 discharges for each polarity.

If the functions of the equipment are not affected at this voltage level, increase the voltage in 2000 V, positive and negative, and repeat the discharges. If nothing occurs again increase the voltage in 2000 V. The maximum voltage level is ±8000 V.

The next step is to perform the air discharges, included in the indirect part, with the metallic screen connected to the ground plane; place the screen parallel at 10 cm from the side you are going to zap. Make 20 discharges of ±2000 V separate by 1 s, 10 for each polarity.

If no distortion occurs at this voltage level, increase the voltage in 2000 V, positive and negative, and repeat the discharges again until a level voltage of ±8000 V. Do the same with every side of the EUT, excluding the bottom side.

Note: If the high of the equipment is less than 5 cm, it is allowed to perform the air discharges only in the top side, not the others sides.

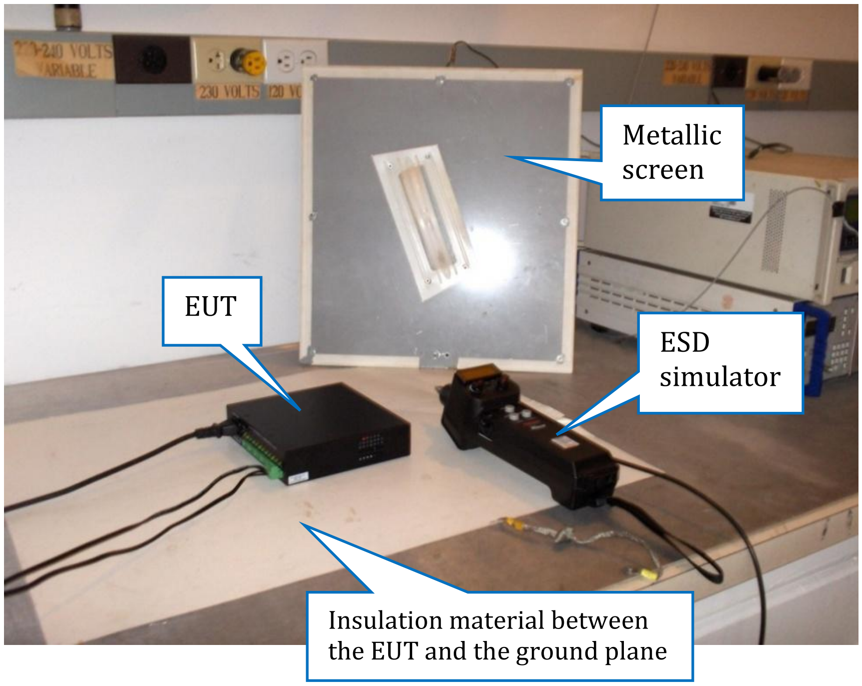


Figure 36 Picture taken of ESD test set up. Source: Author.

For the direct discharge part, perform the same discharge sequence as in the indirect part in all the connectors and sides of the EUT. Do not allow any air gap between the ESD simulator tip and the discharge point.

Keep the results in a table as the one shown in appendix A.

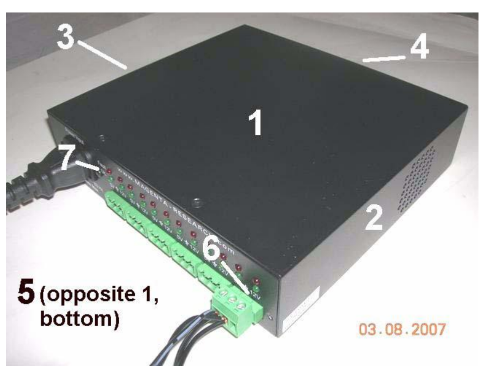


Figure 37 Example of direct discharge points. Source: Author

3.5.2. IEC 61000-4-3: Radiated radio frequency electromagnetic field immunity test

Most of the Radio-Frequency fields are caused directly or indirectly by electric and electronic devices, as well as antennas of radio, television and cell phones.

When conductors and electronic devices are exposed to RF fields, RF currents and voltages are coupled into them. These couple RF currents and voltages have nothing to do with the signals or power that are supposed to carried by those conductors and/or present in the inputs of the electronic devices, so they are classed as noise.

The natural resonances in the conductors and the electronic devices will amplify the amount of noise at some frequencies, attenuating the others causing errors or malfunctions in analogue and/or digital semiconductors; this is a common problem at the clock frequency of digital processors, this kind of problem is called "direct interference".

Also the semiconductors respond non-linearly to these currents and voltages increasing the D.C. offset that depends upon the level of the RF noise and demodulating the RF signal as in a radio receiver.

Another kind of interference is the intermodulation; when more than one RF signal is present at the same time in a non-linear device an intermodulation occurs and new frequencies appear in the circuit; in some circumstances, these new frequencies can have high enough levels to cause direct interference, reducing the quality of the output signals.

The IEC 61000-4-3 standard tests the performance of the equipment under an RF signal of 3 V/m of field strength with 80% of amplitude modulation at 1 KHz. The frequency test change 1% of the previous frequency every second between 80 MHz and 1 GHz. An example of a modulated signal is shown in figure 38.

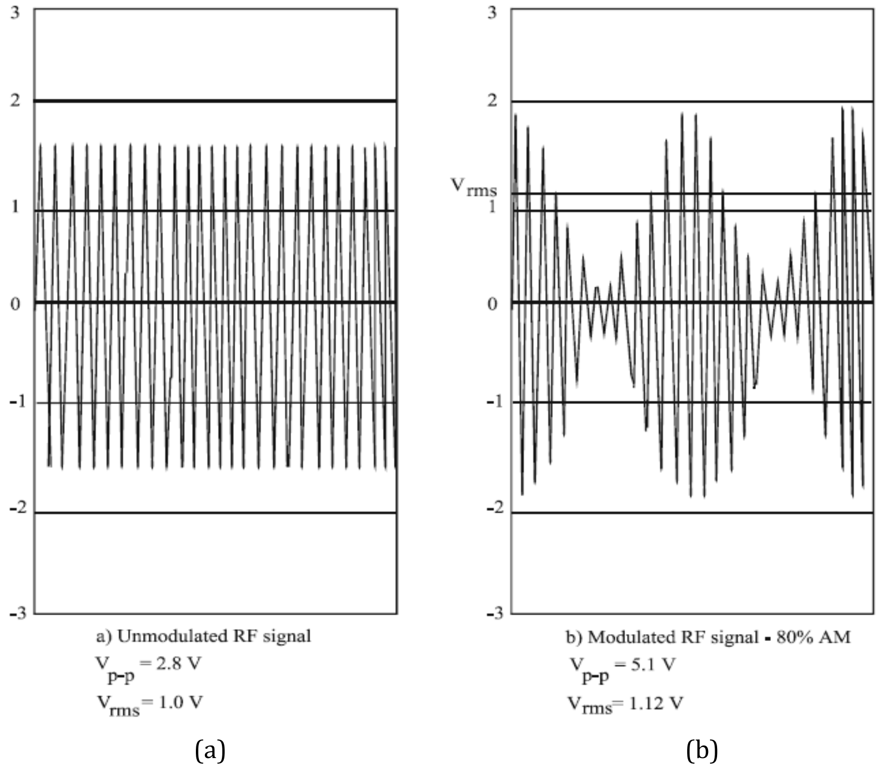


Figure 38 RF signal (a) before and (b) after modulation. Excerpt of reference 3.

Radio Frequency immunity test procedure

Equipment:

- ✓ One Gigahertz Transfer Electromagnetic Cell (GTEM Cell)
- ✓ One Signal Generator
- ✓ One Signal Amplifier
- ✓ One E-Field Monitor
- ✓ One table
- ✓ Equipment Under Test (EUT) and Support Equipment.

Procedure

Install the EUT is the usual way on the table inside the GTEM Cell. Only the EUT, the table and the common-mode cables are inside the chamber; the support equipment is outside the chamber and the common mode cables come from the GTEM Cell through some holes of the chamber. Most of the times, you will need cables longer than usual.

Adjust the signal generator and the signal amplifier to produce a 3 V/m electromagnetic field, measure the field with the E-Field Monitor; if it's necessary readjust the amplitude with the signal amplifier.

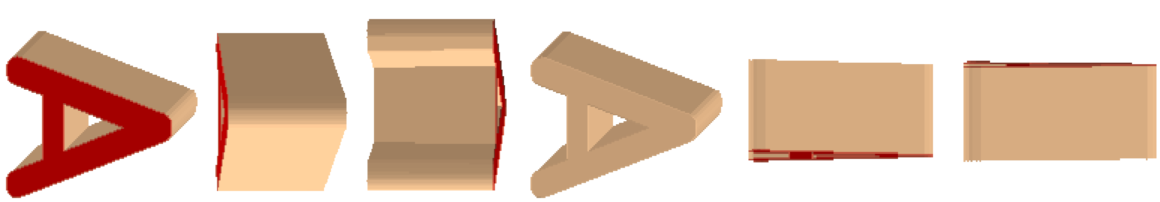
To make sure the whole equipment is immune, is necessary to test all the sides of the equipment. Due to the big size of the cell, is difficult to turn the chamber to face all the sides of the equipment, so is necessary to rotate the EUT 6 times to face the waveform generated in the chamber; but this waveform is unidirectional and it only can affect the EUT in one axis, so it is necessary to rotate again the EUT 6 times. The next graphic shows the positions of the EUT to face the waveform.

The test shall be performed in every position of the EUT.

VERTICAL

Front Right Left Rear Top Bottom

HORIZONTAL



Front Right Left Rear Top Bottom

3.5.3. IEC 61000-4-4: Electrical fast transient/burst immunity test

Electrical Fast Transients (EFT) is the name given to the conducted transient disturbance created by switching power currents using electrical contacts.

All conductors have inductance and some loads have a great lead of inductance, like transformers and motors, this inductance stores energy according to the formula $\boldsymbol{E = \frac{1}{2} L * I^2}$; **E** in Joules, **L** in Henries and **I** in Amps, when a current in a conductor is switch off its inductance prevents the current from stopping instantaneously and the voltage develop across the contacts of the switch is associate with the formula $\boldsymbol{V = -L * \frac{dI}{dt}}$, also the capacitance associate with the conductors help to increase or decrease the rate of rise of this voltage, this voltage is called *flyback voltage.*

While a switch is opening, the current stops instantaneously and the flyback voltage can become very large, enough to break the air gap between the contacts causing a spark discharge and currents that allow the inductance to store energy and cause more sparks. The first spark occurs exactly in the moment the switch has started to open and the frequency of the sparks decrease as the way the parts move further, starts with a few MHz and finishes in KHz. These sparks occur until the store energy of the conductor is dissipated or until the gap between the contacts is so large that the flyback voltage cannot break it down.

As a consequence of this phenomenon an electromagnetic noise to over 100 GHz of frequency appears. Some of the harmonics present in the electromagnetic noise created by the transients have the same frequency as the normal signals of the circuit, the electronic devices, like digital processors and logical components, process these signals as part of the normal functioning of the equipment affecting the performance of the circuit; but not only errors occur, also the components can get damage when the amplitude of these signals is more than the device is designed to handle. This problem is commonly present among equipment connected to the same distribution network.

This test aims to simulate EFT disturbances in the A.C. mains and data cables to evaluate the performance of the equipment. The pulse used for this test (figure 39) has a rise time of 5 ns and an impulse duration of 50 ns; the frequency of the pulse has to be 5 KHz, the burst duration 15 ms and the burst period 300 ms.

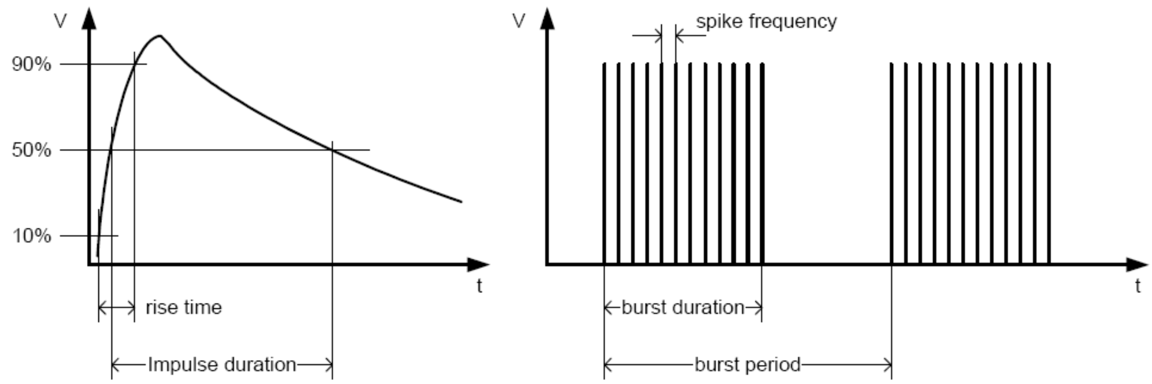


Figure 39 EFT testing waveform.

All the phases of the A.C. mains have to be tested at a maximum voltage of 1 kV and -1 kV for 1 min for each polarity; also all the data cables with more than 3 m of length have to be tested with the same signal described above, but at a maximum voltage of 0,5 kV and -0,5 kV for 1 min for each polarity.

Electrical Fast Transient/Burst immunity test procedure

Equipment

- ✓ EFT Generator
- ✓ Capacitive Clamp
- ✓ One Ground Plane
- ✓ Table of 10 cm tall
- ✓ Equipment Under Test (EUT) and Support Equipment

Procedure

For this test is necessary to keep the temperature between 15°C and 35°C, relativity humidity between 30% and 60% and the atmospheric pressure between 86 kPa and 106 kPa.

The EUT is placed on the table above the ground plane; the EUT is connected to the support equipment in the usual way and the AC cable is plugged to the EFT generator outlet.

To program the test check the user manual of the EFT generator; most of the EFT generators can be programmed from the front panel or by computer with a GUI (Graphical User Interface).

Once the EFT generator is programmed and the set up is done, run the test. Remember to check the user manual to run the test.

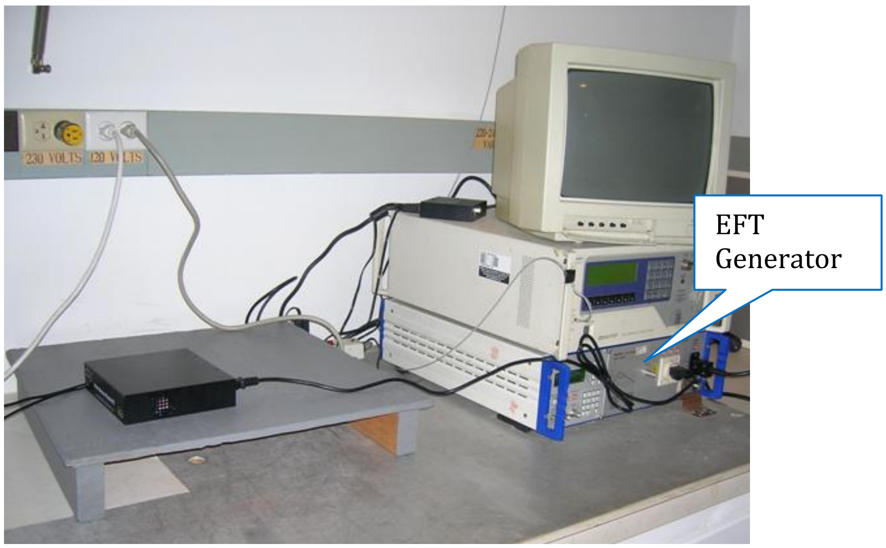


Figure 40 Picture taken to the EFT test set up.

When the AC test is over, place the UTP cable in de capacitive clamp. Connect the capacitive clamp to the EFT generator with the appropriate cable.

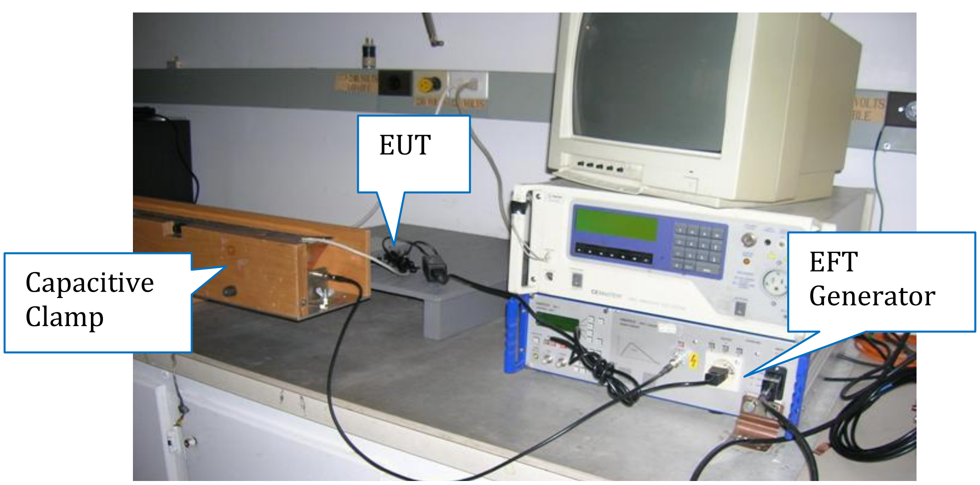


Figure 41 Common-mode cables test set up.

3.5.4. IEC61000-4-5: Surge immunity test

A surge is a transient overvoltage with a rise time of µs (microseconds) and a duration lasting up to several hundred µs, also its amplitude is often measured in KV. It is like an electrical fast transient, but slower.

The surges are created by switching of reactive loads, insulation faults in AC power distribution network and most of all for lighting strikes. These phenomena are essentially caused by the sudden release of energy stored in the inductance associated with the power lines of the electric network; when a lighting strike hits a power line, a huge amount of current is conducted through the power line and the insulation breaks down making the current higher than usual for a few microseconds.

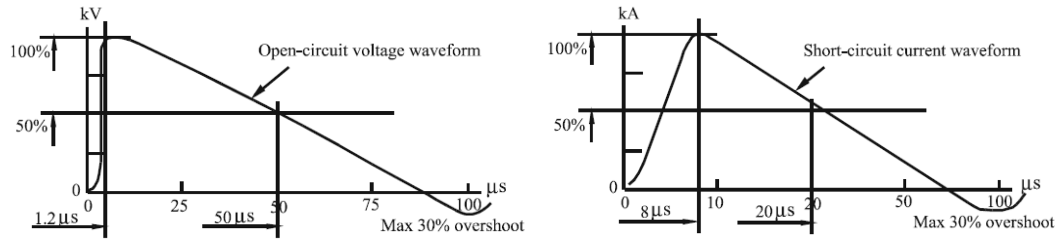
Due to the high voltage and the large amount of current, many electronic devices can suffer damage due to excessive heat and/or energy overstress. The surges are consider as slow events and they are fast enough to vaporize the iron wire in a high-voltage wirewound resistor before the heat is dissipated. Also the electronic devices can get burned because the voltage they receive is higher than what they are designed for.

Another problem caused by the surges, but less destructive, is the amount of harmonics that can be induced in the circuit due to the spectrum over KHz present in the surges. Some of the harmonics induced in the circuit can have the same frequency as the signals proper of the circuit and cause errors in digital ICs and processors.

With this standard, the European community requires to test all the phases of the AC mains of the equipment. For line-line test the voltage levels used are ±250 V, ±500 V, ±1000 V, for line-neutral test the voltage levels used are ±500 V, ±1000 V, ±2000 V.

Five (5) surges of each polarity are inserted in the voltage signal at 0°, 90° and 270° with one minute of separation between surges.

The waveforms used for this test are shown in figure 42.



(a) (b)

Figure 42 Surge test waveforms, (a) voltage and (b) current. Excerpt of reference 3.

Surge immunity test procedure

Equipment

- ✓ Surge Generator
- ✓ Table of 10 cm tall
- ✓ Ground plane.
- ✓ Equipment Under Test (EUT) and Support Equipment

Procedure

Install the EUT on the table above the ground plane, the EUT's AC mains is plugged to the surge generator outlet. The support equipment has to be installed far from the ground plane. And no physical contact between them is allowed. The connections between the EUT and the support equipment are the same.

Program the surge generator by computer or hand to generate surges of ±250 V, ±500 V, ±1000 V for line-line test and surges of ±500 V, ±1000 V, ±2000 V for line-neutral test; 5 surges are applied at 0°, 90° and 270° with one minute between surges for each voltage level, positive and negative. The sequence of the test is L1-N, L2-N and L1-L2; the reference to insert the surges is L1.

The total time spend in this test is 4,5 hours.

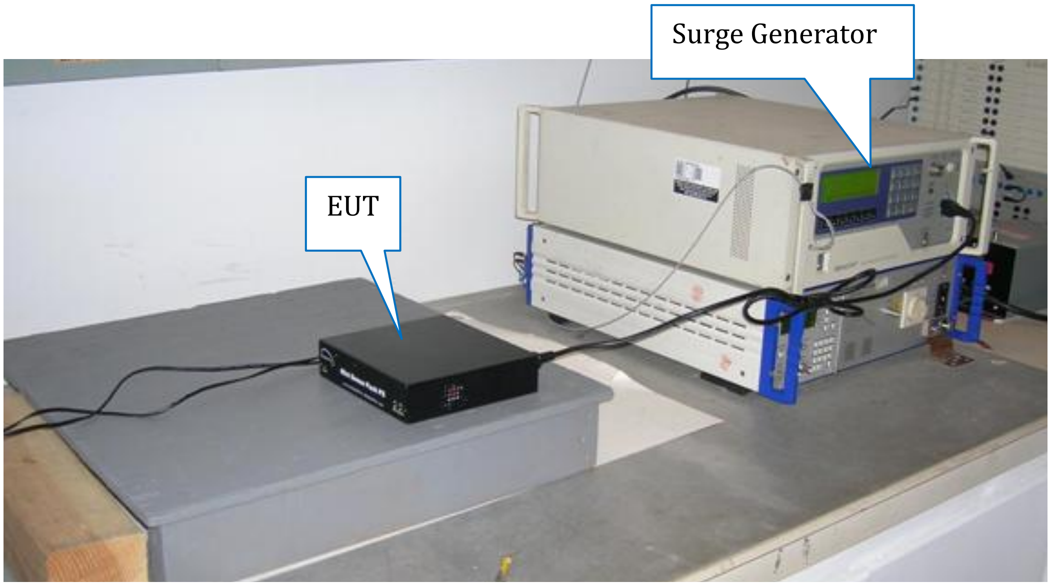


Figure 43 Picture taken to surge test set up.

3.5.5. IEC61000-4-6: Immunity to conducted disturbances, induced by radio-frequency fields

As explained the in section 3.5.2, the radio frequency fields are generated by antennas and wireless equipment, as well as by electronic equipment that radiates RF fields without purpose.

A modern problem is the rapid growth in personal radio communications using cellphones, Bluetooth, Wi-Fi and other wireless technologies. These devices emit fields at low frequencies that can induce currents and voltages into power cables and common mode cables, like Ethernet, serial data, audio or video. The frequency of these currents and voltages is around MHz, same frequencies used by the signals proper of the equipment.

Testing the top assembly of the product according IEC 61000-4-3 does not mean that the cables connected to the equipment are immune to conducted disturbances induced by RF fields. The cables attached to the equipment behave as passive receiving antennas and are usually several wavelengths in length becoming susceptible to conduct RF noise of kHz or even MHz.

The problems caused by the exposure of the cables to RF fields with frequencies between hundreds of kHz and a few MHz are the same as the ones announced in section 3.5.2.

This standard is an extension of the IEC 61000-4-3. The waveform used for this test has the same modulation and frequency step as the one used in the IEC 61000-4-3; but the amplitude of the wave is not measured in field strength, is measured in volts and it has to be 3 V. Also the test frequency range changes from 80 MHz – 1 GHz to 150 kHz – 80 MHz. Only the AC power cable and the common-mode cables are exposed to these fields.

Immunity to conducted disturbances, induced by radio-frequency Fields test procedure

Equipment

- ✓ One Signal Generator
- ✓ One Signal Amplifier
- ✓ One Current Injector Probe
- ✓ One Current Probe
- ✓ One Coupling-Decoupling Network (CDN)
- ✓ Equipment Under Test (EUT) and support equipment
- ✓ Table of 10 cm tall
- ✓ One Oscilloscope
- ✓ Ground plane

Procedure

For this test is recommended to use the same signal generator and signal amplifier used in the test according to IEC 61000-4-3.

The EUT shall be placed on the table that is 10 cm tall above the ground plane; the CDN is placed at 20 cm from the EUT on the ground plane too. The CDN must have electric contact with the ground plane.

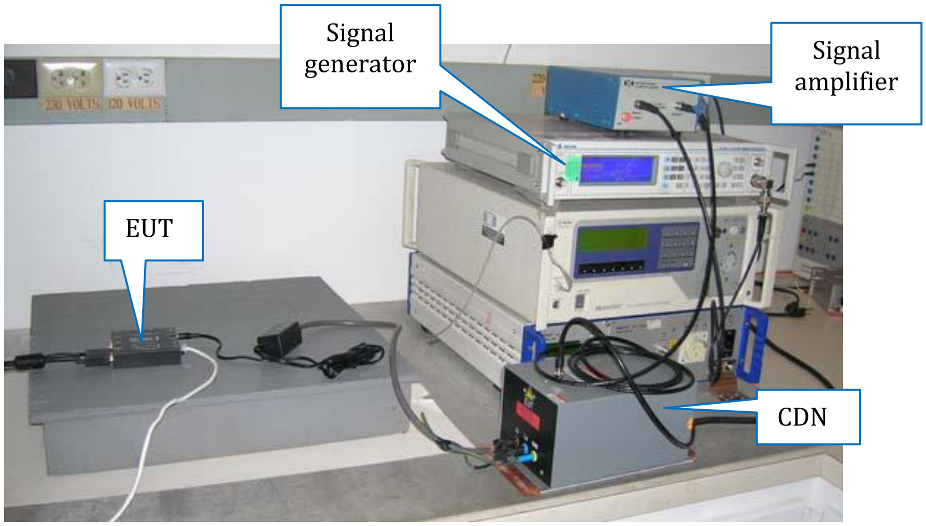


Figure 44 Picture taken to IEC61000-4-6 test set up.

The CDN has three terminals; the first is connected to the electric power system, the second is connected to the signal amplifier and the third is connected to the AC power cable coming from the EUT. The general set up is shown in figure 45.

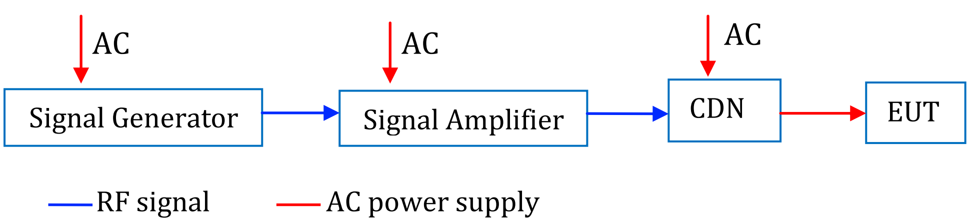


Figure 45 General set up of the measurement equipment and the EUT.

The waveform used in this test has the same modulation and frequency increment as the wave used in the IEC 61000-4-3; but, the test frequency range is 150 kHz to 80 MHz and the amplitude is 3 V. Configure of the signal generator and amplifier to generate an RF signal of 3 V of amplitude.

Run the test for the AC mains.

Once the test in the AC mains is done, place the current injector probe and the current probe on the common-mode Cable. The current injector probe must be connected directly to the signal amplifier.

Connect the current probe to the oscilloscope to make sure that the amplitude of the voltage in the UTP cable is 3 V. If the voltage measure with the oscilloscope does not have the appropriate amplitude, turn 5 times the UTP cable on the current injector probe and readjust the signal amplifier until the 3 V are reached. See figure 46.

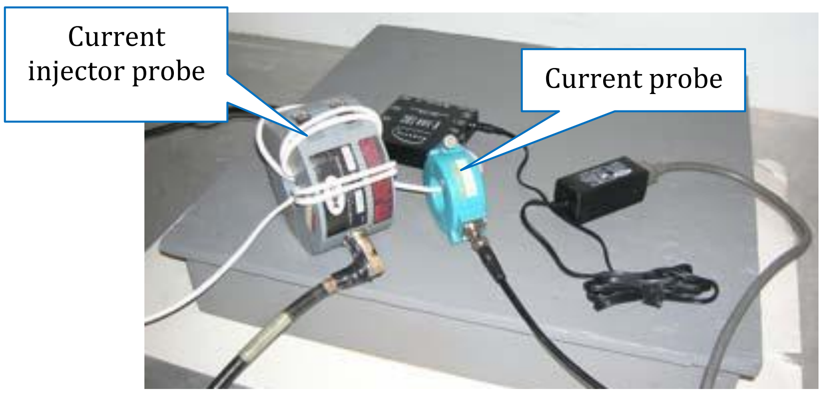


Figure 46 Common-mode cables test set up.

The EUT's AC cable keeps plugged to the CDN.

Run the test for the common-mode cable.

3.5.6. IEC 61000-4-11: Voltage dips, short interruptions and voltage variations immunity test

Voltage dips are reductions in supply voltage rms value caused by load switching and fault in the mains supply network; low, medium or high distribution systems. Also, they can be caused by switching between the mains and alternative supplies in uninterruptible power systems (UPS) or emergency power back-up systems. Dips are specified by their reductions below nominal 230 V mains, and their duration in milliseconds or number of cycles. So a dip of 40% is equivalent to a reduction in supply voltage of 60% (92 V of 230 V) of its nominal value.

The voltage interruptions are considered as voltage dips with reduction of the voltage level more than 90%. Although, they are cause by load switching and fault in the mains power supply networks.

Some electronic circuits rely on counting mains cycles, and these can be fooled by dips and interruptions, but the biggest problem is the hold-up time of products' mains power supply. The figure 47 shows an example of a 3,3 V supplied digital circuit. The mains supply dip causes the unregulated rail to discharge to a level lower than the minimum input voltage for the 3,3 voltage regulator, so the regulated DC rail can fall to below the level required for the integrated circuit to function as specified. In this situation the integrated circuit can almost do nothing, and memory corruption is a real possibility along with malfunctions that could cause problems for whatever the circuit is controlling.[8]

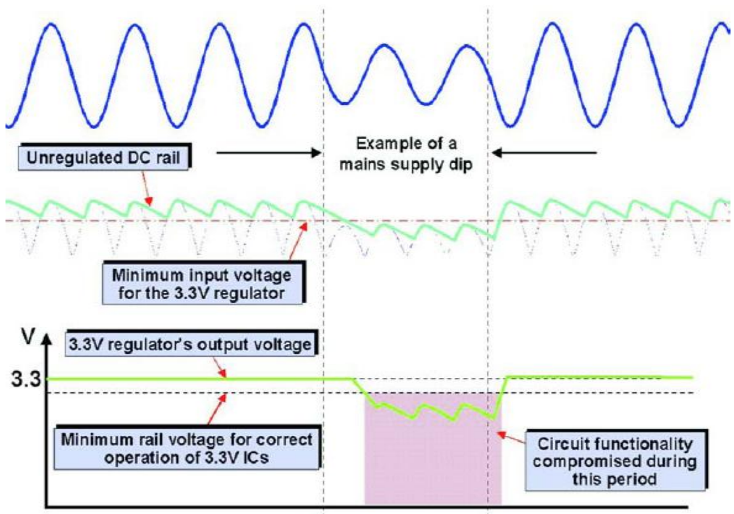


Figure 47 Example of voltage dips. Excerpt of reference 8.

This problem is a great concern when medical and control systems are involved. An example why vital control systems should be immune to these disturbances is the air traffic control systems in airports, failure can cause waste of time, money and in the worst case scenario loss of human lives.

Other example of how critical is the consequence of this phenomenon is the interruption of medical equipment. Most of the medical equipment works with low voltage (2 V) and human signals comparators. If the power supply of the control systems build in this equipment is relativity below of its normal value, the control system is affected and the life of the patient is in risk.

In order to know if the equipment is immune to dips and interruptions, this standard requires testing the equipment for dips of 30% (161 V of 230 V) for 25 periods (0,5 seconds). An example of the signal is shown in figure 48.

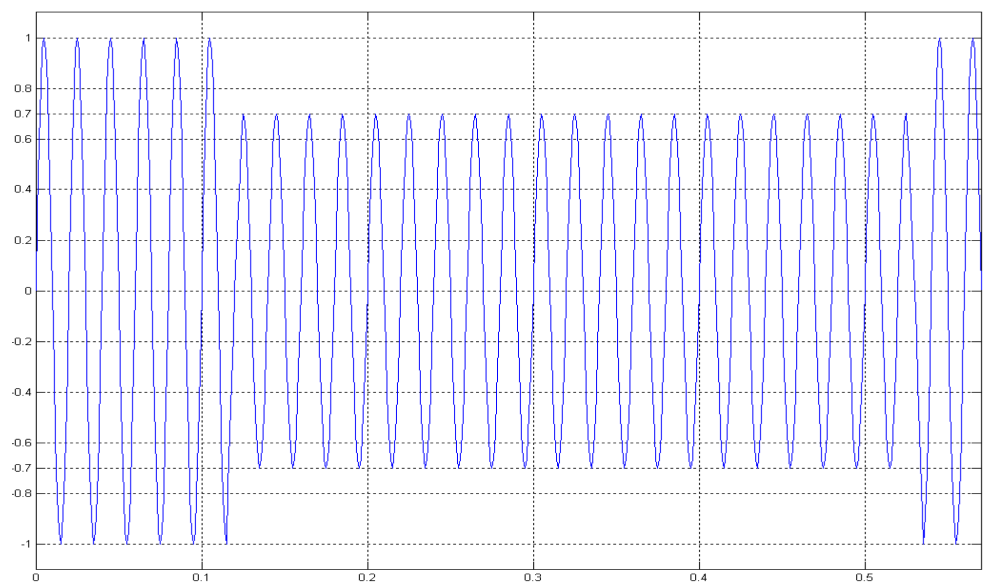


Figure 48 Voltage dip of 30%.

Also, the equipment has to be tested for interruptions. The interruptions applied to the AC mains have to be for 0,5 periods (10 ms) for short interruptions and 250 periods (5 s) for long interruptions. An example of a short interruption is shown in figure 49.

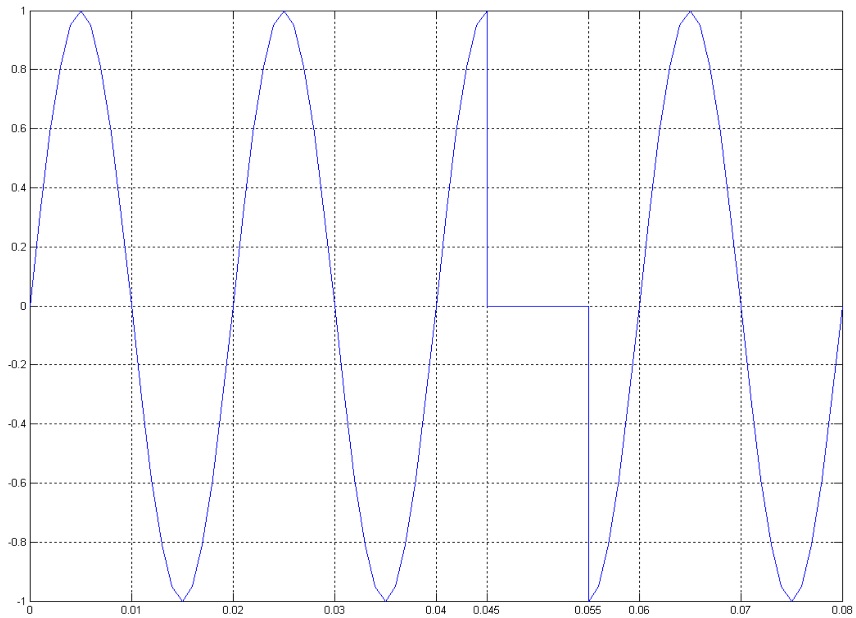


Figure 49 Example of short interruption.

All voltage changes are initiated at zero degree crossing points only.

Voltage dips, short interruptions and voltage variations immunity tests procedure

Equipment

- ✓ Dips and interruptions simulator.
- ✓ Table of 10 cm tall.
- ✓ Ground plane.
- ✓ Equipment under test (EUT) and support equipment.

Procedure

Install the EUT on the table above the ground plane. The EUT's AC power cable is plugged to the dips and interruptions generator outlet. The support equipment is installed as usual.

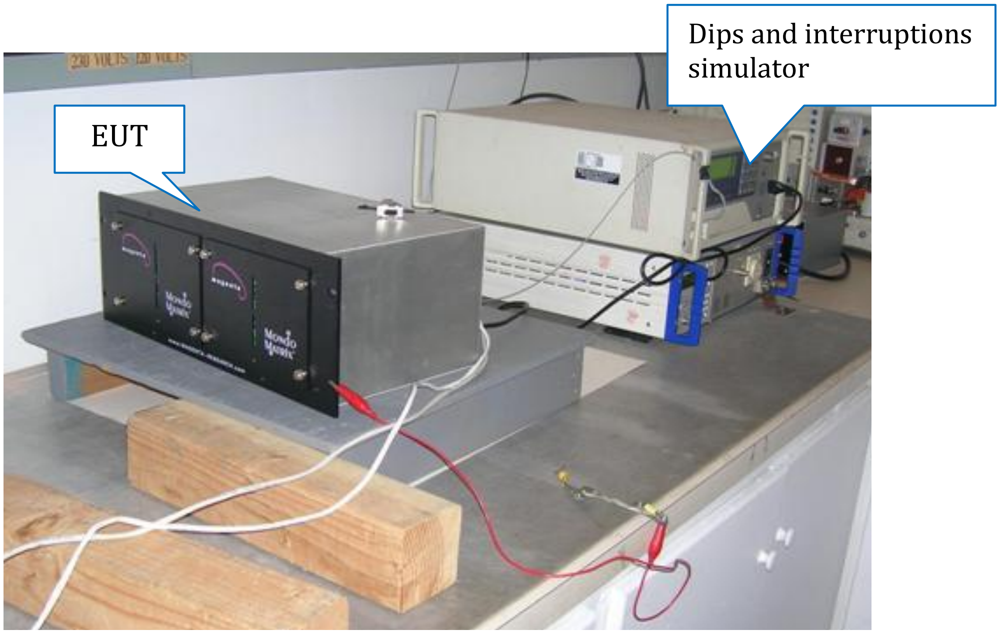


Figure 50 Picture taken to dips and interruptions test set up.

The test is programmed by computer or by hand. Program 3 dips of 30% at 0° and 180° with 10 s of delay between them. Also program 3 short interruptions and 3 long interruptions at the same angle with the same delay time.

4. FINAL RESULTS, CONCLUSIONS AND RECOMMENDATIONS

EMC STANDARDS AND TEST PROCEDURES MANUAL

An EMC manual was written for Magenta Research, which title is ***EMC STANDARDS AND TEST PROCEDURES*** and contains the same information as this book about EMC standards, test procedures and laboratory equipment.

Before this internship, Magenta Research spend more time and money due to the failing of the products during the first intent to certify them; most of the products sent for the first time to the laboratory for certification failed the tests and needed to be redesign in order to comply the limits and requirements of the tests.

The engineering department of the company invested more time in the research of new electronic devices for replacement of those devices within the products which present the highest emissions. The time invested in this research represents a delay in the investigation and development process for new products.

Once the product was modified in order to comply with the limits is send back to the laboratory to start a new certification process and testing, representing an extra monetary outgoing for the company; in other words, it represents to re-pay the tests to the laboratory.

This manual allows the company to save money and time in the certification process of the products. The procedures described in the EMC manual are helpful tools to identify the problems related to the design of the product during its development phase. With the house testing, the engineering department have an idea of how the product is going to respond when is exposed to these phenomena. The results of these tests helps the engineer to find the best solution for the troubleshooting presented before the products are taken to real testing and certification process, reducing time and money avoiding to re-pay the tests when the product fail and has to be modified to pass them.

The structure of the manual is shown in figure 51.

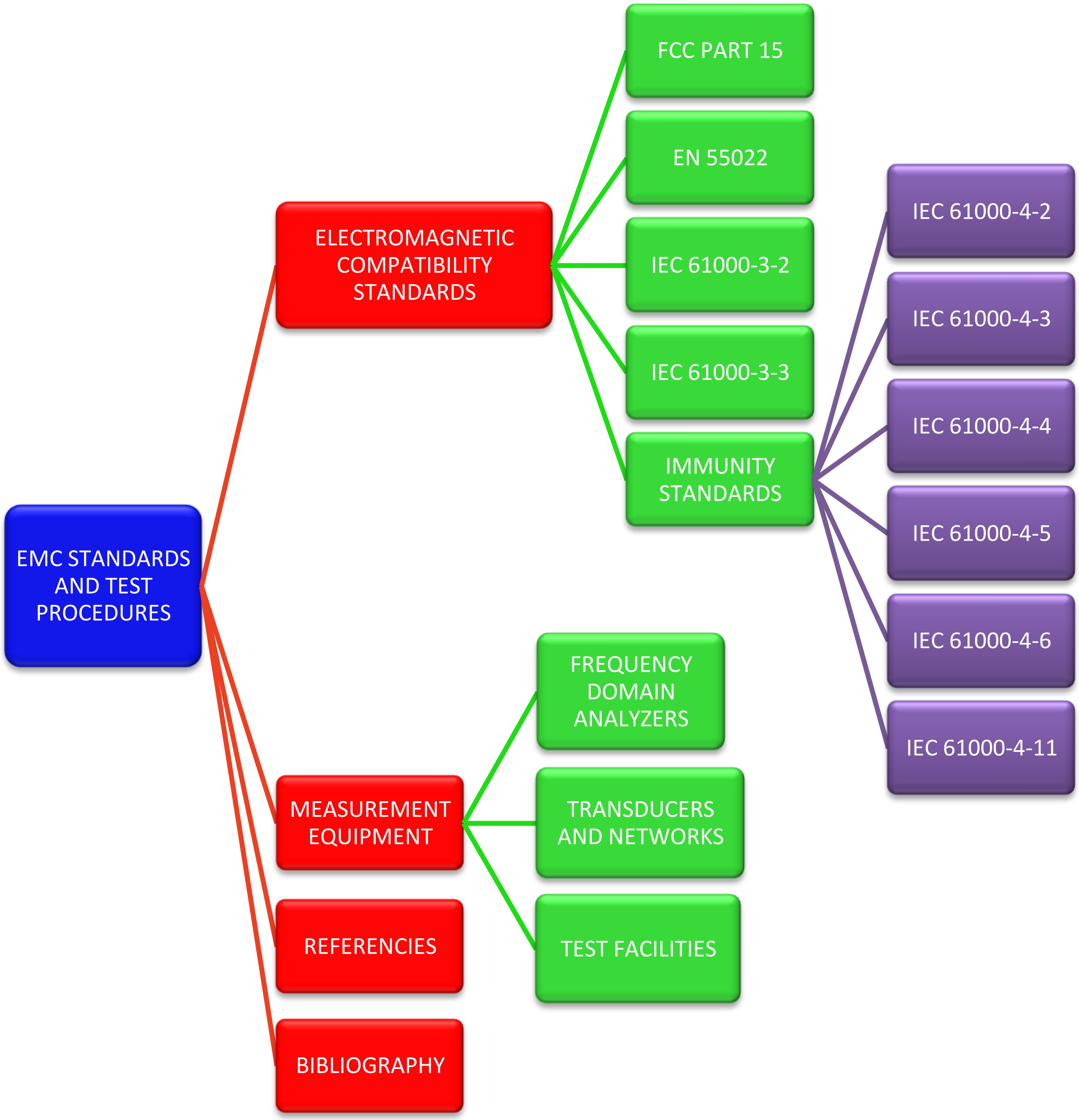


Figure 51 Structure of Magenta Research's EMC manual

CERTIFIED PRODUCTS

Also, eight products designed, manufactured and merchandised by Magenta Research were tested and certified according to the FCC standard and EU standards during this internship. Two declarations of conformity were created for each product, one for the American standard and other for the European standards. The declarations of conformity and the test reports are in Magenta Research's data base.

Those products are:

- Mondo Matrix Scaleable CAT5 Matrix Switch.
- MultiView STx Universal CAT5 Transmitter.
- Infinea DVI Transmitter.
- Infinea DVI Receiver.
- Morph-IT Dual Transmitter Cards.
- Audio Balun II Transmitter.
- Audio Balun II Receiver.
- K500TD(C) Receiver

For more information about these products visit: www.magenta-research.com

Some of the products listed before presented some issues during the tests and were fixed in the laboratory. The Infinea family was rated criterion C during the electrostatic discharge immunity test. When the I/O ports of the Infinea were zapped with the ESD gun the output signal of the equipment disappeared and the energy needed to be restored in order to get an output signal. To get to know the problem presented in the board, a quick inspection to the I/O ports was done. The result of this inspection was that the ground pins of most of the I/O ports were not well soldered.
After all the pins were soldered properly and the ESD test was developed by a second time, the Infinea family was rated criterion B. The results of the second tests are shown in the ESD table of records in appendix A.

Other representative issue presented during the test, was revealed during the radiated emission measurements. Six of the eight products (mondo matrix, multiview stx, morph-it dual transmitter, K500TD(C) and the audio baluns) were grouped to simulate the worst case scenario for radiated emissions.

At 129 MHz the emission measured was 1.2 dBµV above the limits. A quick inspection to each product gave us the product which presented this excess of emissions, the K500TD(C). With the close field probes and the spectrum analyzer, an inspection to the board was developed in order to identify the source of the emission. The clock generator of the equipment radiated this frequency with 1.2 dBµV above the limits; to minimize this emission the crystal in charge of generate the clock signal was replace with a clock oscillator made by CTS with part Nº CB3-3C-40M0000-T. The final results of the tests are shown in the radiated table of records in appendix A.

Finally, this book introduces future engineers into the strict certification process which is required for new products to allow them to be commercialized in different countries. The understanding of the phenomena related to EMC gives to the student an idea about the problems that could appear in the functioning of the product when it is exposed to them. Also, it advices the students to take account into the design of filters, protections and the PCB itself the phenomena related to EMC that can cause damage to the equipment.

The application of these tests during the development phase of a project allows the engineer to improve the equipment by choosing the correct electronic devices that can minimize the emissions and maximize the immunity of the product, making easier the meeting of international requirements. And, as a consequence, high-tech quality products are produced in order to perform in a satisfactory environment for humans, other equipment and itself.

For this reason, this book became an important tool for those students of electrical engineer and electronic engineer who have plans, in a further future, to innovate in different markets with new electronic products and devices.

It is recommended to Universidad Industrial de Santander, especially to the school of electrical and electronic engineering to create new spaces to incentivize the investigation and application of the knowledge related to electromagnetic compatibility in its different research fields.

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7. *ARMSTRONG, Keith*. Handbook On EN61000-4-2, Personnel Electrostatic Discharge (ESD). UK. REO LTDA.

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- http://www.iec.ch/zone/emc/cispr_guide_2004.pdf

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APPENDIX

APPENDIX A: Tables of Records

NOTE: All the tables shown in this appendix are excerpts of tests reports of Magenta Research products

Conducted emissions:

TESTING NEUTRAL:

FREQ. (MHz)	AMPL QUASI-P dB(µV)	AMPL + LISN LOSSES dB(µV)	LIMIT QUASI-P dB(µV)	PASS?	MARGIN dB		AMPL AVER-AGE dB(µV)	AMPL + LISN LOSSES dB(µV)	LIMIT AVER dB(µV)	PASS?	MARGIN dB
0.150	55	55.11	79	YES	23.9				66	YES	10.9
0.217	47	47.11	79	YES	31.9				66	YES	18.9
0.293	40	40.11	79	YES	38.9				66	YES	25.9
1.176	49	49.11	73	YES	23.9				60	YES	10.9
1.235	50	50.11	73	YES	22.9				60	YES	9.9
ALL SIGNALS ARE BELOW 45 dBuV.											
15.552	45	46.16	73	YES	26.8				60	YES	13.8
15.626	45	46.16	73	YES	26.8				60	YES	13.8
16.577	33	34.16	73	YES	38.8				60	YES	25.8
ALL SIGNALS ARE BELOW 40 dBuV.											
18.605	32	33.48	73	YES	39.5				60	YES	26.5
ALL SIGNALS ARE BELOW 35 dBuV.											
22.948	18	19.60	73	YES	53.4				60	YES	40.4
ALL SIGNALS ARE BELOW 25 dBuV.											
24.032	30	32.30	73	YES	40.7				60	YES	27.7
ALL SIGNALS ARE BELOW 25 dBuV.											
30.000	18	21.05	73	YES	52.0				60	YES	39.0
ALL OTHER FREQUENCIES BELOW LIMITS											

TESTING LINE:

FREQ. (MHz)	AMPL QUASI-P dB(µV)	AMPL + LISN LOSSES dB(µV)	LIMIT QUASI-P dB(µV)	PASS?	MARGIN dB		AMPL AVER-AGE dB(µV)	AMPL + LISN LOSSES dB(µV)	LIMIT AVER dB(µV)	PASS?	MARGIN dB
0.150	55	55.11	79	YES	23.9				66	YES	10.9
0.217	47	47.11	79	YES	31.9				66	YES	18.9
0.293	41	41.11	79	YES	37.9				66	YES	24.9
1.176	49	49.11	73	YES	23.9				60	YES	10.9
1.235	49	49.11	73	YES	23.9				60	YES	10.9
ALL SIGNALS ARE BELOW 45 dBuV.											
15.281	49	50.16	73	YES	22.8				60	YES	9.8
15.708	46	47.16	73	YES	25.8				60	YES	12.8
16.577	33	34.16	73	YES	38.8				60	YES	25.8
ALL SIGNALS ARE BELOW 40 dBuV.											
18.605	30	31.48	73	YES	41.5				60	YES	28.5
ALL SIGNALS ARE BELOW 35 dBuV.											
22.948	24	25.60	73	YES	47.4				60	YES	34.4
ALL SIGNALS ARE BELOW 30 dBuV.											
24.032	0	2.30	73	YES	70.7				60	YES	57.7
ALL SIGNALS ARE BELOW 25 dBuV.											
30.000	10	13.05	73	YES	60.0				60	YES	47.0
ALL OTHER FREQUENCIES BELOW LIMITS											

Radiated emissions:

THE 30 TO 300 MHz ANTENNA IS VERTICAL AND AT 10 METERS.								
FREQ. (MHz)	AMPL QUASI-P dB(μV)	AZIMUTH DEGREES	CABLE LOSS, dB	ANTENNA FACTORS dB/m	TOTAL FIELD dB(μV/m)	LIMIT QUASI-P dB(μV/m)	PASS?	MARGIN dB
The following signals are narrowband peaks measured with the spectrum analyzer.								
100.00	12	270	5.31	9.94	27.25	43.5	YES	16.2
The following signals are broadband peaks measured with the spectrum analyzer.								
110.68	15	0	5.97	10.87	31.83	43.5	YES	11.7
The following signals are narrowband peaks measured with the spectrum analyzer.								
112.52	18	135	5.64	11.07	34.71	43.5	YES	8.8
114.55	17	90	5.64	11.21	33.85	43.5	YES	9.6
115.70	15	180	5.92	11.28	32.20	43.5	YES	11.3
The following signals are narrowband peaks measured with the receiver.								
129.92	20	270	6.05	12.78	38.82	43.5	YES	4.7
The following signals are broadband peaks measured with the spectrum analyzer.								
134.36	15	270	5.97	13.06	34.02	43.5	YES	9.5
The following signals are narrowband peaks measured with the spectrum analyzer.								
137.56	17	270	5.23	13.28	35.51	43.5	YES	8.0
140.63	19	180	5.55	13.50	38.05	43.5	YES	5.5
143.19	13	180	5.55	13.39	31.94	43.5	YES	11.6
The following signals are broadband peaks measured with the spectrum analyzer.								
146.92	17	270	5.83	13.25	36.07	43.5	YES	7.4
149.52	15	270	5.45	13.14	33.59	43.5	YES	9.9
The following signals are narrowband peaks measured with the spectrum analyzer.								
153.13	18	180	5.36	13.25	36.61	43.5	YES	6.9
159.42	15	0	5.39	13.65	34.04	43.5	YES	9.5
165.70	12	0	5.06	14.30	31.36	43.5	YES	12.1
168.83	15	270	5.30	14.70	35.00	43.5	YES	8.5
171.90	15	270	4.98	15.00	34.98	43.5	YES	8.5
175.00	15	270	5.17	15.40	35.57	43.5	YES	7.9
178.18	14	270	5.17	15.32	34.49	43.5	YES	9.0
184.38	14	270	4.95	15.18	34.13	43.5	YES	9.4
184.85	17	270	4.95	15.17	37.13	43.5	YES	6.4
The following signals are narrowband peaks measured with the receiver.								
187.51	18	90	4.66	15.16	37.82	43.5	YES	5.7
The following signals are narrowband peaks measured with the spectrum analyzer.								
200.00	8	90	4.75	15.10	27.85	43.5	YES	15.7
203.12	14	90	4.70	15.10	33.80	43.5	YES	9.7
212.49	14	180	4.69	15.60	34.29	43.5	YES	9.2
The following signals are broadband peaks measured with the spectrum analyzer.								
218.77	12	180	4.83	16.10	32.93	46.4	YES	13.5
221.99	14	180	4.83	16.60	35.43	46.4	YES	11.0
231.84	12	90	4.98	17.10	34.08	46.4	YES	12.3
233.68	14	90	4.98	17.10	36.08	46.4	YES	10.3
237.57	11	90	4.98	17.10	33.08	46.4	YES	13.3
NO OTHER SIGNIFICANT EUT GENERATED SIGNALS FOUND FOR THIS RANGE.								

Common-mode cable emissions:

FREQ. (MHz)	AMPL QUASI-P dB(μV)	Current through probe dB(uA)	LIMIT QUASI-P dB(μA)	PASS?	MARGIN dB		AMPL AVERAGE dB(μV)	Current through probe dB(uA)	LIMIT AVERAGE dB(μA)	PASS?	MARGIN dB
0.629	17	12.00	43.00	YES	31.00				30.00	YES	18.0
0.697	18	13.00	43.00	YES	30.00				30.00	YES	17.0
0.838	26	19.00	43.00	YES	24.00				30.00	YES	11.0
0.913	33	25.00	43.00	YES	18.00				30.00	YES	5.0
0.979	41	33.00	43.00	YES	10.00		40	32.00	30.00	NO	2.0
The signal level for the frequency above vanishes when the LCD monitor cable is removed.											
1.726	30	17.63	43.00	YES	25.37				30.00	YES	12.4
2.032	36	21.88	43.00	YES	21.12				30.00	YES	8.1
2.129	41	26.88	43.00	YES	16.12				30.00	YES	3.1
2.542	41	26.88	43.00	YES	16.12				30.00	YES	3.1
2.640	39	24.88	43.00	YES	18.12				30.00	YES	5.1
2.744	37	22.88	43.00	YES	20.12				30.00	YES	7.1
ALL EUT SIGNALS ARE BELOW 35 dBuA.											
4.972	38	22.95	43.00	YES	20.05				30.00	YES	7.1
5.073	40	24.95	43.00	YES	18.05				30.00	YES	5.1
5.479	38	22.95	43.00	YES	20.05				30.00	YES	7.1
6.087	31	15.85	43.00	YES	27.15				30.00	YES	14.2
6.190	42	26.85	43.00	YES	16.15				30.00	YES	3.2
6.289	44	28.85	43.00	YES	14.15				30.00	YES	1.2
6.389	42	26.85	43.00	YES	16.15				30.00	YES	3.2
6.797	42	26.85	43.00	YES	16.15				30.00	YES	3.2
7.000	42	26.75	43.00	YES	16.25				30.00	YES	3.3
7.102	42	26.75	43.00	YES	16.25				30.00	YES	3.3
7.302	40	24.75	43.00	YES	18.25				30.00	YES	5.3
7.813	32	16.75	43.00	YES	26.25				30.00	YES	13.3
8.414	25	9.65	43.00	YES	33.35				30.00	YES	20.4
ALL EUT SIGNALS ARE BELOW 30 dBuA.											
11.038	14	-1.35	43.00	YES	44.35				30.00	YES	31.4
ALL EUT SIGNALS ARE BELOW 20 dBuA.											
13.490	21	5.65	43.00	YES	37.35				30.00	YES	24.4
ALL EUT SIGNALS ARE BELOW 25 dBuA.											
24.038	22	6.50	43.00	YES	36.50				30.00	YES	23.5
ALL EUT SIGNALS ARE BELOW 20 dBuA.											
30.000	5	-10.40	43.00	YES	53.40				30.00	YES	40.4
ALL OTHER FREQUENCIES ARE BELOW LIMITS.											

ESD table of records:

Engineer: Steve Petix
Severity Level: 2
Temperature: 20.5C
Humidity: 8.5%

Date: 3/8/07
Client: MAGENTA RESEARCH
EUT: INFINEA TRANSMITTER
Serial: 400R3403-01

DIRECT DISCHARGE																					
AIR DISCHARGE											CONTACT DISCHARGE										
	VOLTAGE (kV)											VOLTAGE (kV)									
	2		4		6		8		X			2		4		6		8		X	
TEST	Level 1		Level 2		Level 3		Level 4				TEST	Level 1		Level 2		Level 3		Level 4			
POINT	+	-	+	-	+	-	+	-	+	-	POINT	+	-	+	-	+	-	+	-	+	-
1											1	X	X	X	X						
2											2	X	X	X	X						
3											3	X	X	2	2						
4											4	X	X	X	X						
5											5	X	2	2	2						
6											6	X	X	2	2						
7											7	X	X	X	2						
8											8	X	2	X	2						
9											9	X	X	X	X						
10											10	X	X	X	X						
11											11	X	X	2	X						
12											12	X	X	X	X						
13											13	X	X	X	X						

INDIRECT DISCHARGE																					
HORIZONTAL PLANE											VERTICAL PLANE										
	VOLTAGE (kV)											VOLTAGE (kV)									
	2		4		6		8		X			2		4		6		8		X	
TEST	Level 1		Level 2		Level 3		Level 4				TEST	Level 1		Level 2		Level 3		Level 4			
POINT	+	-	+	-	+	-	+	-	+	-	POINT	+	-	+	-	+	-	+	-	+	-
1	X	X	X	X							1	X	X	X	X						
2	X	X	X	X							2										
3	X	X	X	X							3										
4	X	X	X	X							4										

0 - No discharge
X - Normal performance, within limits
2 - Temporary failure, self-recovering
3 - Temporary failure, requires operator intervention
4 - Non-recoverable failure

APPENDIX B: Declarations of Conformity

FCC Conformity

According to FCC PART 15

Manufacturer's Name: Magenta Research, LTD.
Manufacturer's Address: 128 Litchfield Road, New Milford, CT 06776 USA

The manufacturer hereby declares that the product:

Product Name **K500TD(C)**
Model Number: **400R33xx-xx: Variants**

Conforms to the following standards or other normative documents:

Electromagnetic Emissions:	**FCC PART 15**	**Emissions EMC Directive**
Radiated Electric Field Emissions		Class A
Terminal Disturbance Voltage		Class A

When and Where Issued:
April 11, 2007
New Milford, CT, USA
860-210-0546

Contact:
Contact's Address:
Contact's Phone:

Mark of Compliance

FC Tested To Comply With FCC Standards

Robert Freedman
Director of Engineering and Compliance

I hereby declare that the product listed in this declaration have been tested and certified to above standards.

Document # 3510446-01 01

Declaration of Conformity

According to ISO/IEC Guide

Manufacturer's Name: Magenta Research, LTD.
Manufacturer's Address: 128 Litchfield Road, New Milford, CT 06776 USA

The manufacturer hereby declares that the product:

Product Name: **K500TD(C)**
Model Number: **400R33xx-xx: Variants**

Conforms to the following standards or other normative documents:

Electromagnetic Emissions Directive	**EN55022:1998 A1:2000, A2:2003**	**Emissions EMC**
Radiated Electric Field Emissions		Class A
Terminal Disturbance Voltage		Class A
Electromagnetic Immunity (By council Directive 89/336/EEC:1989)	**EN55024:1998 A1:2002, A2:2003**	**Immunity EMC Directive**
Electrostatic Discharge Immunity Test	EN 61000-4-2	
Radiated, RF Electromagnetic Field Immunity Test	EN 61000-4-3	
Electrical Fast Transient/Burst Immunity	EN 61000-4-4	
Surge Immunity Test	EN 61000-4-5	
Immunity to Conducted Disturbances	EN 61000-4-6	
Voltage Dips, Interruptions and Voltage Variations Immunity Test	EN 61000-4-11	
Limits for Harmonics Current Emissions	**EN 61000-3-2:2000**	
Limits of Voltage Changes, Voltage Fluctuations and Flickers	**EN 61000-3-3:1995 A1:2002**	

When and Where Issued:
April 11, 2007
New Milford, CT, USA
860-210-0546

Contact:
Contact's Address:
Contact's Phone:

Mark of Compliance

Robert Freedman
Director of Engineering and Compliance

I hereby declare that the product listed in this declaration have been tested and certified to above standards.

Document # 3510445-01 01

APPENDIX C: Supervisor's Evaluation

magenta

Engineering and Compliance

Date: **June 28, 2007**

To: Angelica Maria Garcia
From: Bob Freedman
CC: Penny Kern
Industrial University of Santander

Host Company – Trainee Evaluation

Scope of Training

Magenta Research Ltd has participated in the CIEE host work study program for Angelica in the area of international product regulatory approval.

This period was from January 8, 2007 to July 6th, 2007 and the initial CIEE training plan was used as a guideline.

I acted as Angelica's supervisor and conducted all training during this period.

Methods

Three basic methods were used for the training:

Classroom	– one on one lecture with Q+A sessions
Independent study	– assignment of research for specific tasks
Practical	– Hands on, working with products and testing at the test lab.

Course Material

Information Technology Equipment - FCC and EU EN EMC and immunity Standards.
Excerpts from trade periodicals (Engineering Compliance magazine)
Excerpts from EMC course text and workbooks (Don white, DSL associates)
Handbooks and reference guides (Compliance Engineering Inc, EU handbook)
Magenta Research Ltd, test reports (prepared with Global Certification Labs)
Supervisor's authored article summaries

Areas of training

(summarized as related to the specific CIEE training plan)

Magenta Research Ltd, company operation and technical product training
EMC fundamentals, electromechanical, analog, digital sourced noise design implications. Design for compliance.
The evaluation of and the suppression of product sourced or targeted emissions.
Domestic and international product EMC compliance standards
Testing schemes, use of certified testing bodies.
The request for quotation process for setting up and using test labs.
Interviews with local test lab EMC test engineers
Mitigation of non conformities - product design to meet compliance
Overview of domestic and international ITE product safety

Trainee Evaluation Criteria

Angelica's evaluation was made as follows:

On going periodical review and summary of course material, with the emphasis on Q&A discussion.

Practical evaluation – both in house product configuration and assistance in performing product testing at the test lab.

Final project paper – EMC standards and test procedure.

Trainee Evaluation

Angelica's overall evaluation was excellent.

Attitude
Angelica showed an eagerness towards her course work at Magenta.
Each of her tasks were approached with vigor, showing eagerness to move on to the next phase throughout the course.

Course Work
The on going summary discussions indicated that she had readily absorbed the course material. When something required further clarification, a follow up was always made to my satisfaction.

Practical
Her ability to set up and configure Magenta products in house and for The EMC testing at hand was demonstrated.
The ability to operate in house and test lab equipment during the product evaluation was also demonstrated.

Final Project
Angelica's final project was a guide for EMC standards and test procedures.

This document represents a culmination of her EMC course of study at Magenta.

I worked with Angelica to review and make changes when required.

While the information within and the presentation made could be further refined, this document is comprehensive and is comparable to actual publications I have seen in print.

Summary

The goals of the CIEE study program were met.
The training plan with enhancements was completed and cooperation between Magenta, Angelica and CIEE was experience.

As a result of the CIEE program, Magenta had experienced a unique interaction between Angelica and staff that was both professionally and culturally enriching. I believe this has been a pleasant experience for all those involved.