GERMAN – MEXICAN MASTER PROGRAM IN MECHATRONICS

EMC EQUIPMENT AUTOMATION
FOR THE MABE'S EMC TESTS FACILITY

THESIS

TO ACHIEVE THE ACADEMIC DEGREE OF

MASTER OF SCIENCE IN MECHATRONICS

PRESENTED BY

ING. LUIS ROBERTO OLGUIN VALENZUELA

SANTIAGO DE QUERETARO, QRO., MEXICO, SEPTEMBER 2009

ACKNOWLEDGMENTS

I would like to thank to my parents, Roberto and Auristela, for all the things that they have taught me because that things have helped me in different moments of my life. I know that they have done until the impossible for giving me the best and that they will be there always for me. So I would like to dedicate this work to them as a way to demonstrate the respect, admiration and love that I feel to them.

I would like to thank to my sister Auristela too for being my mischief partner, friend and confidant and for all the help and advices that she has given me during the realization of this thesis.

Also I would like to thank to the Mabe’s team Ing. Angélica Chávez, Ing. Heriberto Núñez and Francisco Barrón, and my counselors M. of Sc. Eunice Pondigo in Mabe and Dr. Hugo Gamez in CIDESI for all their advices, lessons and comments.

And finally I would like to thank to my family and friends for all their support and motivation since I started this project.

TITLE

"EMC equipment automation for the Mabe's EMC tests facility"

SUMMARY

This project is about the development of a software interface for controlling two different EMC tests, one is for controlling the devices that measures electromagnetic disturbances and the other one is for manipulating the devices that are used in a susceptibility to radiated electromagnetic interferences test.

The different sections that are contained in this thesis explain the procedure followed to develop the software interfaces, that is, the steps which were basically used for the device initialization or communication setting up, parameters configuration, data acquisition, data conversion, data plotting, data reading from a file and file creation for saving results.

INDEX OF CONTENT

INDEX OF FIGURES

INDEX OF TABLES

ABBREVIATIONS

AC	Alternating Current
ar	Amplifier Research
CIC	Controller-In-Charge
CISPR	Comité International Spécial des Perturbations Radioélectriques
	International Special Committee on Radio Interference
DC	Direct Current
DM	Digital Modulation
ECG	Electrocardiogram
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EMS	Electromagnetic Susceptibility
ESD	Electrostatic Discharge
ESR	Equivalent Series Resistance
ETP	Engineering Test Procedure
EUT	Equipment under Test
GE	General Electric
GPIB	General Purpose Interface Bus
HPIB	Hewlett-Packard Interface Bus
ILS	Instrument Landing System
KI	Keying Interference
LEMP	Lightning Electromagnetic Pulse
LISN	Line Impedance Stabilizing Network
NEMP	Nuclear Electromagnetic Pulse
PCB	Printed Circuit Board
rms	Root Mean Square
R&S	Rhode & Schwarz
SCPI	Standard Commands for Programmable Instruments
VI	Virtual Instrument
VOR	Very High Frequency Omnidirectional Range

1. CHAPTER I: INTRODUCTION

1.1 ANTECEDENTS

Having a useful software interface to easily perform electromagnetic compatibility tests has been an objective of the Mabe's R&D managing team. Their test engineers have developed a huge knowledge in that field and they know how the tests have to be performed and what kind of characteristics they should have.

However the development of such an interface is time consuming and Mabe's test engineers do not have enough time to carry out themselves this task. In practice, only a few programs have been developed for a test receiver, but they only establish the communication between the device and the PC and they have some bugs and unnecessary instructions.

So, one of the main tasks of this work is to build a software interface taking into account the expertise of the Mabe's test engineers having all of the options and features suited to carry out this kind of tests according to the needs defined by the user.

1.2 PROBLEM DEFINITION

Nowadays the number of tests that are being performed in the EMC laboratory is increasing due to the new projects that the different development areas of Mabe have.

The devices that are used to perform the tests are for measuring electromagnetic emissions produced by appliances or for inspecting the susceptibility of appliances to electromagnetic disturbances.

In both cases the necessary devices are controlled through the remote mode instead of the manual, thus a software interface is used to allow to the evaluation engineer to perform the tests just by selecting the correct template. The software that is being used at this moment is the EMC32.

These templates facilitate the test performing because they set the devices according to the specified requirements for the tests, but they do not allow to the user to change some parameters if a modification is done to the procedure that Mabe's engineers follow.

At the moment the test procedure that is being followed is the ETP # 910E001 (Engineering Test Procedure) dedicated to power line and EMI product testing which is written, revised and controlled by GE (General Electric).

In order to do such modifications to the software, people from the software supplier company has to come to Mabe, and that means to spend money and time which is not always possible in a company.

Another disadvantage from the actual software that is being used is that a license has to be bought for every computer and for every application. In order words, if a computer has only the license for susceptibility tests, it cannot perform emission tests. At the present time, one computer is used for emission tests and another one is used for susceptibility tests. Obviously the limited number of licenses produces some time delays although there are enough resources to perform different types of tests at the same time.

1.3 JUSTIFICATION

To carry out the EMC tests, that is the emission and susceptibility tests, electronic equipment such as test receivers, amplifiers, power meters and signals generators are necessary.

Those devices can be manually operated but that means to spend more time during test setting and execution. So, in order to make the test performance easier to the evaluation engineer, the remote mode is used. In fact, computer based interfaces simplify parameters configuration, tests execution and report generation, and also allows information storage for upcoming analysis.

In general, those are the main advantages of having a software interface for tests performing, but at this moment it is not enough for Mabe because Mabe's tests facility is under GE approval. So it is necessary for Mabe a software interface that performs the tests as the actual software does, but also, that it can be modified easily if the test procedure, that is the ETP, changes according to the GE requirements.

Therefore, the purpose of this Master's thesis project is to develop a new software interface allowing to the evaluation engineers to perform the EMC tests, to limit the vendor dependency for future template modifications and to reduce licensing costs.

1.4 OBJECTIVES

1.4.1 General objectives

The general objective of this project is to develop a software interface, using the GPIB bus, a programming language and SCPI commands, able to initialize, set and command the devices that are used in the EMC tests in the Mabe's EMC tests facility simplifying the acquisition, display and report generation of the obtained data.

1.4.2 Specific objectives

These are:

- to develop an interface for controlling the test receiver ESPI from Rhode & Schwarz which is used to carry out the "conducted emissions test" using LabVIEW. In Figure 1.1 is shown a block diagram of this test.

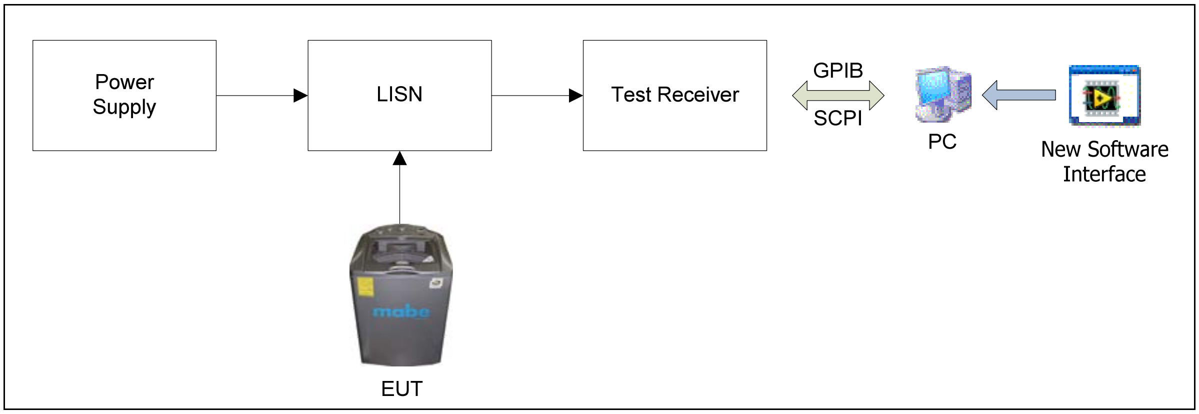

Figure 1.1: *Conducted Emissions Test Block Diagram*

- to develop an interface for controlling the signal generator and power meter both from Rhode & Schwarz and an amplifier from Amplifier Research which are used in the "susceptibility to radiated emissions test" using LabVIEW. In Figure 1.2 is shown a block diagram of this test.

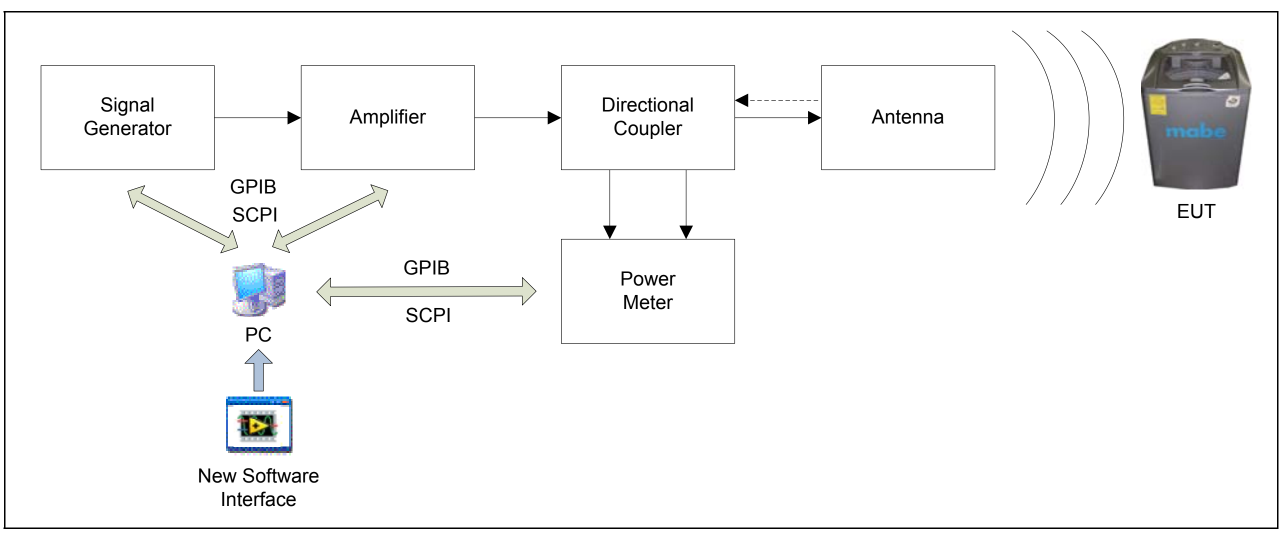

Figure 1.2: *Susceptibility to Radiated Emissions Test Block Diagram*

1.5 HYPOTHESIS

In the first paragraphs it has been outlined that Mabe's engineers need a well suited software interface tool allowing the control and handling of the necessary equipment for the EMC tests in an easy way according to the procedures they use.

In order to control these devices the user or evaluation engineer has two options. The first one has to be a direct way of setting the test parameters and starting the test execution through control elements such as buttons or menus that will be displayed in the front panel or user interface of the developed application.

The second one is that the user will have an option for modifying the developed application in the code level if some adjustments have to be done in the way that the test is executed. In order to do this, the program will be divided into subprograms or modules that will be identified due to the function that they will realize allowing to change the necessary parameters in order to satisfy the new requirements.

Using LabVIEW to create this interface, including the above mentioned options, would be an advantage for Mabe because their engineers will need only a basic knowledge of that software and they will be able to make themselves the modifications to the new software interface instead of waiting for a commercial software supplier's technician to make the modifications to the EMC32. That would reduce tests times and maybe increase productivity.

In the next chapter some fundamentals of the EMC theory and practice will be introduced.

2. CHAPTER II: FUNDAMENTALS

2.1 INTRODUCTION

Nowadays the electromagnetic compatibility is an issue that has to be considered when a new electronic product is going to be design as the application note of Atmel “AVR040: EMC Design Considerations” [1] mentions:

“Electromagnetic compatibility is a subject most designers did not have to worry about a few years ago. Today, every designer putting a product on the global market has to consider this. There are two main reasons for this:

- *The electromagnetic environment is getting tougher:*
  High-frequency radio transmitters, like mobile telephones, are found everywhere. More and more systems are using switching power supplies in the power circuit, and the overall number of electronic appliances is increasing every year.
- *Electronic circuits are becoming more and more sensitive:*
  Power supply voltages are decreasing, reducing the noise margin of input pins. Circuit geometries get smaller and smaller, reducing the amount of energy required to change a logic level, and at the same time reducing the amount of noise required to alter the logic values of signals.

From a designer’s point of view, EMC phenomena have to be considered in two different ways:

- *How the environment may affect the design (immunity).*
- *How the design may affect the environment (emission).”*

As noted above, the new product is going to affect and to be affected by other systems. This is the main reason why its performance is tested in an approved laboratory. If it passes, it may be marketed; however if it do not, there will be problems because a small change in order to correct a failure can cause money and time losses. Passing EMI/EMC-compliance testing is mandatory in all international and domestic markets [2].

2.2 DEFINITIONS

2.2.1 Electromagnetic interference (EMI)

Interference could be defined as an event that produces undesired effects or troubles when an equipment or appliance is running on.

The electromagnetic interference is the emission of electromagnetic energy which may degrade the quality of a signal, or disturb the normal performance of an electronic or electrical system. Some examples of interferences are the electromagnetic noise or any other unwanted signal [3].

The emissions can be naturally or artificially produced such as those emitted by the sun or an electric circuit respectively.

EMI are generally divided into two general types [4]:

- *Radiated emissions:*
  They are those emissions which leave a circuit board, trace or wire, and propagate through the air in the form of electromagnetic waves which interfere with a nearby system.
- *Conducted emissions:*
  It refers to energy received by a circuit or system from another one through wires or cables.

Electromagnetic interference can be analyzed from a source or a receiver perspective [4]:

- *Emissions (source perspective):*
  It refers to the undesirable radiated noise generated by equipment with the potential to affect other system.
- *Susceptibility (receiver perspective):*
  It describes how the equipment is affected by emissions generated from other system.

Sometimes the effects produced by the EMI do not cause any damage to the systems but just an undesired behavior, for example when car alarms are activated due to the presence of a radio transmitter. But there are critical cases in which EMI can cause the total loss of a system, or in the worst case, this may produce severe injuries to people; e.g. the control systems of airplanes can be seriously affected by spurious unwanted signals when they fly near to high power radar installations; this type of perturbations can affect the control system in such a way that they do not respond and the airplane could crash down.

These problems are the reason why nowadays there are organizations like the International Special Committee on Radio Interference (CISPR – *Comité International Spécial des Perturbations Radioélectriques*) that regulates the EMI emitted by the systems.

2.2.2 Electromagnetic compatibility (EMC)

The electromagnetic compatibility is the ability of a system or device to work satisfactorily in its electromagnetic environment without causing electromagnetic disturbance and standing the interference created by other systems [5].

2.2.3 Electromagnetic susceptibility (EMS) and electromagnetic immunity

Two contrary terms, susceptibility and immunity are used to indicate the vulnerability degree to electromagnetic disturbances of a device or system, that means, the susceptibility or immunity level is a property of the system to perform well in an interference environment [6] [7].

In other words, susceptibility level indicates how the system is going to be affected by EMI; and immunity level shows how the system can stand an interference environment having no problems for its normal operation.

There are three groups of elements that determine the susceptibility of a device, system or installation [5]:

- Passive or active electronic components.
- Printed circuit boards, wires or cables and power supplies.
- Mechanical components such as racks or housings.

The electronic components are the susceptible part of the system, while the other elements can be the origin, attraction or propagation medium for disturbances.

2.3 INTERFERENCE TYPES

EMI can be classified in several types depending on different concepts and not only in natural/artificial or radiated/conducted emissions as it was mentioned in section 2.2.1.

Regarding the origin, EMI can be classified as [8] [9]:

- *Natural:*
  Disturbances are produced by atmospheric discharges, environmental electrostatic discharges (ESD), celestial (cosmic) noise, etc.
- *Artificial or man-made:*
  Interferences are a consequence of the operation of an electric device or a system.

Depending on the propagation medium [5]:

- *Conducted:*
  The propagation medium is an electric conductor which connects the interference source directly with the receptor.
- *Radiated:*
  The way of propagation is via electrostatic or electromagnetic fields.
- *Coupled:*
  It is a special case of radiated propagation, appearing when two conductive elements are near enough to produce capacitive or inductive coupling between

them. The main difference between radiated and coupled propagation is the distance separating the conductors.

So there will be capacitive or inductive coupling when:

Propagation distance < wavelength

And radiation when:

Propagation distance > wavelength

According to the interference repeatability [6]:

- *Continuous:*
  It is given by random interferences or pulses that last more than 200 ms.
- *Discontinuous:*
  It is given by random interferences or pulses that last less than 200 ms.

And to conclude this part, according to the frequency range, there are five different groups [6]:

- *Low frequency disturbances (f < 10 kHz):*
  Belonging to this group the interferences produced by power supplies and electrical networks which propagate by conduction.
- *10 kHz – 150 kHz disturbances:*
  EMI are produced by pulses originated from the operation of relays, switches and other electromechanical commuting devices. The propagation via is a combination of conduction and coupling.
- *150 kHz – 30 MHz disturbances:*
  The origin of these disturbances is similar to that for the 10 kHz – 150 kHz group, but they are propagated by radiation and coupling.
- *30 MHz – 300 MHz disturbances:*
  The propagation way of this type of EMI is through radiation.
- *500 MHz – 18 GHz disturbances:*
  Interferences are produced by devices used for communications and logic fast-switching circuits. For this group the propagation medium is the radiation.

2.4 NATURAL EMI SOURCES

As it was mentioned above, the sources of electromagnetic interference can be natural or human-made. Natural sources are the sun, stars, lightning, electrostatic discharges, etc. And the human-made interferences are consequences of the use of electrical or electronic devices. Table 2.1 lists some typical EMI sources [3].

EMI SOURCES			
Human-made Sources		**Natural Sources**	
Systems	**Circuits and Components**	**Terrestrial**	**Celestial**
Communication, radar, navigation equipment	Local oscillators	Atmospherics	Cosmic noise
Fluorescent tube lights	Switches	Lightning	Solar noise
Automobile ignition	Motors	Electrostatic discharge	
Industrial equipment (welders, heaters, etc.)	Filters		
Appliances (microwave ovens, mixers, etc.)	Relays		
	Circuit breakers		
	Magnetic armatures		
	Logic and digital circuits		

Table 2.1: *EMI Sources [3]*

2.4.1 Thermal noise

As the operating temperature in any material will be always higher than the absolute zero (-273°C) in any material, there will be a random movement of the electrons located inside of it. If this movement is equivalent to an electric current, an electromagnetic signal will be produced [10].

The thermal power of this current when it is dissipated by means of a resistor can be known calculating the rms (root mean square) value of the amplitude. As this value depends on the temperature, this effect is called thermal noise.

The thermal noise voltage V_{th} is defined as:

$$V_{th} = \sqrt{4kTBR} \qquad (2.1)$$

Where:

T = absolute temperature (K)

R = resistance (Ω)

B = bandwidth (Hz)

k = Boltzmann constant ($1.38e^{-23}$ J/K)

The thermal noise is an important factor since it determines the minimum value for a signal to be detected; a signal with amplitude below this level can be lost within the noise.

Notice that thermal noise has always random amplitude and frequency values. Therefore, signals having constant amplitude and frequency with lower values than the thermal noise can be recovered.

2.4.2 Lightning discharge

Lightning is caused by the accumulation of charges in the clouds. So when they acquire enough high potential with respect to the ground, the field intensity breaks the air isolation resulting in an electric discharge. The discharge can be originated from cloud to ground, cloud to cloud and from ground to cloud with positive or negative polarity with respect to ground [10].

The discharge between a cloud and the ground is called flash, and it lasts about 0.5 s. It consists of a series of high-current pulses called strokes. Each stroke lasts about 1 ms with a separation time between them about 40 to 80 ms. The pulse currents have values of the order of 1 kA [3].

The current produced by a lightning discharge can be in the range of 1 to 200 kA; about 1% is equal to 100 kA or more, and about 80% exceeds 50 kA. The discharge is dissipated in the surface where the impact occurs and because of the surface resistance a potential is produced between two arbitrary points located in this area. So the surface potential can be calculated with:

$$P_s = \frac{\rho I}{2\pi}\left(\frac{1}{D} - \frac{1}{D + x}\right) \qquad (2.2)$$

Where:
ρ = surface resistance
I = discharge current
D = distance to the impact point
x = distance between two arbitrary points

The interference of a lightning discharge is called sometimes lightning electromagnetic pulse (LEMP) and the fields created by this pulse will induce currents in any conductor material near to the impact point [10] (e.g. The field produced by a lightning discharge in a point 1 km far away from the impact point is about 3000 V/m).

2.4.3 Celestial electromagnetic noise

It is well known that celestial bodies like the stars, galaxies, moon and planets emit electromagnetic radiations.

In stars and galaxies, the electromagnetic radiation is produced by the random motion of charged ions resulting from the thermal ionization caused by the high temperature of these bodies.

The radiations produced by the planets or the moon are attributed to the thermal noise produced by the heating of one side of these bodies when it is exposed to the sun for a given interval of time.

The level of electromagnetic noise emitted by a cosmic source does not vary appreciably with time, but in a specific point over the Earth's surface it will change depending on the hour of the day because of Earth's rotation [3].

2.4.4 Electrostatic discharge

Static electricity is generated when two objects of different dielectric constant are rubbed against each other causing an excess of electrons in one object's surface and a lack of them in the other one. A similar effect is observed when two insulating materials are in contact and suddenly they are separated. Once they are separated, the charge will remain constant, until the object can be discharged.

Another way of charging may result from heating (loss of electrons), or through contact with a charged body.

The static charge generated in one object is discharged to another one which has a lower resistance to the ground. The electric charge magnitude depends on the material, the contact pressure, the contact area and the speed of separation.

The natural phenomenon in which accumulated static charges are discharged is called electrostatic discharge (ESD) and it produces electromagnetic interference. The effects caused by an ESD can vary from noise and disturbances in electronic devices such as measuring instruments to unpleasant electrical shocks to the involved equipment or person [3] [10].

Several materials which exhibit ESD are listed in Table 2.2. These tables are commonly known as the triboelectric series of materials [11]. The triboelectric effect is an electrical phenomenon where certain materials become electrically charged after coming into contact with another different material [12]. Materials listed at the beginning of the table generally acquire a positive charge relative to materials at the lower end of the table. The further away two materials are from each other on the series, the greater the charge transferred.

Asbestos
Acetate
Glass
Human Hair
Nylon
Wool
Fur
Silk
Aluminum
Paper
Polyurethane
Cotton
Wood
Steel
Sealing Wax
Hard Rubber
Mylar
Epoxy Glass
Nickel, Copper, Silver
Brass, Stainless Steel
Synthetic Rubber
Acrylic
Polystyrene Foam
Polyurethane Foam
Polyester
Polyethylene
Polypropylene
PVC
Teflon
Silicon Rubber

Table 2.2: *Triboelectric Series [11]*

A common example of ESD occurs when a person wearing shoes with soles made of an insulating material such as polyurethane foam walks over a carpet made of wool. Both materials are good insulators, and the sole becomes charged due to the rubbing with the carpet. This charge is transferred to the human body, and this is how a charge of 1×10^{-6} coulombs or more can be accumulated which could produce a voltage of 15 kV. The discharge will take place when the person touches a metallic object which is grounded through a low resistance path.

A person can safely attain voltages of 35 kV. Although discharges below 3500 V are not noticed by a person, they can damage many devices which can stand only hundreds of volts.

2.4.5 Electromagnetic pulse (EMP)

The explosion of a nuclear weapon causes an emission of X-rays, γ-rays, neutrons and electrons. γ-rays are the most significant to EMC because they can produce a high speed electron flux which causes an electromagnetic pulse. This phenomenon is also known as nuclear electromagnetic pulse (NEMP) because of its origin.

NEMP is considered an EMI source when the X-rays and γ-rays interact with different materials of a system or equipment that is located in the close proximity of a nuclear burst and lead to uncontrolled emission of electrons. Motion of these electrons produces electromagnetic fields, which may damage electronic systems [13].

The γ-rays produced by a nuclear explosion in or above Earth's atmosphere [14] can travel in all directions colliding with air molecules which produce fast-moving electrons and therefore a current. The effects of an explosion close to ground and the effects of one 35 km away from Earth's surface are not the same. The first one is called ENDO-atmospheric burst and the second one EXO-atmospheric burst, resulting in ENDO-EMP and EXO-EMP respectively.

At high altitudes γ-rays are more intense, hence, there is a higher electron flux producing a higher current over a wide surface of Earth. The electromagnetic field strength created by this current is about 50,000 V/m and 130 A/m, and it covers a frequency spectrum of some KHz to 100 MHz. To understand what effects can produce this field consider that a

1 μW produces a field of 20 mV/m, which is the power a radio receptor is able to detect, so it is obvious that a field generated by an EMP is thousands times higher and it can damage electronic equipments or even destroy them [10].

The electrons generated by ENDO-EMP have a shorter life time than the EXO-EMP. It is in the order of a few nanoseconds because of their quick capture by the ground, and more frequent collisions with air molecules.

The intensity of the electromagnetic field generated by a nuclear explosion depends on the intensity of the nuclear detonation. It is also a function of the distance from the point of explosion. A detonation at an altitude of 40 km affects electrical equipment located at distances of up to 5000 km and a detonation occurring at altitudes between 0 and 20 km have smaller long-distance effects [3].

2.5 ARTIFICIAL EMI SOURCES

The electromagnetic noise or interference generated in electrical, electromechanical and electronic systems is a result of electromagnetic interactions inside such circuits and systems. These emissions are considered human-generated EMI and may be divided into two categories [3]:

- Intentionally emitted signals.
- Unintentionally electromagnetic emissions during the operation of equipment.

2.5.1 Systems

Some examples of systems that emit intentionally electromagnetic radiations during its operation are the radars, communication equipment, television and radio broadcast transmitters. The desired signals and the unintended and undesired electromagnetic emissions generated by the system during its normal operation could interfere with the operation of other electronic equipment.

Generally, sources of coherent radiation are intentional emissions from some equipment at a specified frequency of operation. However, such equipment may also emit unintentional radiation around the same or some other frequency. Both coherent and non coherent radiations are potential sources of electromagnetic interference [15].

Other systems that are designed to emit electromagnetic energy at an intended or designated frequency are the oscillators, amplifiers and transmitters. However, they also emit energy over a range of frequencies centered around the desired frequency. This energy is known as noise in the vicinity of the carrier and it may affect other systems near to them.

2.5.2 Appliances

Use of switches, relays, or commutators in appliances such as electric fans, electric shavers, refrigerators or mixers is a source of electromagnetic noise. This noise is generated by transient currents during a make or break of contact and the sudden changes in magnitude and direction of currents.

Appliance	Electric Field Intensity (V/m)
Electric blanket	250
Boiler	130
Stereo	90
Refrigerator	60
Electric iron	60
Hand mixer	50
Toaster	40
Hair dryer	40
Color TV	30
Coffee pot	30
Vacuum cleaner	16
Incandescent bulb	2

Table 2.3: *Electric field intensity levels at 30 cm from 115 V home electrical appliances[16]*

This type of systems is considered as unintentional EMI sources. In Table 2.3 and Table 2.4 [16] can be seen the levels of electric and magnetic field emissions from different appliances.

Appliance	Magnetic Flux Density (mT)		
	distance 3 cm	distance 30 cm	distance 1 m
Electric ranges (over 10 kW)	6-200	0.35-4	0.01-0.1
Electric ovens		0.15-0.5	0.01-0.04
Microwave ovens	75-200		0.25-0.6
Garbage disposals	80-250		0.03-0.1
Coffeemakers	1.8-25	0.08-0.15	<0.01
Can openers	1000-2000	3.5-30	0.07-1
Vacuum cleaners	200-800		0.13-2
Hair dryers		<0.01-7	<0.01-0.3
Electric shavers	15-1500	0.08-9	<0.01-0.3
Television	25-50	0.04-2	<0.01-0.15
Fluorescent fixtures	15-200	0.2-4	0.01-0.3
Sabre and circular saws	250-1000		0.01-1

Table 2.4: *Magnetic flux densities measured at different distances from various 115 V appliances [16]*

2.5.3 Noise from relays and switches

Most types of relays used in electrical and electronic circuits are basically electromechanical switches and their operation involves making or breaking electrical contacts which results in the generation of transient electrical currents.

To understand better how a switch generates electromagnetic noise, the switching of a telephone relay is examined [3]. In Figure 2.1 is shown an equivalent circuit of the telephone relay where R_g, L_g, C_g are the resistance, inductance and capacitance of the source side, and R_l, L_l, C_l represent the load impedance. Then, when the relay switch is closed (i.e. contact made) current flows through C_g and C_l. The initial current rises very rapidly to a high peak value and then gradually decays to the normal load current after undergoing a damped oscillation at a frequency of:

$$f_d = \frac{1}{2\pi\sqrt{L_g C_l}} \qquad (2.3)$$

Similarly, when the relay switch is interrupted (i.e. contact broken), damped oscillations take place on the load side at a frequency of:

$$f_{d1} = \frac{1}{2\pi\sqrt{L_l C_l}} \qquad (2.4)$$

In the “contact made” and “contact broken” operations, there is a possibility of the tip contact material either melting or vaporizing as a result of high current density and the heat generated. In addition the process of arcing during the make or break also produces transients in the line.

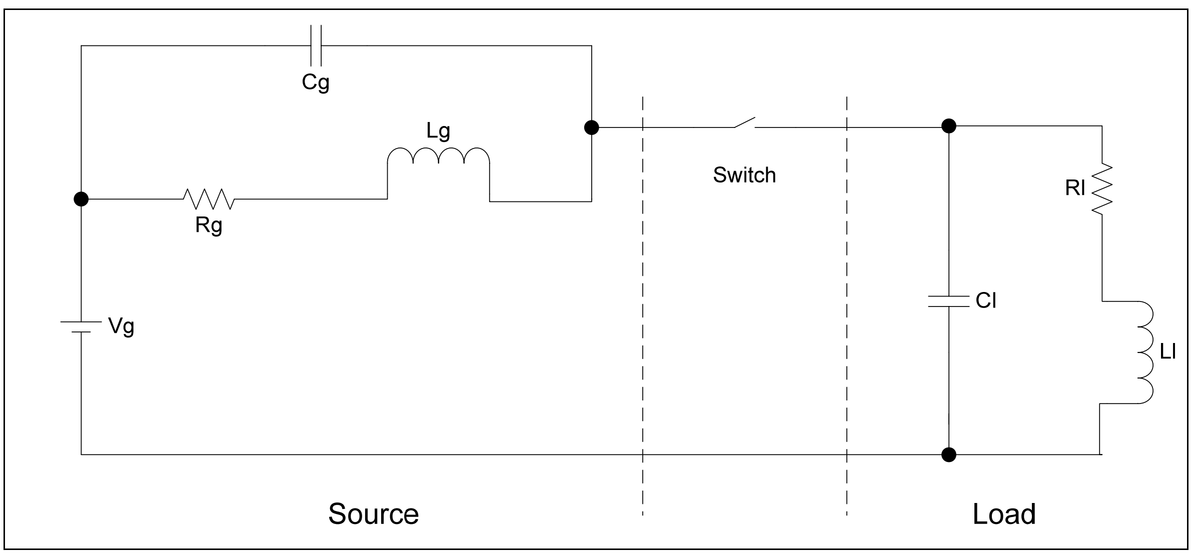

Figure 2.1: *Equivalent Circuit of a Relay/Switch Circuit [3]*

The transient noise from switches and relays may destroy sensitive electronic components, cause interference to radio and television reception, or lead to malfunctioning of electronic circuits.

2.5.4 Passive elements

Imperfections in passive elements are also human-made sources of EMI. The no-ideal behavior of these elements in high frequencies is the main reason of electromagnetic noise [5].

- *Resistors:*

An important fact to be considered is that electric resistance of materials in DC is different from resistance in AC. Resistance in AC decreases while frequency increases as is shown in Figure 2.2.

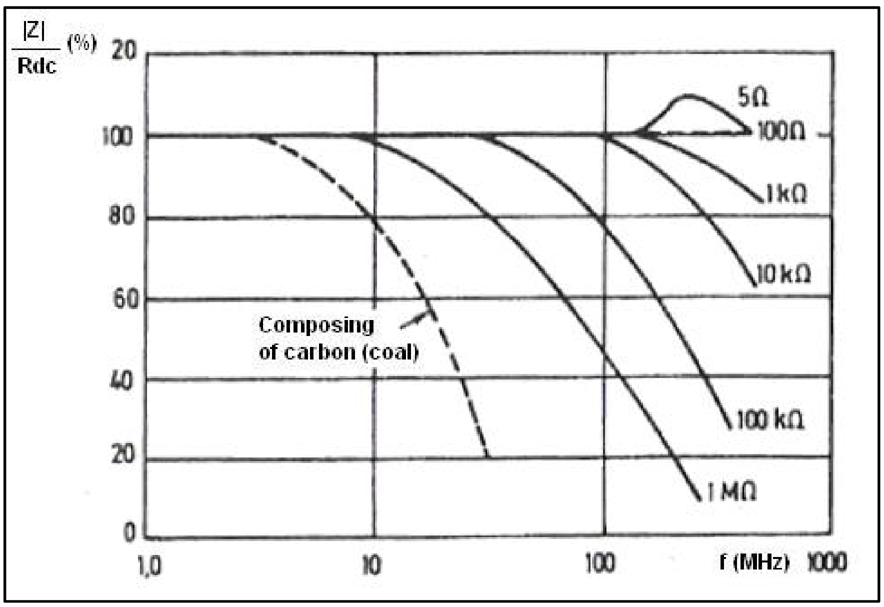

Figure 2.2: *Behavior of different resistors in a frequency range of 1 to 1000 MHz*

The resistance is an intrinsic property of a material but it is not constant, it depends on dimensions, impurities, frequency, temperature, and the applied voltage and current. In fact, frequency is the reason why a resistor cannot be considered as a purely resistive component, it shows also a capacitive and an inductive component.

In order to characterize the real behavior of a passive element, an equivalent circuit is used. This circuit is made of ideal elements and its values may vary for different frequencies just to obtain a correct impedance description of the element.

The equivalent circuit for a resistor is shown in Figure 2.3. Where *R* is the resistance in DC, *L* the inductance (in tens of nH) between the two terminals, and *C* (from 0.1 pF to 1.5 pF) represents the total capacitance.

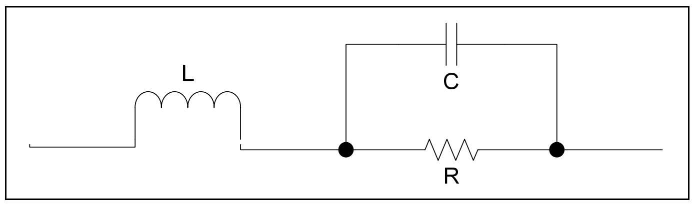

Figure 2.3: *Resistor Equivalent Circuit*

The real impedance of the resistor is given in the form:

$$Z = ESR + jX \qquad (2.5)$$

Where the equivalent series resistance (ESR) is:

$$ESR = \frac{R}{1 + \omega^2 C^2 R^2} \qquad (2.6)$$

Notice that $ESR \neq R$ and *ESR* depends on frequency because of ω.

Another parameter that should be considered for passive elements is the quality factor *Q*. It is defined as the ratio of the imaginary component of the impedance to the real component. A high value of *Q* means low energy dissipation which is not exactly the behavior expected for an ideal resistor.

$$Q \approx \omega \left(\frac{L}{R} - CR \right) \qquad (2.7)$$

Equation 2.7 shows how an increment in *L* or *C* makes the resistor behavior differ from the ideal.

- *Capacitors:*

The capacitance of a capacitor is the property of storing electric charge when a potential is applied between the conductor plates of the capacitor. The capacitance is a function of the dielectric, the capacitor shape and its dimensions. And it varies with the changes of humidity, temperature and vibrations.

As the resistor, the real behavior of a capacitor is represented by different passive elements. The capacitor equivalent circuit is shown in Figure 2.4 and it is formed by two resistors, (the resistance R_s of the terminals, plates and contacts, and the resistor R_p that represents the leakage current in the dielectric), the inductance of the terminals and plates *L*, and finally the capacitor capacitance *C*.

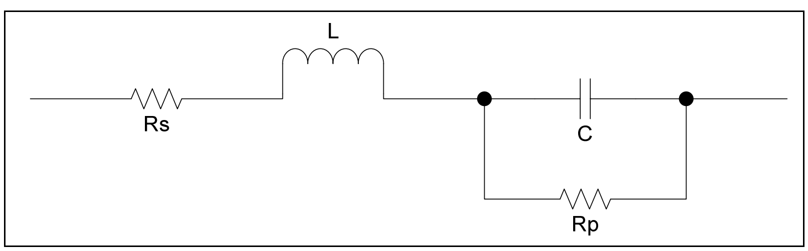

Figure 2.4: *Capacitor Equivalent Circuit*

The real impedance for this equivalent circuit is given as:

$$Z = ESR + \frac{1}{j\omega C_e} \qquad (2.8)$$

Where *ESR* is the equivalent series resistor and it is higher than R_s; C_e is the equivalent capacitance. The term *ESR* indicates energy dissipation which increases the capacitor temperature and therefore the value of the equivalent capacitance will change.

In Figure 2.5 is shown how the impedance of three different capacitors changes due to the frequency.

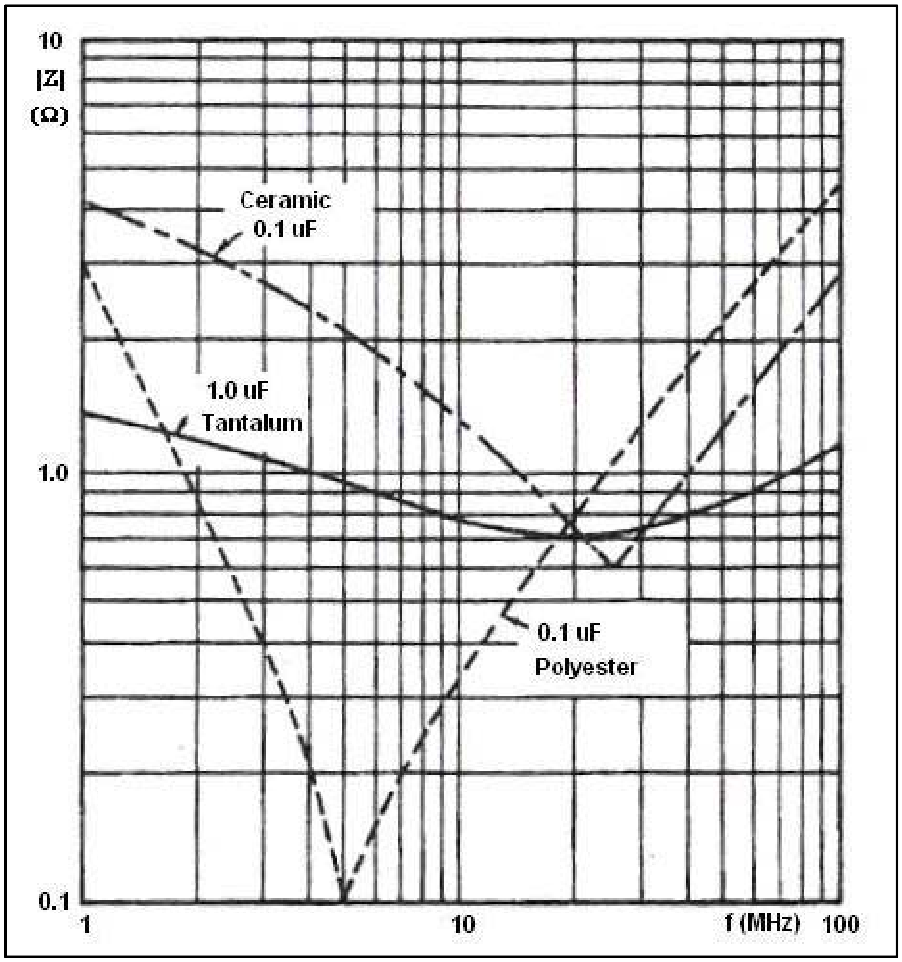

Figure 2.5: *Impedance changes of capacitors due to frequency*

For the case in which R_p is too high:

$$ESR \approx R_S \qquad (2.9)$$

$$C_e \approx \frac{C}{1-\omega^2 LC} = \frac{C}{1-\left(\frac{\omega}{\omega_r}\right)^2} \qquad (2.10)$$

where

$$\omega_r = 2\pi f_r = \frac{1}{\sqrt{LC}} \qquad (2.11)$$

and f_r is the resonance frequency. C_e depends on the frequency and the value of L. For low frequencies until resonance frequency, C_e decreases as the frequency increases, and it is higher than the capacitance C. And for higher frequencies than the resonance frequency, the value of C_e is negative, which means that the component behaves as an inductance. For this reason, a high value of resonance frequency which means a low value of L should be used. This can be obtained with very short terminals in capacitors.

- *Inductors:*

The inductance of a coil depends on its dimensions, the number of turns and the core permeability μ. Of all passive elements, the inductor is the one which changes more due to frequency.

The equivalent circuit for a real inductor, shown in Figure 2.6, has an inductance L, a series resistor R and a capacitance C distributed along the coil.

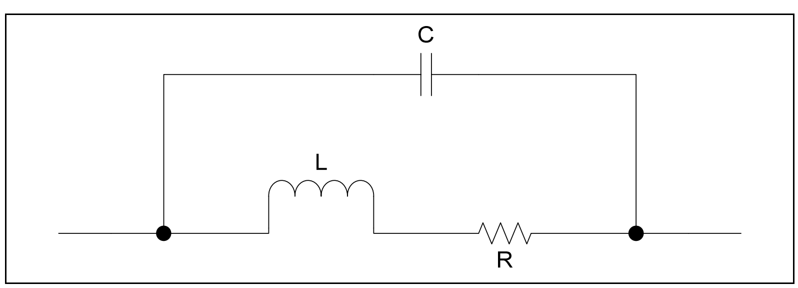

Figure 2.6: *Inductor Equivalent Circuit*

Figure 2.6 fits perfectly for a coil with air core, where the real impedance (if *R* and *C* values are small) can be written as:

$$Z \approx \frac{R}{(1-\omega^2 LC)^2} + \frac{j\omega L}{1-\omega^2 LC} \qquad (2.12)$$

And the quality factor for these conditions is given by:

$$Q \approx \frac{\omega L}{R}(1-\omega^2 LC) \qquad (2.13)$$

In equation 2.13 can be seen that a high value of capacitance among turns reduces the quality factor.

The equivalent series resistance is defined by:

$$ESR \approx R(1+2\omega^2 LC) \qquad (2.14)$$

and the equivalent inductance is:

$$L_e \approx \frac{L}{1-\omega^2 LC} \approx L(1+\omega^2 LC) \qquad (2.15)$$

The equivalent inductance is higher than *L* and it increases as the frequency does.

Equations 2.14 and 2.15 are only for small values of *R* and *C*, for a general case *ESR* and L_e are defined as:

$$ESR = \frac{R}{1+\omega^2 R^2 C^2 - 2\omega^2 LC + (\omega^2 LC)^2} \qquad (2.16)$$

$$L_e = \frac{L-\omega^2 L^2 C - R^2 C}{1+\omega^2 R^2 C^2 - 2\omega^2 LC + (\omega^2 LC)^2} \qquad (2.17)$$

From equation 2.17, it can be seen that for high frequencies the equivalent inductance can be negative, that is, the inductor can behave as a capacitor.

The main advantage of the coils with air core is their stability. The effects of current, temperature and frequency are smaller than the effects in the coils with magnetic core. But their disadvantages are the poor quality factor and the dispersion flux due to the lack of a core which encloses the magnetic flux.

In figure 2.7 is shown the behavior due to frequency of inductors with ferrite cores. In low frequencies the quality factor increases because of the equivalent inductance also does, but for higher frequencies Q decreases due to the capacitance influence.

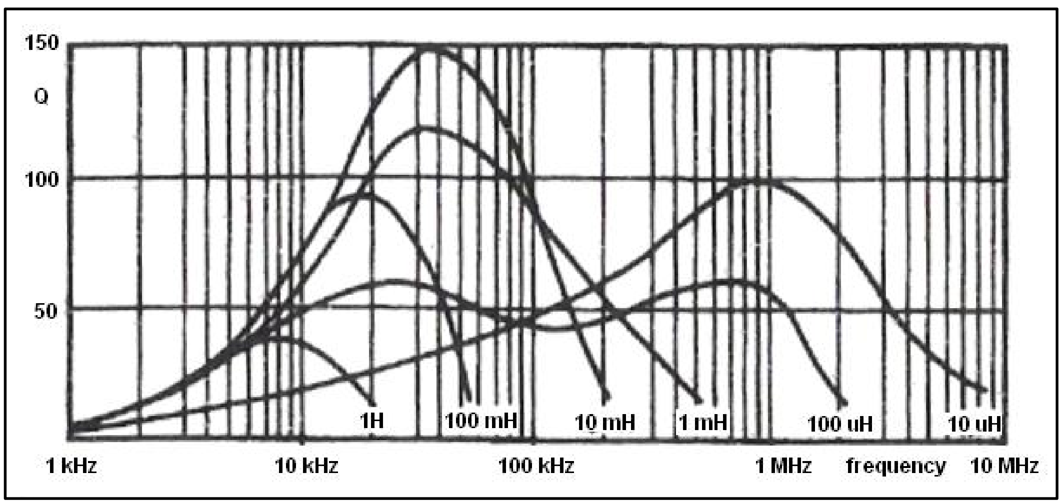

Figure 2.7: *Changes of Q due to the frequency for inductors with ferrite cores*

- *<u>Ferrite Cores:</u>*

Ferrite cores are ceramic composites made of a mixture of iron-oxide powders with either oxides or carbonates of other metals like zinc, cobalt, nickel, manganese, etc. The main advantage of ferrite cores is their high electric resistivity. This property reduces losses due to Eddy currents and maintains a high quality factor even for frequencies of GHz.

The ferrite cores are used not only for construction of inductors but also for interference suppression. For example, when an undesired high frequency current flows through a conductor, a ferrite core is located around it. The resulting inductive effect is similar to a series impedance and it attenuates high frequencies without affecting low frequency signals which can be the desired ones. The high resistivity of ferrite cores makes them suitable to put them on wires without insulation.

The equivalent circuit for a ferrite core bead is shown in Figure 2.8 where:

$$L = \mu_i L_0 \qquad (2.18)$$

$$R = 2\pi f_r L l a_R \qquad (2.19)$$

$$C = \frac{1}{(2\pi f_r)^2 L} \qquad (2.20)$$

$$L_0 = 0.2l \ln(d_o l d_i)\, nH \qquad (2.21)$$

and l is the bead length in mm, d_o is the outer diameter, d_i the inner diameter, μ_i is the material permeability, f_r the resonance frequency, and a_R are the losses which are specified by the manufacturer.

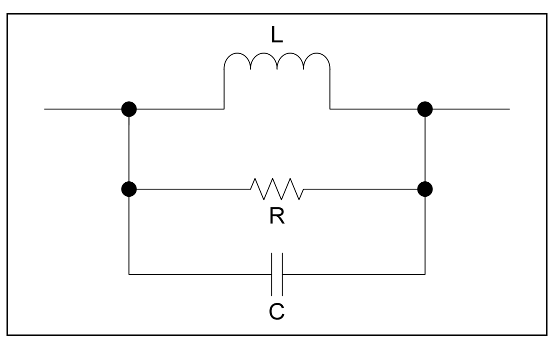

Figure 2.8: *Ferrite Core Bead Equivalent Circuit*

In Figure 2.9 is shown the impedance changes of three different ferrite core beads due to frequency. In order to increase the impedance value in a specific frequency range, larger beads can be used or some of them can be located in series on the conductor.

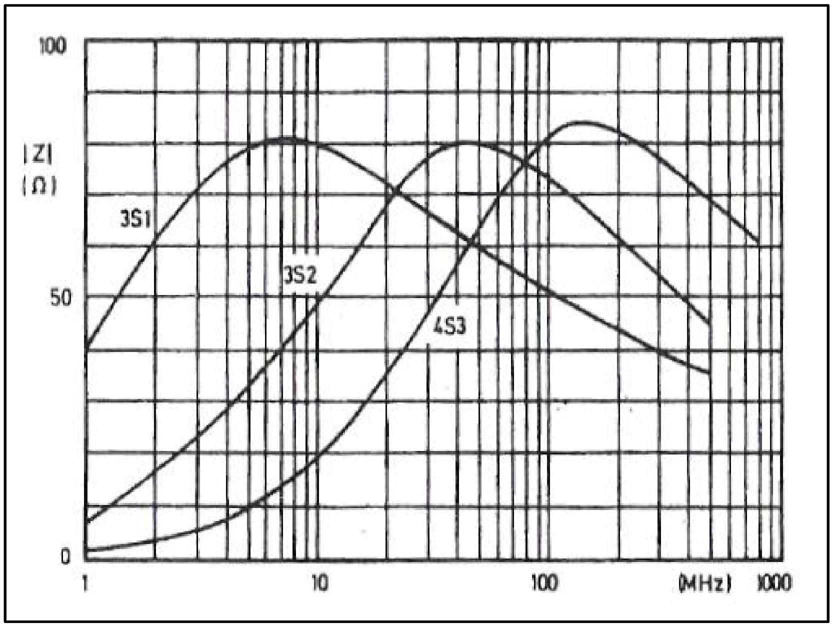

Figure 2.9: *Impedance of three ferrite beads in function of the frequency*

- *Transformers:*

The transformer is the passive element which imperfections affect more to the systems. As the other components, the transformer has also an equivalent circuit, shown in Figure 2.10, to represent its real behavior. In the circuit, C_p and C_s are the primary and secondary capacitances respectively, C_{ps} is the capacitance between the primary and secondary, R_1 is the primary resistance and R_2 is the secondary resistance, L_1 and L_2 are the dispersion inductances, R_n is the core losses resistance and L_{ca} is the inductance for the primary in open circuit.

The value of these inductances, capacitances and resistances depends on the transformer size, the materials used for its fabrication and the transformer type.

These parameters affect to the efficiency and the frequency response of the transformer.

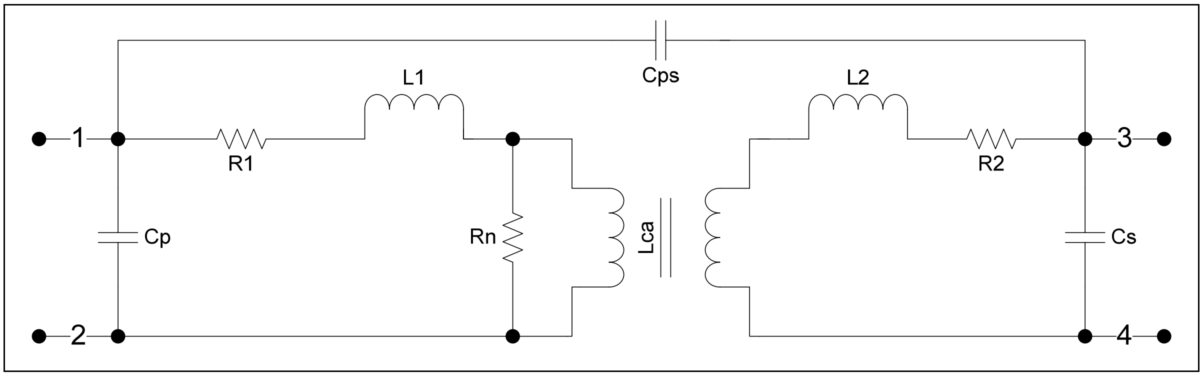

Figure 2.10: *Transformer Equivalent Circuit*

The elements to take into account are the resistances because heating is related to them; dispersion inductances because they determine the magnetic flux not enclosed by the core which affects to other circuits; and the capacitance between the primary and secondary because it couples the primary tension to the secondary and vice versa by a not magnetic way.

2.5.5 Printed circuit boards

It is known that antennas are used to transmit and receive signals through the radiation of electric energy.

In a circuit board unintended antennas are responsible for receiving and transmitting radiated emissions and they are the key behind EMI problems in digital systems [4]. In a PCB, there may be unintended antennas, shown in Figure 2.11, such as:

- Long traces.
- Leads for components.
- PCB board connectors.

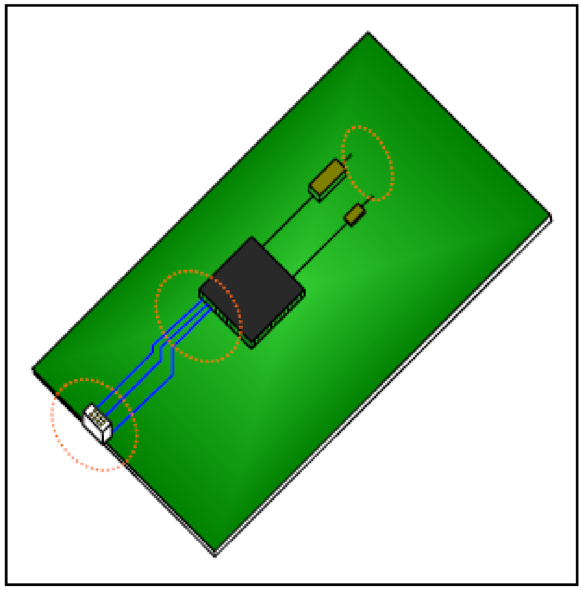

Figure 2.11: *Unintended Antennas in a PCB [4]*

For example an unterminated surface trace (such as an unpopulated connector) can be an unintended whip antenna. A whip antenna, shown in Figure 2.12, is an antenna with a single driven element and a ground plane which is the most common example of a monopole antenna.

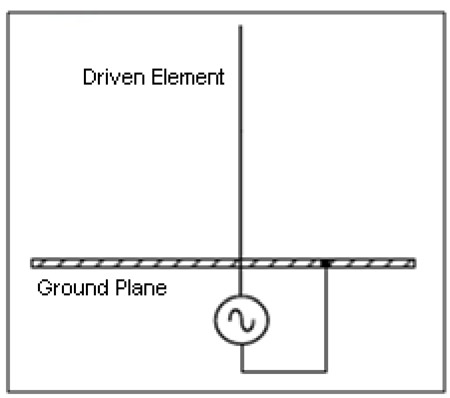

Figure 2.12: *Whip Antenna [4]*

Other kind of accidental antennas in a PCB is the loop antenna, shown in Figure 2.13, which encompasses any path in where both forward and return currents are on a well defined conducting path.

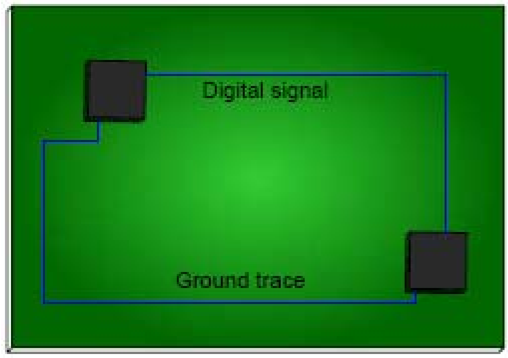

Figure 2.13: *Loop Antenna in a PCB [4]*

2.6 ELEMENTS OF AN EMC PROBLEM

Every EMC problem consists of three essential elements as illustrated in Figure 2.14 [17]. There must be a source of electromagnetic energy, a receptor that cannot function properly due to the electromagnetic energy, and a path between them that couples the energy from the source to the receptor. Each of these three elements must be present although they may not be readily identified in every situation [18].

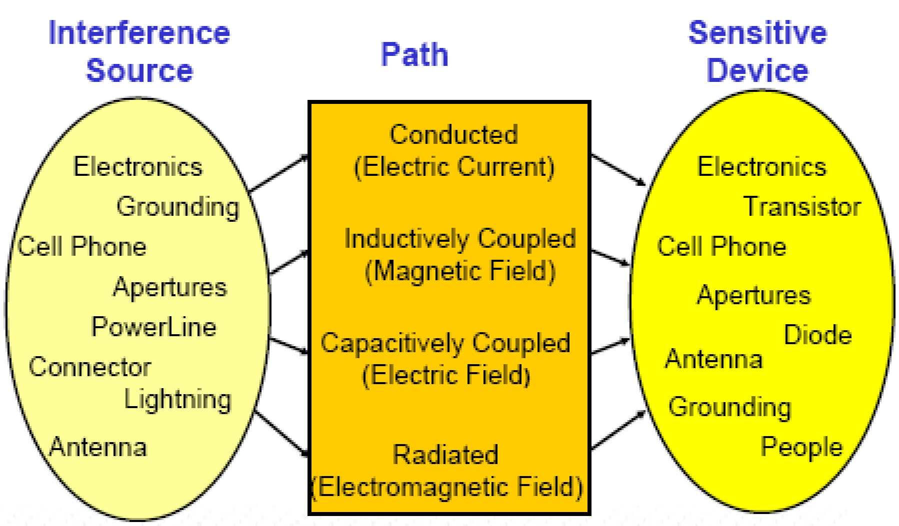

Figure 2.14: *Factors of EMI/EMC [17]*

When an EMC problem is being studied it is very important to define at least two of these elements in order to find a solution because there are only three ways to eliminate or reduce EMI [5]:

- Eliminate them in the source.
- Make less susceptible to the receptor.
- Decrease the energy that is being transferred through the coupling medium.

EMI problems can occur among independent systems in a wide frequency range such as airplanes, television transmitters and electric energy distribution lines. But also, they can occur in the same system, for example, in a power control for a motor, the power supply cables and the motor are EMI sources for the digital circuits that perform the control because they can produce stray signals that disturb its normal operation.

Some examples of EMC problems are observed when [19]:

- a computer interferes with FM radio reception
- a vacuum cleaner causes "snow" on a TV
- a car radio buzzes when the car is under a power line
- a helicopter goes out of control when it flies too close to a radio tower
- the screen on a video display jitters when the fluorescent lights are on
- a new memory board is destroyed by an unseen discharge when it is installed
- the airport radar interferes with a laptop computer display
- a hospital's ECG machine picks up Channel 5

Usually, standards about interferences have a classification for the affected receptors and the produced effects by EMI [6].

The receptors types are:

a) *Devices:*

The simplest elements or components a system has.

b) *Equipments:*

They are functional groups that perform a specific function.

c) *Systems:*

They are equipment groups for more complex processes.

And the effect types are:

a) *Class O:*

The disturbance does not affect the device or equipment, it operates well.

b) *Class A:*

The disturbance causes acceptable effects but it does not affect the device or equipment performance.

c) *Class B:*

The disturbance affects temporally to the device or equipment performance but it does not experience permanent damage and it will operate again without technical support.

d) *Class C:*

The disturbance affects the device or equipment in such a way it will need technical support in order to operate again.

e) *Class D:*

The disturbance causes permanent damage in the device or equipment.

In general, EMI affects to devices, equipments or systems when it disturbs their normal operation or characteristics or even when EMI causes their destruction.

2.6.1 Coupling

Coupling between two systems will exist when one of them transfer energy to the other through some medium or path.

Methods of coupling are divided into four categories [5]:

- ***Conduction or common impedance (electric current):***

It is originated when two circuits have a common impedance, this means that the energy transfer occurs through a conduction path. This impedance is generally the conductor resistance.

One way in which interferences can be carried from the interference source to the receptor is by power supply lines when both are connected to the same power supply line. And another way is by signal or control lines when they connect both.

- ***Capacitive coupling (electric field):***

It is also called electrostatic coupling and it occurs when a circuit is affected by an electric field. It is produced by the capacitance that exists between the conductors of an interference source and the affected system.

Stray capacitance exists in every system that has charged conductors due to the electrostatic induction phenomenon. The electrostatic induction is generated by the variation of charges in any conductor. This change modifies the electric field distribution in the system which affects, at the same time, the charge distribution of the others conductors. Therefore, stray capacitances are undesired in a system since they transfer energy among conductors.

The capacitance in pF/m between two parallel round cables of diameter *d* separated a distance *D* in the air is given by:

$$C \approx \frac{12.1}{\log \frac{2D}{d}} \qquad (2.22)$$

where D>>d.

- *Inductive coupling (magnetic field):*

It occurs when a magnetic field affects a circuit. This type of coupling is produced by the mutual inductance between the receptor and the interference source.

The magnetic induction is originated when the current flowing through a conductor changes. This variation modifies the magnetic field distribution which creates induced electromotive forces in the circuits around it. Therefore, any conductor of a system with a current flowing through it will create a magnetic field which can affect another system.

In fact, the variation of the magnetic field in a circuit is due to the changes of current flowing through the same circuit (auto-induction) and due to the variations produced by a circuit near to it (mutual inductance).

Mutual inductance is about the influences that are established when some circuits share the same magnetic field. Then, a change in the current flowing through one circuit will produce a field variation which induces a voltage in the other circuits.

The mutual inductance coefficient between two parallel conductors separated a distance *d,* when are collocated over a ground plane with a height *h* is defined by:

$$M = 0.098425 \ln\left[1 + \left(\frac{2h}{d}\right)^2\right] \quad \left(\frac{\mu H}{m}\right) \qquad (2.23)$$

If the conductors are too close, the mutual inductance is high; but if they are separated a distance equivalent to twice its diameter there is a reduction of the mutual inductance of 25%. And, if the separation is around 10 cm the reduction is about 50%.

- *Electromagnetic radiation (electromagnetic field):*

In EMC, radiation is a term generally related to the combined effects of the electric and magnetic fields which change with respect to time. The ratio of electric field *E* to magnetic field *H* in a specific point is called wave impedance. For the far-field region the wave impedance is equal to the impedance of free space:

$$Z_n = \frac{E}{H} = 377\Omega \qquad (2.24)$$

The term far-field region is used when the signal source is located at a distance greater than λ/2π from the receptor. There is another region of space known as near-field region that is related to distances less than λ/2π. These regions are shown in Figure 2.15 [10].

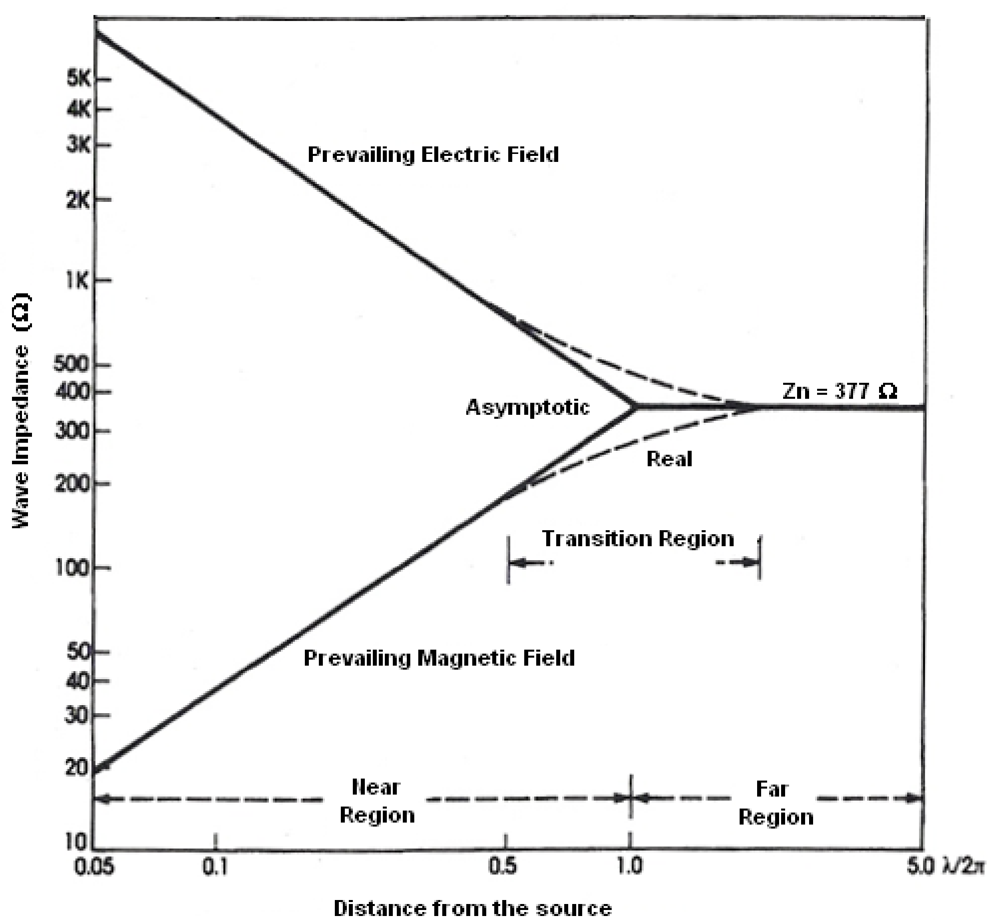

Figure 2.15: *Near and Far Region [10]*

In the near region, energy transfer between source and receptor is done through inductive and capacitive coupling; but in the far region, it is done through electromagnetic radiation.

The radiated waves have three components: the electric field, the magnetic field and the propagation direction. These components are orthogonal between each other in space as is shown in Figure 2.16 [10].

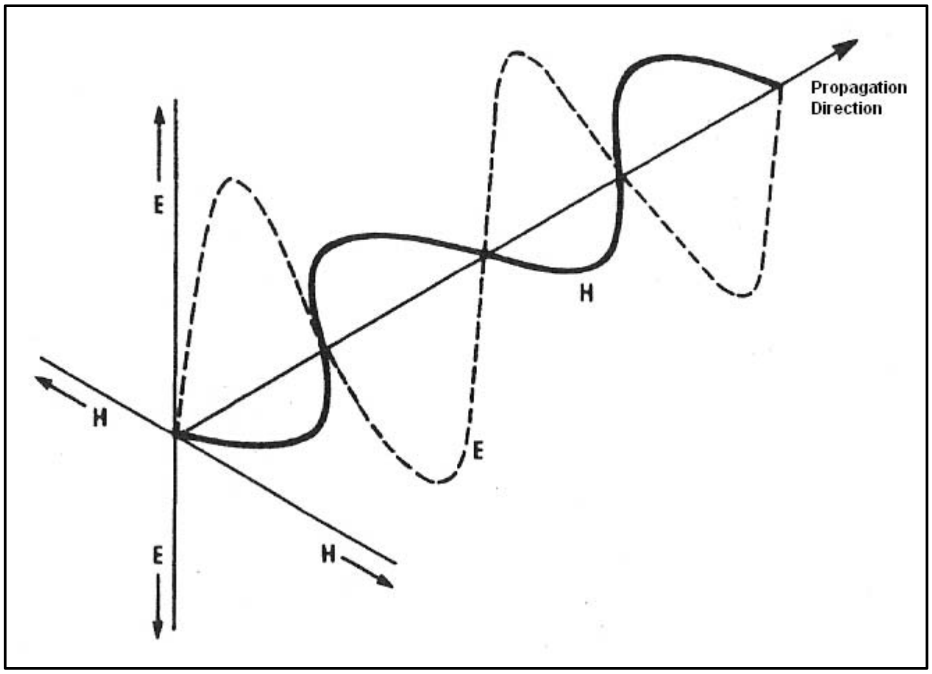

Figure 2.16: *Propagation of a wave in space [10]*

In the propagation direction there is a power flux that is a vector quantity known as Poynting vector and it is defined by E x H. This power flux of electromagnetic radiation may produce interference on a circuit and it is very difficult to eliminate it because every conductor in the system acts as a receptor antenna.

The electromagnetic radiation sources that affect an electronic or electric system can be either artificial or natural. The artificial sources may be divided in two types: narrowband and broadband.

The narrowband sources can be electronic devices such as radar equipment and radio or television transmitters, which generate a signal with a narrow and well defined bandwidth. In the other hand, sources with a broadband spectrum as electric machinery, ignition or illumination systems are more difficult to control since its bandwidth is not well defined. Finally, the natural sources of electromagnetic radiation are atmospheric discharges or cosmic radiation.

The field intensity of a radiation source at a specific distance in the air can be calculated approximately with:

$$E = \frac{0.173\sqrt{P}}{D} \qquad (2.25)$$

Where:

E = field intensity (V/m)

P = radiated power (kW)

D = distance (km)

Coupling paths often use a complex combination of these methods making the path difficult to identify even when the source and receptor are known.

2.7 INTERFERENCE MEASUREMENTS

The EMC problem needs two basic measurements:

- Measurement of disturbances produced by systems or EMI measurement.
- Measurement of system susceptibility or EMS measurement.

In order to perform an EMC test there will be a method which is defined by standards and rules, and the technical means or mediums for simulating and measuring such as interference generators, receivers, signal adapters, test sites, etc.

It is important to notice that most of standards are more interested on defining emission limits than on susceptibility limits, hence, methods for emission measurement are more defined and developed. Nevertheless this fact, EMC depends on both, and the designer and manufacturer have to guarantee the good performing of its system in an interference environment.

In every EMC test, its three elements: source, path and receptor should be considered. Therefore, the general methodology includes a set of tests which are mentioned in Table 2.5 [5].

EMC TESTS				
Emission Tests		**Susceptibility Tests**		
Conducted	**Radiated**	**Conducted**	**Radiated**	**ESD**
Power Supply Cables	Magnetic Field	Power Supply Cables	Magnetic Field	Equipment cover
Signal Cables	Electric Field	Signal Cables	Electric Field	Control Panels
Antenna Terminals	Electromagnetic Field	Antenna Terminals	Electromagnetic Field	Wiring and Shielding

Table 2.5: *EMC Tests [5]*

There are five stages [10] where EMC testing can be performed in order to assure the product to satisfy the chosen electromagnetic standard for it:

a) Design
b) Development
c) Prototype
d) Pre-production model
e) Certification model

Tests in the design and development stages are realized in the design laboratories by the engineers with conventional instruments such as spectrum analyzers and oscilloscopes. These tests should be cheap and easy to perform and they show if the design is in the correct way or if something should be modified. The results obtained in these stages are very useful for future projects.

In the prototype stage, the tests are done in the same way than in the two previous ones, but in this point engineers have to be more careful with testing because since this stage every modification will be more expensive.

For the pre-production and certification model, tests should be realized by qualified personnel with the appropriate analysis equipment in a controlled site. Sometimes for these stages, the product is tested in another place different from the company that is developing the product. The certification process sometimes means delay and extra costs for the company when it is realized by an external company, but it is absolutely necessary for the product to be marketed.

To save money and time, EMI and EMS measurements are carried out since the first stages. If the designer waits until the product is in the production stage and something is wrong, it would be more expensive to correct the mistake in this stage than in the design one.

2.7.1 Tools for EMS Tests

As it was mentioned above, tests for susceptibility are not well defined in standards and the method depends more on the equipment or system that is going to be tested than in the standard. In fact, a susceptibility test consists in the generation of standard disturbances using simulators or signal generators, and then is observed the system behavior under these testing conditions.

For conducted interferences are used overvoltage generators and network disturbances generators. The overvoltage generator produces a high voltage peak using a capacitor. And the network disturbances generator simulates a cut off of the power supply during a specified period of time.

For radiated interferences are used RF generators and emitter antennas which produce signals with a field intensity of 1, 3 and 10 V/m, with a frequency sweep from 20 to 500 MHz.

Finally, for ESD simulation are used generators which consists of a capacitor with a value between 100 and 150 pF which is charged with a voltage from 2 to 15 kV and a 150 Ω-resistor for discharging.

2.7.2 Tools for EMI Tests

Emission tests consist in the measurement of the interferences either conducted or radiated by the system. Two instruments are used for EMI testing, spectrum analyzers and test receivers.

Spectrum analyzers and test receivers are used because both instruments measure the amplitude of signals in the frequency domain. But the spectrum analyzer may not be the best tool for the job because its basic settings do not satisfy at all the specification or standard being used to qualify the product and various workaround methods (e.g. sub-ranging the span) must be used in order for the results to be accurate.

For an EMI test the following parameters are required (which is the basic test receiver setup):

- Start / Stop Frequency
- Resolution Bandwidth Filter
- Measurement (dwell) Time
- Step size

On the other hand, the spectrum analyzer has only:

- Start / Stop Frequency
- Resolution Bandwidth Filter
- Sweep Time

Although the test receiver is the best option for EMI measurement, the spectrum analyzer is used because of its versatility and familiarity of engineers with it. In conclusion, using a “compliant” test receiver and calibrated test environment set according to the standard, should yield correct results [20].

2.7.3 Software for EMC Tests

Although instruments and generators for EMC tests can be manually operated, automated tests using software are used more frequently because they allow users to run complete series of measurements in an easy way.

Software does everything from data acquisition, to correcting for transducer factors, to graphing and printing final test results. It can support manual, partly automated and automated measurements in line with commercial and military standards. This allows the reliable acquisition, analysis, documentation and traceability of measurement results.

Software is used not only for measuring and analyzing disturbance voltage, disturbance power and disturbance field strength originated by either radiated or conducted emissions using test receivers and spectrum analyzers, but also for controlling signal generators and accessory components such as turntables and antenna masts which are used in susceptibility tests.

Some advantages of software are:

- Graphical operating concept for configuring instruments and measurement systems.
- Intuitive user interface for all measurements.
- EUT-specific test selection and data management.
- Support of commercial and military standards.
- Data storage in text format.
- Report generation also as PDF or HTML file.

Some examples of software for EMC measurement are:

- *<u>Tektronix EMC 120</u>:*

  Used for conducted and radiated emission measurements [21].

  It supports Tektronix 2712 or 2711 Spectrum Analyzers (Figure 17).

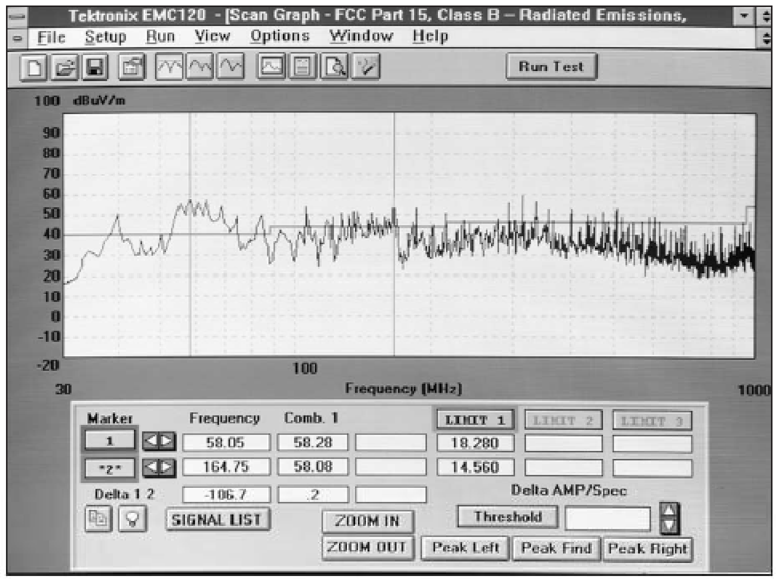

Figure 2.17: *Tektronix EMC 120 [21]*

- *<u>R&S EMC32 by Rohde&Schawrz</u>:*

  It has two basic options: R&S EMC32-EB for EMI (emission) measurement and R&S EMC32-S for EMS (immunity) measurement [22] (Figure 18).

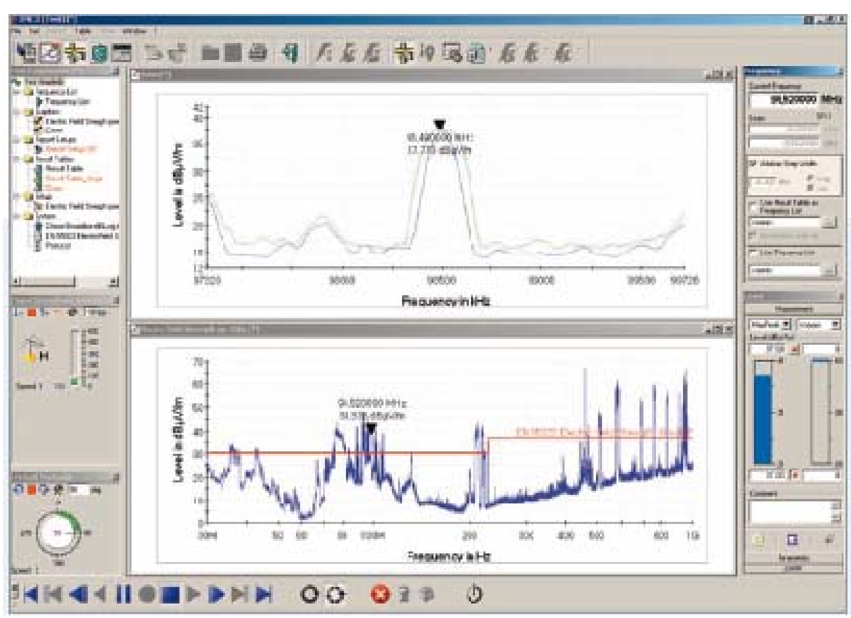

Figure 2.18: *R&S EMC32 [22]*

This software may be combined with almost all current Rohde & Schwarz EMI test receivers and spectrum analyzers.

- *<u>The EP5 series of automatic EMI measurement software</u>:*

  It is a line of software products such as EP5/RE for radiated emission measurement and EP5/CE for conducted emission measurement [23] (Figure 19). It supports spectrum analyzers from Rohde&Schwarz, Agilent Technologies, ADVANTEST and Tektronix, and test receivers from Rohde&Schwarz and Schaffner.

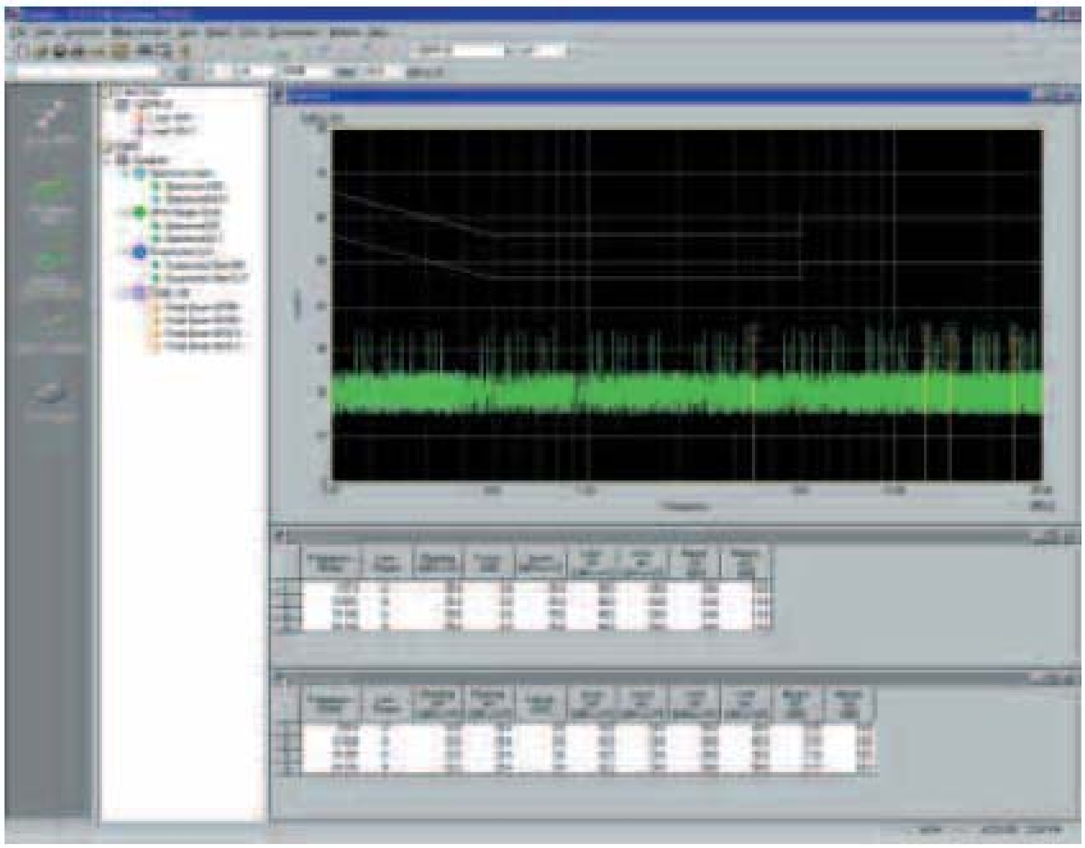

Figure 2.19: *EP5 Series [23]*

- *<u>OASIS spectrum management software by Summitek Instruments</u>:*

  It is used for spectrum monitoring and interference analysis. Also, it has the option Emitter Manager that is used to create and/or work with an emitter database [24] (Figure 20).

It supports spectrum analyzers from Agilent, HP, Rohde&Schwarz, Anritsu, Tektronix and ADVANTEST.

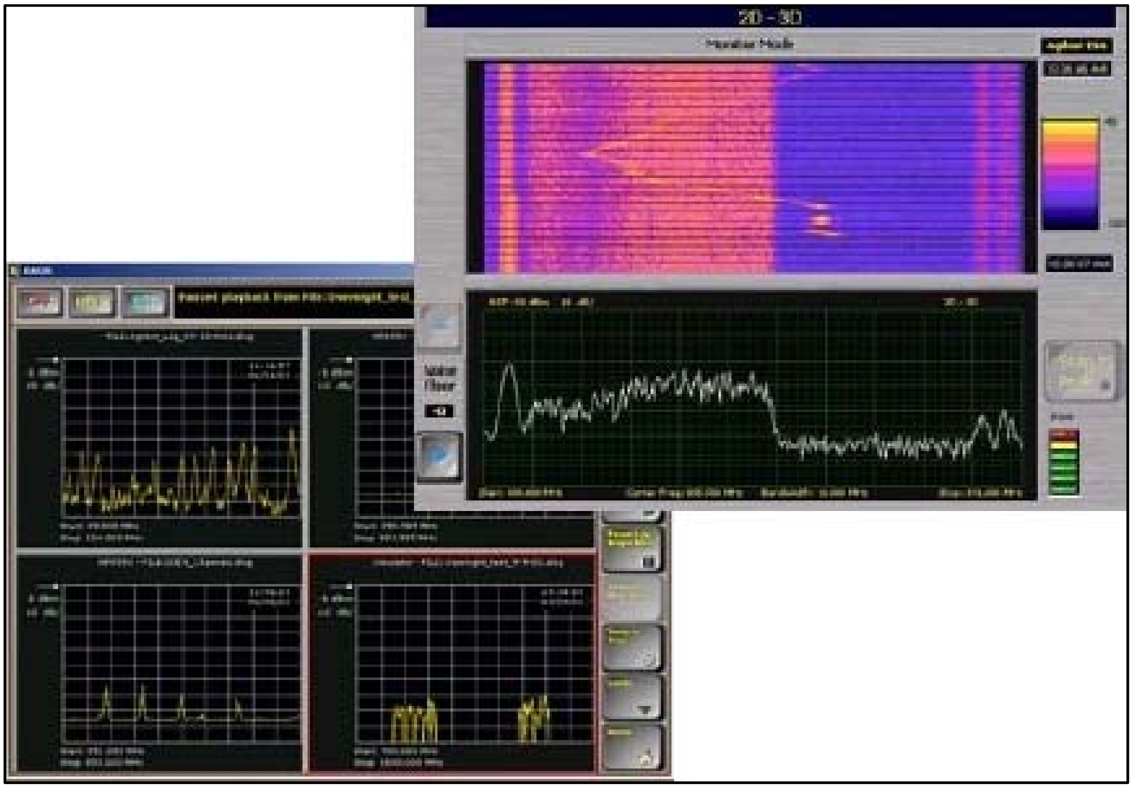

Figure 2.20: *OASIS [24]*

In the next chapter the adopted procedure to develop the software interfaces for the EMC tests will be described.

3. CHAPTER III: PROCEDURE

3.1 INTRODUCTION

The purpose of this chapter is to mention and explain the steps that were followed to get the general objective of this thesis which is the development of a software interface to control the devices which are used in the EMI and EMS tests in the Mabe's EMC tests facility. These steps are shown in Figure 3.1.

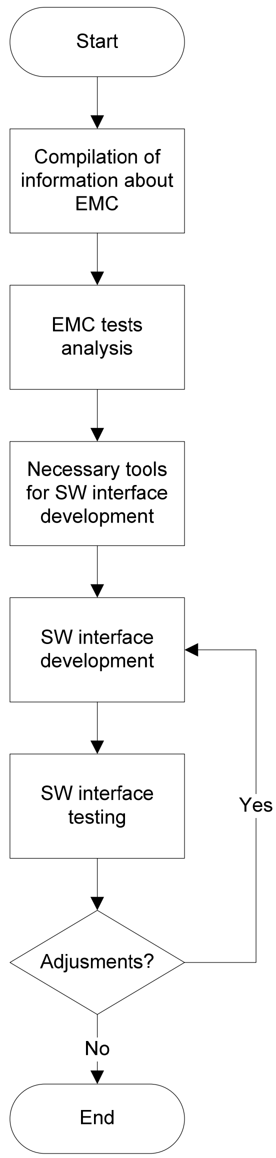

Figure 3.1: *Procedure*

The procedure or methodology is very important because it will allow to Mabe's EMC team to understand how this project was developed and it will give the basis for future modifications or projects that will complement this work.

3.2 COMPILATION OF INFORMATION ABOUT EMC

The purpose of this step, which is in fact the Fundamentals chapter of this thesis, was to know what is being measured and why.

In this part, it was learned what EMC is, the basic definitions such as electromagnetic interference, compatibility, susceptibility and immunity, and how interferences are classified and how they are produced.

The most important point for this project was to understand what an EMC problem is and how to measure or create the disturbances that produce such problems.

In summary, at this stage it was important to understand the fundamentals of the tests dedicated to EMC which constitute the backbone of this thesis.

3.3 EMC TESTS ANALYSIS

In this part, it was studied how the tests are performed and what is necessary to carry out them. It was also analyzed how the software EMC32 works as it is the tool that is being used at the moment in the Mabe's EMC tests facility.

The analyzed tests are for emission and susceptibility. Both tests are for qualifying appliances such as washing machines, dryers, stoves and refrigerators. Every product should be EMI and EMS compliant in order to be commercialized.

For the EMI test a test receiver is used to measure the conducted interferences and for the EMS test a signal generator, a power meter and an amplifier are controlled in order to produce a standard radiated disturbance of 6 V/m. The equipment used for every test is controlled by means of a general purpose PC with the EMC32 software.

In this part were also studied the operating manuals of the devices and it was learned how to operate them.

3.3.1 Conducted interference test

The purpose of this test is to measure the disturbance level that is conducted by the power supply and signal cables.

The measurement of EMI voltages is done using a standard impedance adapter known as LISN (Line Impedance Stabilizing Network) and either a spectrum analyzer or a test receiver. This measurement is done in a frequency range of 10 kHz to 30 MHz [5].

LISN

The basic LISN model contains inductors, capacitors and 50 Ω-resistors as shown in Figure 3.2. For 50 and 60 Hz line frequency, the inductors are basically shorted; the capacitors are open and the power passes through to supply the EUT. For EMI noise frequency, the inductors are essentially open, the capacitors are shorted and the noise sees 50 Ω-resistors. The noise voltage measured across the 50 Ω-input impedance of a spectrum analyzer or test receiver is defined as the conducted EMI emission [25].

The LISN has principally three functions:

a) It acts as a load for the disturbance voltage generated by the EUT. The usual load used is 50 Ω, although some standards accept 150 Ω-loads.
b) It connects the test receiver input to the EUT.
c) It attenuates the EMI voltages that are originated by the power supply.

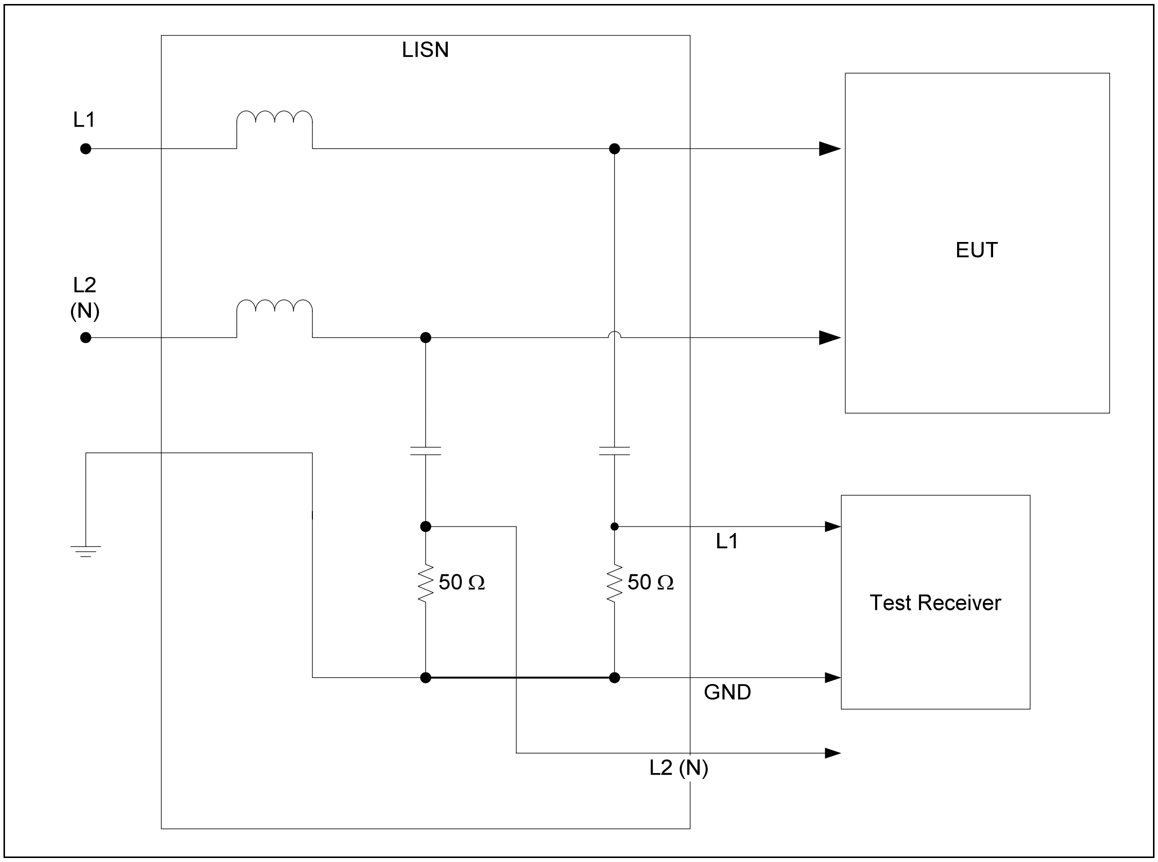

Figure 3.2: *LISN and Setup of Conducted Interference Test [25]*

Test Receiver

For this test, the instrument that is used to measure the conducted interferences is an EMI Test Receiver R&S ESPI 3, shown in Figure 3.3. This measuring device can be handled either as spectrum analyzer or test receiver. As a test receiver, which is the mode required for EMI testing, measures the level at the set frequency with a selected bandwidth and measurement time. The measurement time is the time during which ESPI measures the input signal and forms a measurement result weighted by the selected detector. Signal weighting is by means of the average, max peak, min peak, RMS and quasi-peak detectors [26]. (The purpose of detectors is going to be explained after in the Final Measurement section).

ESPI supports the SCPI version 1997.0 and the standards IEEE 488.2 and IEEE 488.1, which are the tools to be used for developing the device control.

Figure 3.3: *EMI Test Receiver R&S ESPI [26]*

3.3.2 Radiated susceptibility test

The purpose of this test is to determine the immunity level of equipments to electromagnetic interferences (far-region) which are coupled on their circuits.

In order to determine this immunity level, a uniform field has to be created in the test area. For this, a disturbance generator and an emission antenna are used. In this case, the test area is an anechoic camera.

For this test, two types of RF disturbances are generated. The first one, that is called Digital Modulation (DM), is an AM signal with a depth (percentage modulation) of 90%, where the envelope is a square wave of 10 kHz and the carrier is a RF sinusoidal wave which frequency changes in the range of 26 MHz to 1 GHz in log steps of 1%. The time in which remains every frequency value is the dwell time and it is equal to 1 s. For every frequency step there is a level value in dBm that is obtained in a calibration process. The level value obtained in the calibration, after an amplification stage, should be enough to generate a field strength of 6 V/m.

The second disturbance that is generated, called Keying Interference (KI), is a pulse modulated signal. The envelope is a pulse signal with a frequency equal to 1 Hz, a width of 500 ms and a pulse delay of 1 us. The carrier is again a RF sinusoidal signal in the range of 26 MHz to 1 GHz with log steps of 1%; in this case the dwell time is 50 ms. The level value for each frequency step is again obtained using a calibration process to assure a field strength of 6 V/m for every frequency.

The devices that are used to create these types of interferences are a signal generator, an amplifier and a power meter. The power meter is used to measure the forward and reflected power that is emitted and received by the antenna as is shown in Figure 3.4.

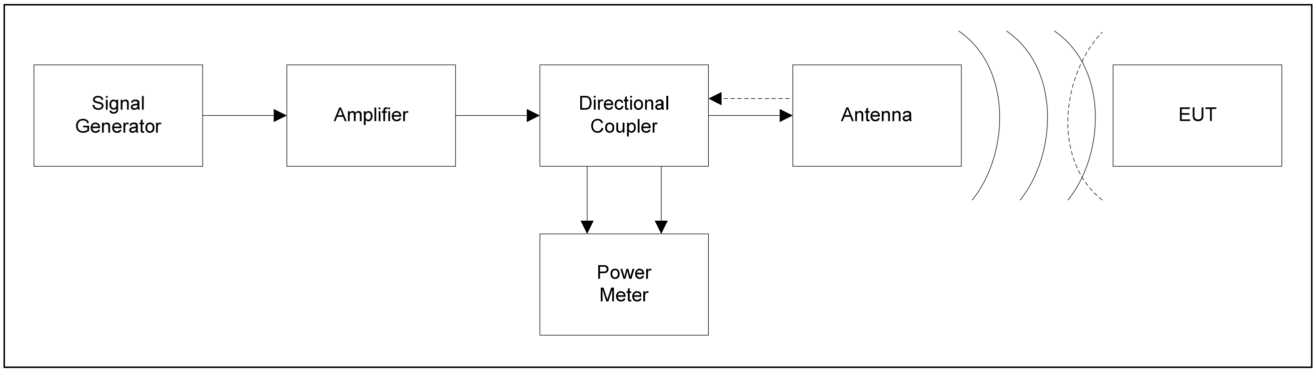

Figure 3.4: *Radiated Susceptibility Test*

For this test, the elements of interest are the signal generator, the amplifier and the power meter because they are controlled with the EMC32 software.

Signal Generator

The signal generator that is used to produce the electromagnetic disturbances is the Signal Generator R&S SMT shown in Figure 3.5. It covers the complete range of conventional analog receiver measurements up to 6 GHz. The SMT affords a wide variety of modulation and signal generation modes. It is used as source for EMS measurements because of its features such as programmable RF, LF and level sweeps. The modulation options are AM, FM, φM and pulse modulation. The options for signal generation are pulse generator, LF generator which supplies sinewave, squarewave, triangular and noise signals, and multifunction generator for VOR/ILS signals [27].

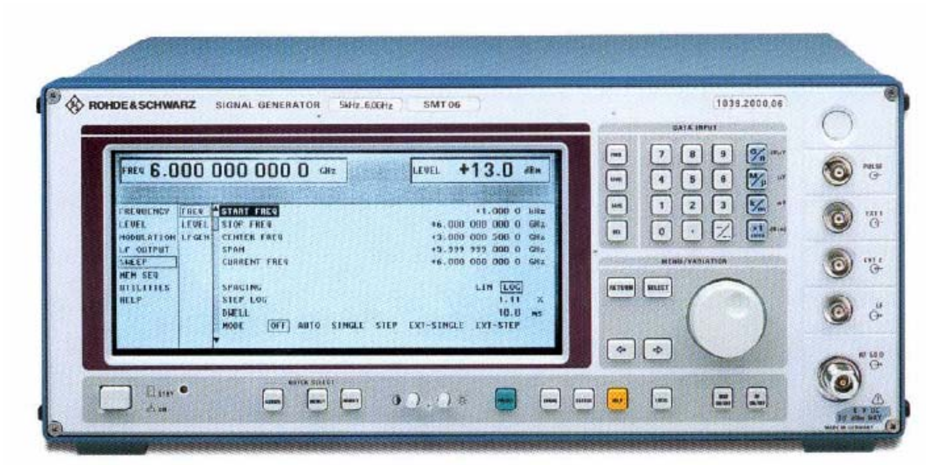

Figure 3.5: *Signal Generator R&S SMT [27]*

Amplifier

The model 100W1000B from Amplifier Research (**ar**), shown in Figure 3.6, is the amplifier that is used in this test. The 100W1000B, when used with a frequency-swept signal source, provides 100 watts of RF power output from 1 to 1000 MHz. The typical applications for this type of amplifier are antenna and component testing, and electromagnetic interference susceptibility testing.

Figure 3.6: *Power Amplifier **ar** 100W1000B [28]*

The 100W1000B or *"IAR"* as it is also called in the operating manual has a front panel display for monitoring amplifier status and forward or reflected output power, and a front panel gain control for adjusting the amplifier's gain when operating in the manual mode. It has also RF output level protection.

Moreover, all amplifier control functions and status indications are available remotely in IEEE 488 and RS 232 format [28].

Power Meter

The power meter that is used is the R&S NRVD shown in Figure 3.7. The NRVD covers a total bandwidth of 40 GHz and a power span from 100 pW up to 30 W depending on the measuring head. It covers this variety of ranges since suitable measuring heads are available for the various applications and ranges. The range of measuring heads includes thermal power sensors as well as diode power sensors, peak power sensors, probes and insertion units for voltage measurements.

Figure 3.7: *Power Meter R&S NRVD [29]*

The NRVD has two inputs and functions like two independent measuring instruments that perform measurements simultaneously and exchange data with one another. The two channels can be also separately set so that two completely different measurements can be carried out at the same time.

For this test, the two heads or sensors used are the URV5-Z2. They are for low-load RF voltage measurements in 50 Ω coaxial systems and for low-loss power measurements on well matched RF lines. Their frequency and power ranges are 9 kHz – 3 GHz and 200 uV – 10 V respectively.

All measuring and setting functions of the NRVD can be remote-controlled. The IEC/IEEE-bus syntax complies with the Standard Commands for Programmable Instruments [29].

3.3.3 EMC32 software

This software allows to manage the different types of tests through templates where the parameters of everyone are set and the devices defined.

In the conducted interference test, the software first “asks for” a calibration or correction table which has level values for different frequencies to compensate the attenuation generated by the ESPI cable, then initializes the ESPI to the remote mode, sets the measurement parameters and starts the scan (measurement). Afterwards, the data obtained by the scan are transmitted from the ESPI to the PC to plot and select points for analysis. In order to perform the analysis or final measurement the application sets again the ESPI and starts a new scan. Finally, obtained results are saved for generating a report.

In the radiated susceptibility test, the software first asks for the table where the level values for the signal generation are defined, then initializes the signal generator, the amplifier and the power meter. Once all devices are ready, the signal generation starts. During this process, it is possible to pause or stop the radiation. When the radiation is paused, a comment can be written, and after the stopping of the radiation it is possible to continue the radiation from a specified frequency. The purpose of these functions is to allow to the evaluation engineer to stop the radiation when an undesired effect occurs in the EUT due to the radiation and to write a comment about this. The advantage of starting the radiation in any frequency gives the possibility of reproducing the effect that was observed before. Finally, the comments of the observed effects are saved including details such as the frequency values at which they occurred.

The devices used in both tests are controlled by a conventional computer with the EMC32 software using IEEE 488.1 and IEEE 488.2 standards.

3.4 TOOLS FOR DEVICE AUTOMATION

In this procedure step were analyzed the necessary tools for the automation of the devices. The automation for each device was developed using LabVIEW as programming language, GPIB (General Purpose Interface Bus) as communication bus between the computer and the device, and finally SCPI (Standard Commands for Programmable Instruments) as programming command set for controlling the equipments using the computer.

These tools were chosen mainly because they were part of the Mabe's requirements. Choosing these requirements make sense, because, as it was observed in the previous section, the devices that are used for the tests have GPIB interfaces and also support SCPI.

The selection of LabVIEW as the programming language was made because Mabe has licenses enough for this software, so there was no need to buy a new license for the development of this project.

3.4.1 GPIB

The key for virtual instrumentation is the communication. An instrumentation bus is used for connecting different electronic equipments which will perform a measurement or a test. Some examples of such devices are oscilloscopes, power supplies, signal generators, etc. Usually all of them are controlled by a PC, which programs them, processes the results and offers and interface for the final user.

Hewlett-Packard, in 1965, was the first one in designing a bus to connect their line of programmable instruments to their computers. This bus was called Hewlett-Packard Interface Bus (HP-IB). Because of its high transfer rates (nominally 1 Mbytes/s), this interface bus quickly gained popularity, and it was later accepted as IEEE Standard 488-1975 with the name of GPIB (General Purpose Interface Bus). In 1987, the standard IEEE 488.2 appears with modifications that improve the previous one that is known since that moment as 488.1. ANSI/IEEE 488.2 strengthened the original standard by defining precisely how controllers and instruments communicate.

In summary, IEEE 488.1 defines the mechanical, electrical and functional requirements that instruments should have to communicate. And IEEE 488.2 specifies a common command set, the data format and a protocol to follow for communication [30].

GPIB signals and lines

GPIB Devices can be Talkers, Listeners, and/or Controllers. A Talker sends data messages to one or more Listeners, which receive the data. The Controller manages the flow of information on the GPIB by sending commands to all devices.

The GPIB interface system consists of 16 signal lines and eight ground-return or shield-drain lines. The 16 signal lines are grouped into data lines (eight), handshake lines (three), and interface management lines (five) as is shown in Figure 3.8 [31].

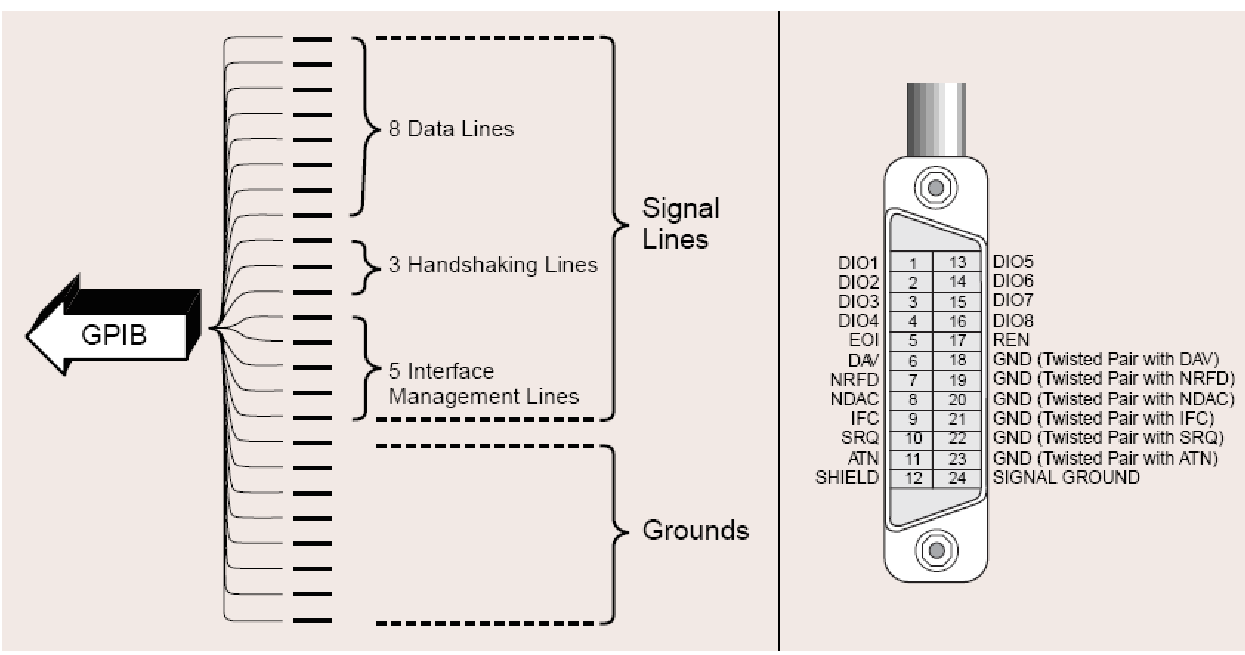

Figure 3.8: *GPIB Signals and Lines [31]*

- *Data Lines:*

The eight data lines, DIO1 through DIO8, carry both data and command messages. The state of the Attention (ATN) line determines whether the information is data or commands. All commands and most data use the 7-bit ASCII or ISO code set, in which case the eighth bit, DIO8, is either unused or used for parity.

- *Handshake Lines*

Three lines asynchronously control the transfer of message bytes between devices. The process is called a 3-wire interlocked handshake. It guarantees that message bytes on the data lines are sent and received without transmission error.

NRFD (not ready for data) – Indicates when a device is ready or not ready to receive a message byte. The line is driven by all devices when receiving commands.

NDAC (not data accepted) – Indicates when a device has or has not accepted a message byte. The line is driven by all devices when receiving commands.

DAV (data valid) – Tells when the signals on the data lines are stable (valid) and can be accepted safely by devices.

- *Interface Management Lines*

Five lines manage the flow of information across the interface.

ATN (attention) – The Controller drives ATN true when it uses the data lines to send commands, and drives ATN false when a Talker can send data messages.

IFC (interface clear) – The System Controller drives the IFC line to initialize the bus and become Controller-In-Charge (CIC).

REN (remote enable) – The System Controller drives the REN line, which is used to place devices in remote or local program mode.

SRQ (service request) – Any device can drive the SRQ line to asynchronously request service from the Controller.

EOI (end or identify) – The EOI line has two purposes; the Talker uses the EOI line to mark the end of a message string, and the Controller uses the EOI line to tell devices to identify their response in a parallel poll.

IEEE 488.2 instruments

IEEE 488.2 instruments are easier to program because they respond to common commands and queries in a well defined manner using standard message exchange protocols and data formats. All devices must be able to send and receive data, request service, and respond to a device clear message.

The IEEE 488.2 standard focuses mainly on the software protocol issues and thus maintains compatibility with the hardware-oriented IEEE 488.1 standard.

IEEE 488.2 defines precisely the format of commands sent to instruments and the format and coding of responses sent by instruments. These common commands and queries are shown in Table 3.1 [31].

The IEEE 488.2 message exchange protocol is the foundation for the SCPI standard that makes test system programming even easier. (A protocol combines several commands to execute the most common operations required by any test system).

Mnemonic	Group	Description
*IDN?	System Data	Identification query
*RST	Internal Operations	Reset
*TST?	Internal Operations	Self-test query
*OPC	Synchronization	Operation complete
*OPC?	Synchronization	Operation complete query
*WAI	Synchronization	Wait to complete
*CLS	Status and Event	Clear status
*ESE	Status and Event	Event status enable
*ESE?	Status and Event	Event status enable query
*ESR?	Status and Event	Event status register query
*SRE	Status and Event	Service request enable
*SRE?	Status and Event	Service request enable query
*STB?	Status and Event	Read status byte query

Table 3.1: *IEEE 488.2 Mandatory Common Commands [31]*

3.4.2 SCPI

SCPI simplifies the programming task by defining a single comprehensive command set for programmable instrumentation, regardless of type or manufacturer. Before SCPI, each instrument manufacturer developed its own command sets for its programmable instruments. This lack of standardization forced test system developers to learn a number of different command sets for the various instruments used in an application, resulting in schedule delays and development costs.

The 488.2 commands are used to control the basic functions of the instruments; however it is missing the configuration of their specific functions. This configuration can be achieved using SCPI commands.

In SCPI the commands are grouped in different families or subsystems which are represented as functional blocks in the SCPI instrument model that is shown in Figure 3.9. Although this model applies to all the different types of instrumentation, all of the functional components may not apply to every instrument.

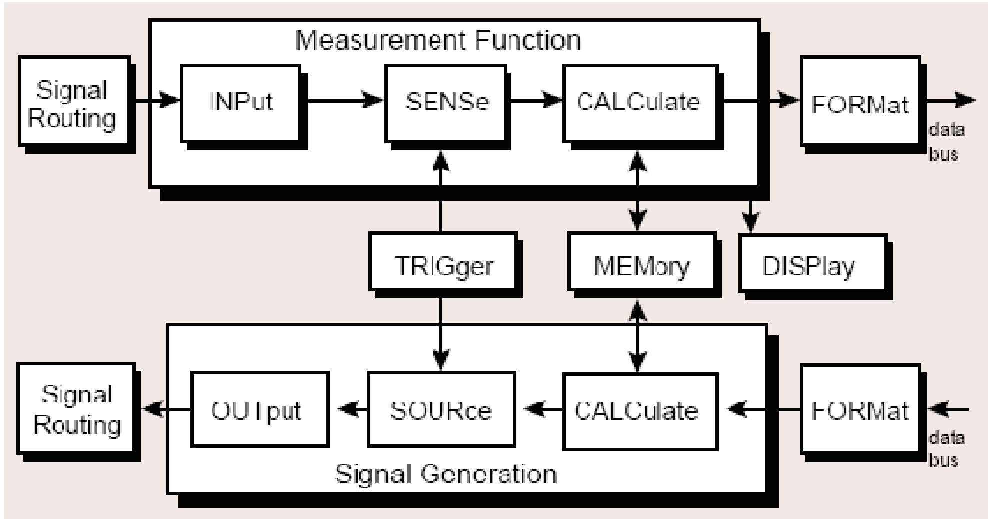

Figure 3.9: *The SCPI Instrument Model [31]*

The signal routing component controls the connection of a signal to the instrument's internal functions; the measurement component converts the signal into a preprocessed form; and the signal generation component converts internal data into output as physical signals. The memory component stores data inside the instrument. The format component converts the instrument data to a form that can be transmitted across a standard bus. And the trigger component synchronizes instrument actions with internal functions, external events, or other instruments.

In the instrument model every system or subsystem is identified by a keyword and the command set is organized in a hierarchical way, so adding commands for more specific or newer functionality is easily accommodated.

The principal families that are included in the instrument blocks are: CALCulate, CALlibration, CONTrol, DIAGnostic, DISPlay, FORMat, HCOPy, INPut, INSTRUMent, MEMory, OUTPut, PROGram, ROUTe, SENSe, SOURce, STATus, SYSTem, TEST, TRACe, TRIGger, UNIT and VXI.

A command line example is:

SYSTem;COMMunicate:SERial:BAUD 9600

Every SCPI command line can be written in a large or short way. The short way is writing only the part that is in capital letters:

SYST;COMM:SER:BAUD 9600

Due to command structure, SCPI systems are much easier to program and maintain because in many cases it is possible to interchange or upgrade instruments without having to change the test program. This can be seen with the example, it does not matter what type of instrument is being used; the command for setting serial port speed will always be the same.

3.4.3 LabVIEW

LabVIEW is a program development application, much like various commercial *C* or *BASIC* development systems. However, LabVIEW is different from those applications because it uses a graphical programming language, *G*, to create programs in block diagram form, while the other programming systems use text-based languages to create lines of code. In other words, LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications.

In LabVIEW, a user interface is built by using a set of tools and objects. The user interface is known as the front panel. The code is added using graphical representations of functions to control the front panel objects. The block diagram contains this code. In some ways, the block diagram resembles a flowchart.

LabVIEW has extensive libraries of functions and subroutines for most programming tasks. It contains application specific libraries for data acquisition and VXI instrument control. LabVIEW also contains application-specific libraries for GPIB and serial instrument control.

LabVIEW programs are called virtual instruments (VIs) because their appearance and operation imitate actual instruments. However, they are analogous to functions from conventional language programs. VIs have both an interactive user interface and a source code equivalent, and accept parameters from higher-level VIs. So, a VI can be used as a top-level program, or as a subprogram within other programs. A VI within another VI is called a *subVI*.

LabVIEW includes conventional program development tools, so it is possible to set breakpoints, animate program execution to see how data passes through the program and single-step through the program to make debugging and program development easier.

With LabVIEW is easy to create test and measurement, data acquisition, instrument control, datalogging, measurement analysis, and report generation applications even for persons with limited programming experience [32] [33].

3.4.4 GPIB interface

The computer that was assigned for the development of this project had no GPIB interface to communicate it with the devices specified before, so the National Instruments PCMCIA-GPIB, shown in Figure 3.10, was used. It is a low-cost, high performance IEEE 488 interface for computers with PC Card (PCMCIA) slots, such as laptop and notebook computers.

Figure 3.10: *PCMCIA-GPIB [34]*

The PCMCIA-GPIB is compatible with the Plug and Play standard. The system automatically configures the PCMCIA-GPIB on startup or when it is inserted in the PC. It also performs the basic IEEE 488 Talker, Listener, and Controller functions and those functions required by IEEE 488.2 [34].

3.5 SOFTWARE DEVELOPMENT FOR THE EMI APPLICATION

In this part of the procedure are explained the steps, which are shown in Figure 3.11, that were necessary to develop the EMI application. These steps to program the application were chosen after analyzing the way the EMC32 works and studying some examples for Visual Basic about initialization, measurement and data acquisition included in the ESPI operating manual.

One thing that made programming not so difficult is the way that commands are organized according to the SCPI instrument model (Figure 3.9). For example, for scan parameters setting, in SENSE:SCAN module can be found the necessary commands to set the start frequency, stop frequency, step, etc.

At this point, the programs developed before for the ESPI initialization were a good help to understand the principles of how works GPIB and SCPI.

Most of the steps are programmed as sub-VIs in order to make the application code easier to understand and more organized.

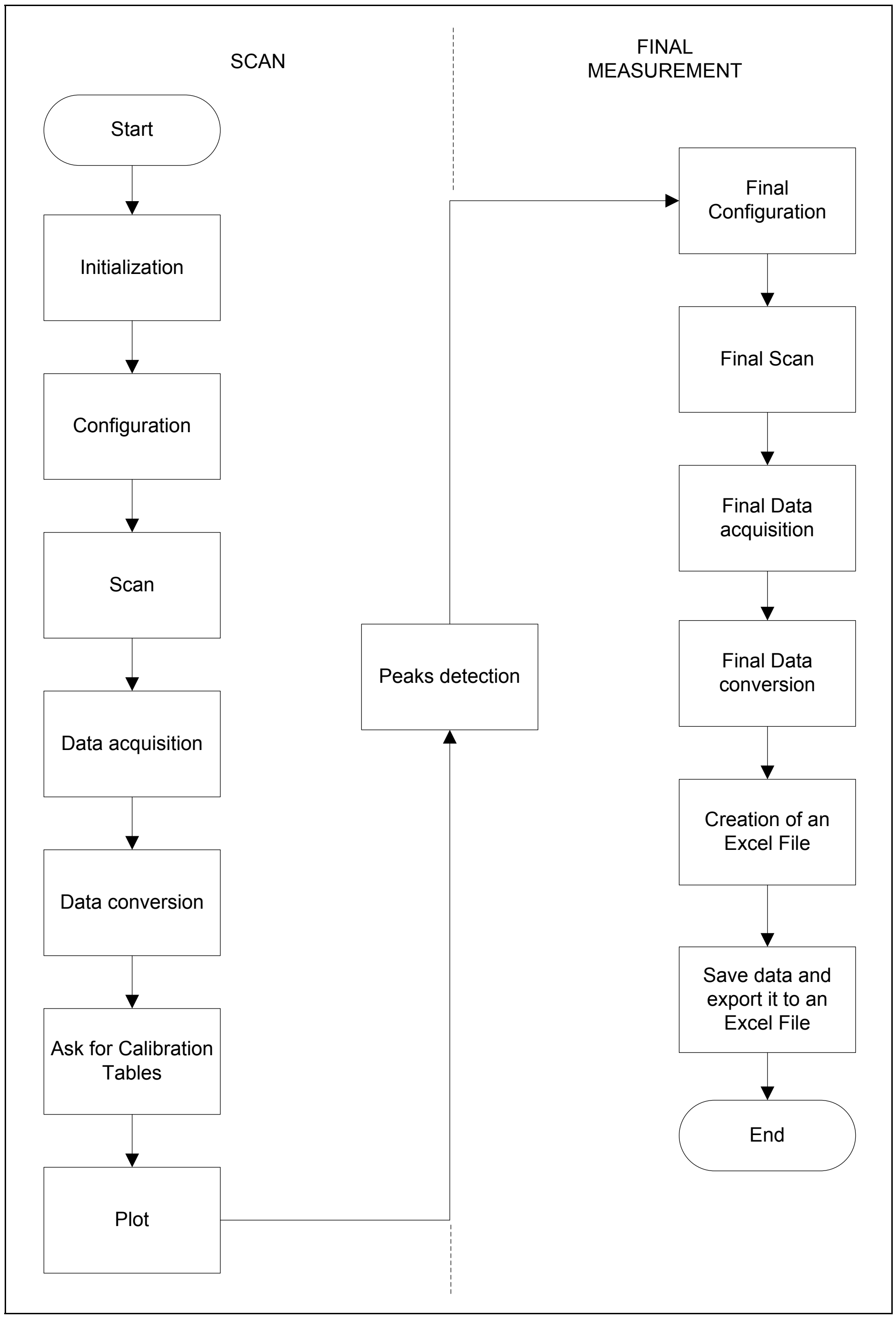

Figure 3.11: *Flow Chart designed to develop the EMI application subject of this work.*

3.5.1 Initialization

This is the initial part of the program and it is done by the Initialization sub-VI. Here, the ESPI is set to remote mode and the communication between computer and device is established.

To start the communication, the Controller and Talker/Listener addresses should be defined. The Controller is the PC with the GPIB interface and the Talker/Listener is the ESPI. In this case, the controller address is "0", which is the default Controller ID specified by LabVIEW. The Talker/Listener address is defined manually in the ESPI setup menu.

Initialization manages two lines of the Interface Management Lines, REN and IFC. REN is used to place ESPI in remote mode; and IFC initializes the bus, makes the GPIB controller CIC and clears the bus fault conditions.

After this, the LabVIEW function "ResetSys" is used to send a Device Clear (DCL) message to all connected devices which ensures that all IEEE 488.2-compatible devices can receive the Reset (RST) message that follows.

During Initialization, it is also configured the ESPI as a test receiver and the screen is configured to display the scan plot.

In this part of the program, it is also executed the IDN sub-VI, which sends an identification query (*IDN?) just to know the name, model and serial number of the device that is being controlled. This sub-VI ensures that the communication between device and computer is being executed without problems.

Finally, the Option Identification Query (*OPT?) queries the options included in the instrument and returns a list of the options installed. The options are separated from each other by means of commas as it shown below:

B2,B4,0,B6,0,0,B9,B10,0,0,0,0,0,B16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

The meaning of each term is explained in Table 3.2.

Position	Option
1	R&S FSP-B3 Audio Demodulator
2	R&S FSP-B4 OCXO
3	R&S ESPI-B2 Preselector
4	R&S FSP-B6 TV and RF Trigger
5-6	Reserved
7	R&S FSP-B9 Tracking Generator 3 GHz / can be I/Q-modulated
8	R&S FSP-B10 Ext. Generator Control
9-13	Reserved
14	R&S FSP-B16 LAN Interface
15 – 31	Reserved
32	R&S FS-K7 FM Demodulator

Table 3.2: *Options that may be included in ESPI [26]*

3.5.2 Configuration

The Configuration sub-VI allows the parameters setting that are necessary to perform the test. The parameters that should be manipulated in the front panel of this sub-VI are:

- Start frequency of the scanning range.
- Stop frequency of the scanning range.
- Step size.
- Bandwidth resolution.
- Measuring time.
- Level units.
- Min level (Y-axis).
- Max level (Y-axis).

The meaning of these parameters can be seen below in Figure 3.12.

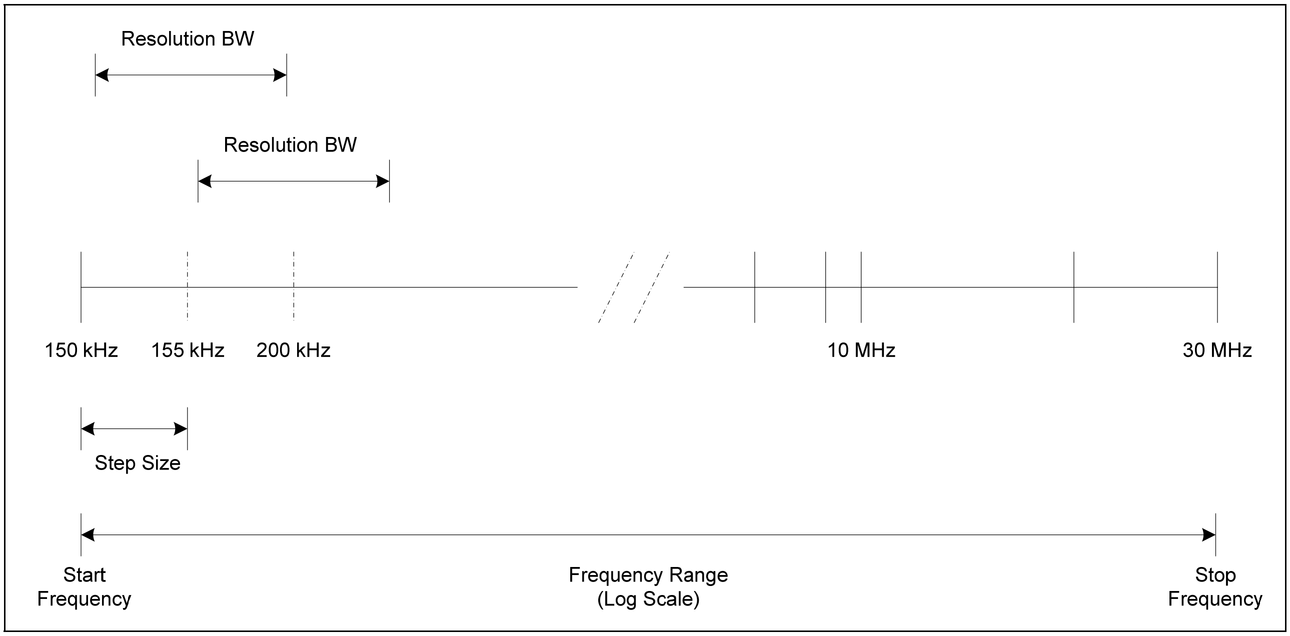

Figure 3.12: *EMI Test Parameters*

For the conducted interference test, the parameters should have the next values:

- Start frequency = 150 kHz
- Stop frequency = 30 MHz
- Step size = 5 kHz
- Bandwidth resolution = 9 kHz
- Measuring time = 1 ms
- Level units = dBuV
- Min level (Y-axis) = -10
- Max level (Y-axis) = 90

The measurement bandwidths that offer the ESPI are 200 Hz, 9 kHz, 120 kHz and 1 MHz which are defined by CISPR. These resolution bandwidths are implemented by digital band-pass filters.

Also in this part, the RF attenuation and preamplifer modules are activated or deactivated.

ESPI is provided with a switchable preamplifier of 20 dB gain in the frequency range up to 3 GHz when it is equipped with option ESPI-B2, Preselector. Switching on the preamplifier improves the sensitivity.

The attenuation module is strongly recommended to provide at least 10 dB RF attenuation at the RF input in order to protect the input circuit when unknown (RFI) signals are to be measured.

The chosen values for the parameters are sent to the ESPI using the LabVIEW function “GPIB Write”.

Finally in Configuration, the data-transmission-during-a-scan function is switched on using the command “:TRACE:FEED:CONTROL ALWAYS”. Also, the measurement format, data format and display scales are set. The measurement format consists in a single scan with only one frequency range. The data format in which the obtained data is transmitted from ESPI to the PC is the binary format (REAL, 32). And the X-axis scale is logarithmic.

3.5.3 Scan

Once the ESPI is initialized and configured with the specified parameters for the test, the scan or measurement can start. For this, the command “:INITIATE2” is sent.

In order to assure the scan is complete and all data is saved in the ESPI’s memory, a “t” seconds delay has to be used. “t” is defined by:

$$t = \left(\frac{Stop\ Freq - Start\ Freq}{Step}\right)(Measurement\ Time) \qquad (3.1)$$

To make this point clear, in conducted interference test there are 5971 points where a measurement is done, and for every point the measurement takes 1 ms, which is the measurement time. So, the necessary time to complete the scan is 5.97 seconds.

3.5.4 Data acquisition

After the measurement is finished, the data acquisition can start. If the data transmission from the ESPI to the PC starts before the scan is complete, there will be an error because data is being requested before it is complete.

The data is queried to the ESPI using the “:TRACE? SCAN” command. The ESPI answers this query sending the measurement data to the PC as a data block. Data block is a transmission format which is suitable for the transmission of large amounts of data and it has the following structure:

Example: #45168xxxxxxxx

ASCII character # introduces the data block. The next number indicates how many of the following digits describe the length of the data block. In the example the 4 following digits indicate the length to be 5168 bytes. The data bytes follow. During the transmission of these data bytes all control signals are ignored until all bytes are transmitted.

As it was mentioned before, the format in which the data is sent is the binary format REAL, 32, so the data block will have the next format:

Example: #42004<data value 1><data value value2>...<data value 501>

With:

#4	digits of the subsequent number of data bytes (4 in the example)
2004	Number of the subsequent data bytes (2004 in the example)
<data value x>	4 byte floating point values

The number of transmitted measurement results depends on the scan settings.

The structure of transmitted data is:

- 4 bytes: trace status: bit 0 to 9 subscan; bit 10: last block of subscan; bit 11: last block of last subscan of scan; bit 12: last of all blocks (for multiple scans after the last scan).
- 4 bytes: number n of the transmitted measurement results of a trace.
- 4 bytes: trace1 active (0/1).
- 4 bytes: trace2 active (0/1).
- 4 bytes: trace3 active (0/1).
- 4 bytes: reserved.
- n*4 bytes: measurement results of trace 1 if trace 1 is active.
- n*4 bytes: measurement results of trace 2 if trace 2 is active.
- n*4 bytes: measurement results of trace 3 if trace 3 is active.
- n*1 bytes: status information per measurement result:
  bit 0: underrange trace1; bit 1: underrange trace2; bit 2: underrange trace3; bit 3: overrange trace1 to trace4.

The term trace is referred to the measured values that are displayed in the ESPI. It is capable of displaying up to three different traces at a time in a diagram. Every trace consists of a maximum of 501 pixels on the horizontal axis (frequency or time). If more measured values than pixels are available, several measured values are combined in one pixel [26].

The data block is obtained by the LabVIEW function “GPIB Read” and it is read as a string where the bytes are represented as ASCII (hex) characters.

3.5.5 Data conversion

It was seen in the previous section that every data value in the data block is formed by 4 bytes, which means that every data value has 32 bits, hence the name REAL, 32. This 32-bit representation is the “IEEE 754 floating point single-precision” format.

The 32-bit representation consists of three parts. The first bit is used to indicate if the number is positive or negative. The next 8 bits are used to indicate the exponent of the number, and the last 23 bits are used for the fraction and it is known as mantissa [35].

This representation can be better explained with the next conversion example from binary to decimal (real) number:

1100 0011 0101 0010 0100 0000 0000 0000

First the sign, exponent and fraction bits should be identified:

1 10000110 10100100100000000000000

Here can be noted by the leading 1 that the number is negative. Next the exponent is determined subtracting 127 (the maximum number that can be expressed with 8 bits (2^8-1 or the numbers 0 to 127)) to 134 which is the decimal representation of 10000110. After doing this, it is found that the exponent is equal to 7.

Then to the mantissa is added at the beginning (in left part) a 1 followed by the decimal place to get:

1.101001001

In this case, the following bits are not written because they are zeros.

Finally the decimal place is moved to the right by 7 (corresponding to the exponent):

11010010.01

This binary number is equal to 128+64+16+2 + 1/4 or 210.25. Once applying the negative sign (indicated by the leading bit set to 1) the number is gotten:

-210.25

Before applying this process, the ASCII character # and the number that follows it are eliminated from the obtained string using the LabVIEW functions “Scan from String” and “String Subset”. The “String Subset” function is used to assure that the data block has the length specified by the header (the number after #).

Once the data block is separated from the header, it is converted from string format to long format (32-bit integer) using the “Type Cast” function and the conversion process is applied to every data value. So, the trace status, the number of transmitted measurement results *n,* the measurements results of the trace and the status data are obtained.

In this point it is important to mention that the converted measurements results are handled as vectors because the data block has many measurement results as it was mentioned before.

3.5.6 Calibration tables

As it was explained in the EMC tests analysis section, the level values corresponding to the attenuation due to ESPI cable should be considered for plotting. These values are obtained using a calibration process realized by the EMC32 software.

The calibration table is exported from the EMC32 to an Excel file as is shown in Table 3.3, then the frequency values are saved in one Excel file and the level values are saved in another one.

In Table 3.3 can be seen that the frequency values are in log steps of 5% thus there are 110 level values. For this application, it is necessary to have 5971 calibration values because they are going to be added to the acquired values of the measurement.

In order to obtain these missing values a polynomial interpolation was used.

[TableHeader]		
Name=	Frequency	Attenuation
Unit=	MHz	dB
	11	12
ColTyp=	Frequency	Attenuation
Detector=	0	0
Intpol=	1	0
Format=	6	1
ColWidth=	-1	-1
[TableValues]		
1.50E-01	2.27E-02	
1.58E-01	2.33E-02	
1.65E-01	2.33E-02	
1.74E-01	2.39E-02	
1.82E-01	2.48E-02	
1.91E-01	2.49E-02	
2.01E-01	2.84E-02	
:	:	
1.97E+01	2.01E-01	
2.07E+01	2.06E-01	
2.17E+01	2.11E-01	
2.28E+01	2.16E-01	
2.40E+01	2.20E-01	
2.52E+01	2.26E-01	
2.64E+01	2.32E-01	
2.78E+01	2.38E-01	
2.91E+01	2.43E-01	
3.00E+01	2.47E-01	

Table 3.3: *Example of Calibration Table for EMI Test*

The most compact representation of the interpolating polynomial is the Lagrange form:

$$P(x) = \sum_{k} \left(\prod_{j \neq k} \frac{x - x_j}{x_k - x_j} \right) y_k \qquad (3.2)$$

that is a polynomial in *x* of degree less than *n* whose graph passes through the given *n* points in the plane, (*xk*; *yk*); *k* = 1,… n, with distinct *xk's*. *n*, the number of data points, is also the number of coefficients.

The polynomial interpolation was performed using the MATLAB function “interp1”. This function uses polynomial techniques, fitting the supplied data with polynomial functions between data points and evaluating the appropriate function at the desired interpolation points. Its most general form is:

yi = interp1(x,y,xi,method)

where *y* is a vector containing the values of a function, and *x* is a vector of the same length containing the points for which the values in *y* are given. *xi* is a vector containing the points at which to interpolate. *method* is an optional string specifying an interpolation method [36].

When performing the interpolation, three methods were used:

- Linear interpolation (method = 'linear'). This method fits a different linear function between each pair of existing data points, and returns the value of the relevant function at the points specified by *xi*. This is the default method for the “interp1” function.

- Cubic spline interpolation (method = 'spline'). This method fits a different cubic function between each pair of existing data points, and uses the spline function to perform cubic spline interpolation at the data points.
  spline function uses cubic spline interpolation to find *yi*, the values of the underlying function *y* at the points in the vector *xi*. The vector *x* specifies the points at which the data *y* is given.

- Cubic interpolation (method = 'cubic'). They use the pchip function to perform piecewise cubic Hermite interpolation within the vectors *x* and *y*. These methods preserve monotonicity and the shape of the data.
  pchip function returns vector *yi* containing elements corresponding to the elements of *xi* and determined by piecewise cubic interpolation within vectors *x* and *y*. The vector *x* specifies the points at which the data *y* is given.

The code for linear interpolation is:

```
k=1;
f=0.15:0.005:30;
correction=zeros(k);
while(k<5972)
   correction(k)=interp1(freq,dbs,f(k));
   k=k+1;
end

figure(1)
plot(freq,dbs,'o',f,correction)
```

The code for spline interpolation is:

```
f=0.15:0.005:30;
correction_sp= interp1(freq,dbs,f,'spline');

figure(2)
plot(freq,dbs,'o',f,correction_sp)
```

And the code for cubic interpolation is:

```
f=0.15:0.005:30;
correction_sp= interp1(freq,dbs,f,'cubic');

figure(3)
plot(freq,dbs,'o',f,correction_sp)
```

For the three codes *f*-vector is the frequency range from 150 kHz to 30 MHz with steps of 5 KHz. *freq* is a vector with the frequency values that is imported from the Excel file generated before and *dbs* is another vector imported from the other Excel file that has the attenuation values. Both vectors are stored in the MATLAB workspace and are used for the M-files.

Once the correction-vector was obtained using the interpolation, it was exported to an Excel file in CSV format, that is, comma delimited format. This is necessary because of the manipulation that is done in LabVIEW.

The sub-VI that reads or imports the calibration values from the CSV file is called Read from File, and it works basically using the LabVIEW functions “Open/Create/Replace File” and “Read from Text File”. The values are imported by LabVIEW as a string vector, so it is converted into a number vector using the function “Spreadsheet String to Array”.

3.5.7 Plotting

After the calibration vector is created, it is added to the measurement vector and then the sum is plotted using the “Waveform Graphs” function.

For this function, the initial value for the X-axis and the step size has to be defined.

The X scale minimum and maximum, and the Y scale minimum and maximum parameters of the waveform graph are manipulated when setting the test parameters. This assures that the graph displays the correct scales for each axis in automatic way.

Besides the measurement waveform, two limit lines are plotted in this part. The limit lines are used as a visual help to check if the measured values are or not over them. If it occurs, the EUT fails the test.

The limit lines are not explicitly demanded by the ETP # 910E001, but it refers to the standard CISPR 14-1 in the way that the conducted emissions test should be performed, there is where these limit lines are defined and required. Both lines are shown in Figure 3.13.

These limits lines are plotted using the Limit Check sub-VI which creates a vector for each one. For ranges 500 kHz to 5 MHz and 5MHz to 30 MHz there is no problem for plotting since the values for each range are constant horizontal straight lines. But for the range of 150 to 500 kHz a function is necessary for obtaining the points of the straight line with slope.

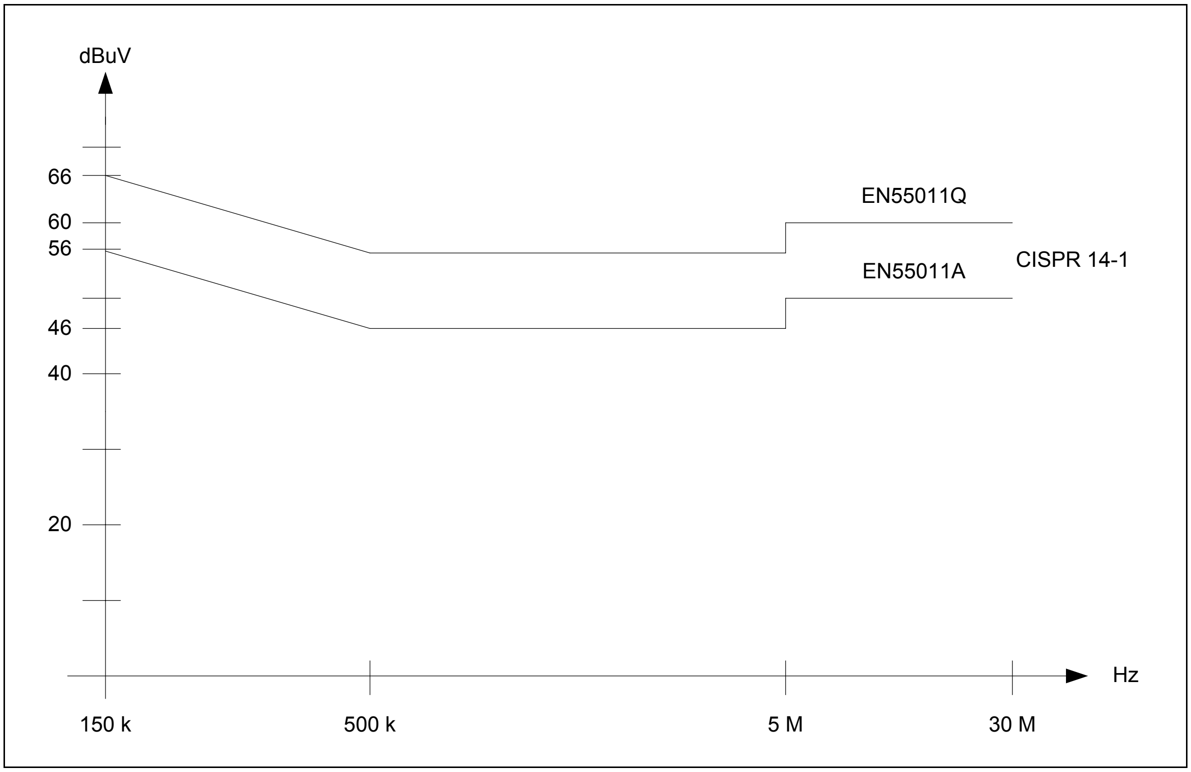

Figure 3.13: *CISPR 14-1 Limit Lines*

The function that is used is the common slope-intercept form because two points are known:

$$y - y_1 = m(x - x_1) \qquad (3.3)$$

where:

$$m = \frac{y_2 - y_1}{x_2 - x_1} \qquad (3.4)$$

But there is an important detail to be considered, the graph is in semi-logarithmic scale. That is, the Y-axis is linear and the X-axis is logarithmic. Thus, some modifications were done to Equation 3.2 and Equation 3.3 to obtain the following equations which are the equations used in the Limit Check sub-VI:

$$y = y_1 + m(\log x - \log x_1) = y_1 + m \log\left(\frac{x}{x_1}\right) \qquad (3.5)$$

$$m = \frac{y_2 - y_1}{\log x_2 - \log x_1} = \frac{y_2 - y_1}{\log\left(\frac{x_2}{x_1}\right)} \qquad (3.6)$$

3.5.8 Peaks detection

In this part the controller asks to the ESPI to position a marker in the maximum measured value or max peak of the trace. After this max peak is localized, the next smaller maximum values are queried. When no next maximum value is found on the trace an execution error is produced.

The level values measured by the marker are sent to the PC using the ":CALCULATE1:MARKER1:Y?" query.

The peak values are stored in a vector, and then these values are searched in the measurement vector in order to find the vector index where the peak value is stored. With this index, the respective frequency of the peak is searched in the frequency vector. Finally frequency and peak values are stored in a matrix. With this, the evaluation engineer can know in which frequency the peak was detected. Choosing the peak frequency is the first step for the final measurement analysis.

Because of this, it can be said, that the Peaks Detection is the end of the scan or initial measurement and the beginning of the final measurement analysis.

3.5.9 Final configuration

Once the evaluation engineer chooses the peak frequencies for the final measurement, the configuration for this process starts.

In the Final Configuration sub-VI, the screen format is changed to split to show the measurement waveform and the results of the detectors.

Detectors are used to evaluate the measured disturbances and usually test receivers have four detectors [5]:

- *Peak detector:*
  It measures the maximum value of a disturbance in a determined frequency bandwidth.

- *Quasipeak detector:*
  The quasipeak measurement is performed using a RC adapter with charging and discharging time constants according to the capacitor that is being used. In standards is not well defined the bandwidth and the charging and discharging times that should be used in the tests, but the most accepted parameters are:

  BW = 9 kHz, t_c = 1 ms, t_d = 160 ms
  BW = 120 kHz, t_c = 1 ms, t_d = 550 ms

  The measured value takes into account the repetition frequency of interference pulses.

- *Average detector:*
  This detector uses an adapter that provides the average of the absolute measured values in the bandwidth.

- *RMS detector:*
  This detector uses an adapter that provides the disturbance RMS value for the chosen bandwidth.

Detectors that have to be used in the EMI application because of the ETP # 910E001 are the average and quasipeak detectors.

After initializing the detectors, the peak frequency and sweep time or final measurement time are defined. The sweep time is the time that takes the measurement in the chosen frequency.

Here is set also the final measurement format as a single scan.

3.5.10 Final scan

The final scan is started with the command ":INITIATE1;" and the average and quasipeak values are obtained.

A delay of 4 seconds is used to assure that the measurement is finished. This value was estimated after observing how was performed this measurement by the EMC32. If the measurement is not complete and the controller asks for the results, there will be an execution error.

At the end, the average and quasipeak values are the important results in the test in order to know if the appliances satisfy EMI/EMC-compliances and that is why they have to be reported.

3.5.11 Final data acquisition

After the final measurement is finished, the data acquisition starts. The detectors values are queried using the ":TRACE? SINGLE" command.

The principal difference between this acquisition and the first one is that in the first one large amount of data is sent and here are sent only two values the average and quasipeak values.

Another difference between this acquisition and the first one is in the data block format, it is also in REAL, 32 format, but this acquired data block only includes the measurement values, nor the trace status neither the status data.

3.5.12 Final data conversion

Since the values included in the data block are in REAL, 32 format, the data conversion process is the same that the explained in the section 3.5.5.

3.5.13 Creation of an Excel file

This is the final part of the EMI application and it is realized by the Write to File sub-VI. It exports the setting parameters and the obtained results to a spreadsheet, that is, an Excel file.

The setting parameters that are sent to that file are:

- Start frequency
- Stop frequency
- Bandwidth resolution
- Measuring time
- Step size

And the results that are also exported are:

- Value of the chosen peak
- Peak frequency
- Quasipeak value
- Average value
- Correction value for that peak frequency
- Final measurement time
- Bandwidth resolution
- The line where the test is performed

The first step for saving this data is to create arrays with the information and then change them from number to string format; this is done using the LabVIEW function “Array to Spreadsheet String”.

Once the data is in string format, it is saved using the “Write to Text File” function. The Excel file in which the data and results are saved was created previously by the “Open/Create/Replace” function and it has the CSV format.

3.6 SOFTWARE DEVELOPMENT FOR THE EMS APPLICATION

As in the EMI Application section, the steps that were followed for the EMS Application development are explained in this part. Again, the steps to program the application were chosen after analyzing how the EMC32 performs this test and studying the examples for Visual Basic included in the SMT and NRVD manuals.

For this interface some sub-VIs created in the EMI application such as Initialization and IDN were used. This was possible because of the common commands that SCPI has for instruments.

Although in this application two disturbances are produced, the process for generating them is almost the same, so the steps described in Figure 3.14 applies for both. Only few modifications were done in the signal generator configuration and signal generation steps for each disturbance.

As in EMI application, almost every step was programmed as a sub-VI.

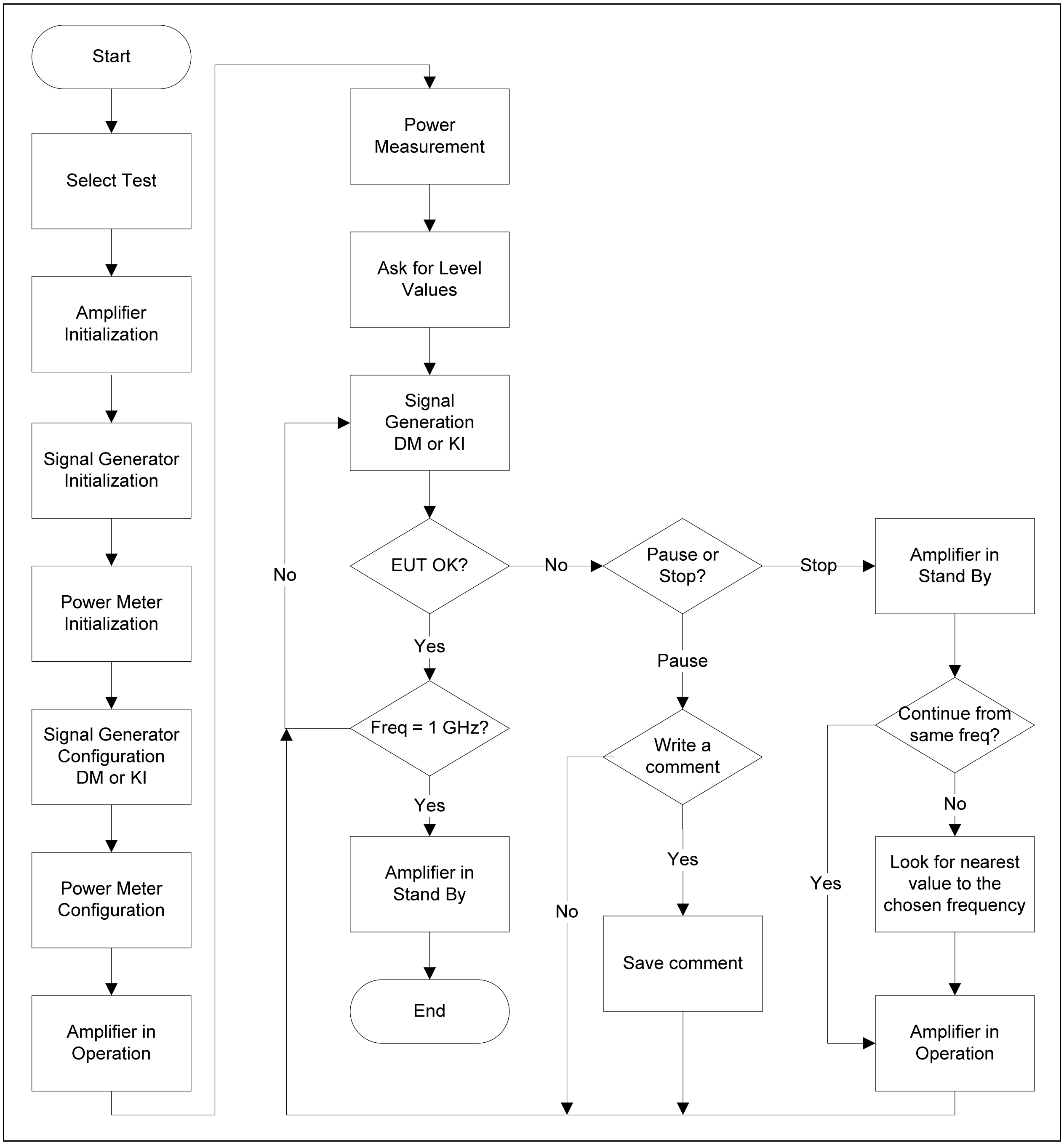

Figure 3.14: *EMS Application Flow Chart designed to carry out susceptibility tests.*

3.6.1 Select test

The two types of disturbances generated for the EMS test are the Digital Modulation (DM) and Keying Interference (KI), so the first step in the application is to select what type of disturbance is going to be generated. This selection can be done using a button in the front panel of the application.

The second step is to select the antenna polarity, which means the antenna position. The position can be horizontal or vertical. The antenna is moved manually, but it is important for the application process to specify the antenna polarization.

3.6.2 Amplifier initialization

First the amplifier is set to remote mode manually. Then the GPIB address is also defined in manually way; this amplifier model has only two options 0 or 1, in this case the address was defined as 1. Usually GPIB addresses are defined in the range of 0 to 30.

The amplifier initialization is done using two sub-VIs:

- *Power IAR:*
  This sub-VI sends the command “P1” (turn on) to the amplifier and manages the lines REN and IFC. With this sub-VI it is also possible to turn the amplifier off using the command “P0”. After turn the amplifier on, it will be in standby mode.

- *Reset IAR:*
  With this sub-VI the amplifier is reset using the command “R”.

In this point, it is important to notice that the amplifier does not use the command structure mentioned before in the SCPI section. Amplifier’s commands are defined with only one or two characters and a line feed <LF> that have to follow the characters to terminate the command.

The commands were programmed in different sub-VIs because the amplifier does not respond to the commands when they are all together in one sub-VI.

3.6.3 Signal generator and power meter initialization

To initialize both devices was used the ESPI’s Initialization sub-VI. The modifications that had to be done were to erase the commands used to set the ESPI as test receiver and the ones for setting the display.

So, one sub-VI for initializing the signal generator was programmed and one for the power meter. Both sub-VIs conserve the IDN sub-VI and perform the functions described in the ESPI initialization section.

3.6.4 Signal generator configuration DM or KI

In this sub-VI the modules that the SMT has are set in order to obtain the desired signal. The modulation options that are used for the disturbance generation is the AM and the pulse modulation.

One sub-VI sets the AM modulation which is necessary for the DM test and one sub-VI sets the pulse modulation for the KI test.

First, the signal output of the generator is turned off and then a level of -100 dBm is set. This is done to protect the amplifier of receiving a high signal level value. At this moment the amplifier can have any gain programmed and if the SMT sends a high value at the amplifier’s input and it is programmed with its maximum gain it could be damaged if the signal at its RF output is higher than 100 watts.

After turn the RF output off and set the initial level value, the attenuator is set to the fixed mode, so, the level settings are carried out without interruption. The attenuator is switched only when certain fixed levels are exceeded. The fixed levels are set automatically by the SMT, and the RF signal level can be set within the 20 dB that extends from the level set on switching on the attenuator fixed mode until 20 dB below.

Then, the frequency is set to 26 MHz which is the initial frequency for both tests.

In SMT DM sub-VI are turned off the FM, φM and pulse modulation options while the AM mode is turned on. Here are set also the following AM parameters:

- Depth percentage = 0%
- Envelope frequency = 10 kHz
- Shape of envelope = square wave
- Amplitude of envelope = 1 V

The depth percentage is changed to 90% in the Signal Generation DM sub-VI.

The generator that produces the envelope is a LF generator included in the SMT and it is initialized and turned on in this sub-VI with the commands ":OUTPORT2:SOURCE 2;" and ":OUTPORT2:STATE ON" respectively.

The carrier frequency is a sinusoidal RF wave which frequency and level values are set in the Signal Generation DM sub-VI.

In SMT KI sub-VI are turned off the AM, FM, and φM and also the pulse modulation; in this sub-VI is initialized the LF generator for the envelope. The LF generator parameters that are set are:

- Envelope frequency = 1 Hz
- Amplitude of envelope = 1 V

The pulse modulation is turned on in the Signal Generation KI sub-VI. There, it is also set the pulse width.

3.6.5 Power meter configuration

The first thing to do is to check if the sensors or URV5-Z2 heads are connected. For this, the queries “:INP1:SENS?” for input A and “:INP2:SENS?” for input B are sent to the NRVD. If the answer for both is 1, they are connected to the power meter.

Also in this part, a filter is selected. The NRVD has 13 digital filters for noise suppression. Filtering consists of average-value generation of various numbers of subsequent measured values. The selected filter is the 01, which has a measurement time of 0.07 s for the URV5-Z2. The measurement time is considered from trigger to output of first byte.

This filter was chosen because it is the filter that the EMC32 sets; this choice makes sense due to the dwell time is 1 s. (Very small test signals and a high display resolution require the most efficient filter and thus result in the smallest measurement rate).

Finally, the units for every input are set to dBm.

3.6.6 Amplifier in operation

Once the signal generator and power meter are initialized the amplifier gain is set using the Gain IAR sub-VI. The command that is sent is “Gxxxx” where xxxx is a number from 0000 to 4095. For this application the maximum gain is used, that is 50 dB which is specified with “G4095”. This gain is set because it is the gain used in the calibration process.

Then, the Query IAR sub-VI is used to confirm that the amplifier has received the gain command. This sub-VI can ask for either the gain or the identification of the amplifier using the queries “I?” or “G?”.

After checking that the gain was correctly set, the amplifier is changed from the standby mode to the operation mode with the “O” command. This command is programmed in the IAR Operate sub-VI.

3.6.7 Power measurement

In order to measure the forward power in the directional coupler, the input A of the power meter is used and for measuring the reflected power the input B is used.

To perform the measurement, the input A or B has to be selected with the commands “:INP:SEL "A";” and “:INP:SEL "B";” before sending the query “:MEAS?”.

At this point, the power measurement is very important for knowing if the antenna is connected to the amplifier output. If the antenna is not connected, the lecture of input B is almost equal to the input A because the transmitted power is reflected. If this occurs, the amplifier is set to standby mode and the application ends. The command for standby mode is “S”.

3.6.8 Frequency and level values

As in the application developed for the ESPI, the calibration data obtained by the EMC32, which is shown in Table 3.4, is exported to two Excel files that are saved in CSV format. One file has the frequency values and the other one has the level values.

The calibration tables generated for the EMS test are:

- DM – Vertical
- DM – Horizontal
- KI – Vertical
- KI – Horizontal

So, for the EMS application there are five tables, four with the level values and one with the frequency values. The evaluation engineer has to choose the corresponding level file depending on the test selection made at the beginning.

For doing this, it was used the Read from File sub-VI that was created for the EMI application with some modifications. For reading the frequency file, the path where it is localized has to be specified at the beginning in the front panel of the Read from File wPath sub-VI, once the path is specified it is not necessary to write it down every time that the program is started. The read values are stored in one vector.

[TableHeader]		
Name=	Frequency	Generator Level/V
Unit=	MHz	dBm
ColTyp=	11 Frequency	17 Generator Level
Detector=	0	2
Intpol=	0	0
Format=	6	1
ColWidth=	-1	-1
[TableValues]		
2.60E+01	-2.31E+01	
2.63E+01	-2.34E+01	
2.65E+01	-2.34E+01	
2.68E+01	-2.34E+01	
2.71E+01	-2.34E+01	
2.73E+01	-2.34E+01	
2.76E+01	-2.34E+01	
2.79E+01	-2.30E+01	
2.82E+01	-2.30E+01	
:	:	
9.44E+02	-3.14E+01	
9.53E+02	-3.17E+01	
9.63E+02	-3.17E+01	
9.73E+02	-3.17E+01	
9.82E+02	-3.22E+01	
9.92E+02	-3.27E+01	
1.00E+03	-3.34E+01	

Table 3.4: *Example of Calibration Table for EMS Test*

To read the level values, first the file's path and name have to be specified using the "File Dialog" function that makes a pop-up to appear in the screen, then the read data is stored in another vector. This sub-VI that reads the levels is the Read Calibration and Polarity sub-VI.

The Read Calibration and Polarity sub-VI checks also according to the test selection if the calibration file is for DM or KI and if it is for horizontal or vertical polarization. For this the "Scan from String" is used, so if the selected test is a DM – Horizontal, that function will scan for the words DM and Horizontal in the name. If those words are not found an error message is displayed and the evaluation engineer has to select again a calibration file. In order to assure that this process works, the files have to be saved with the next format:

- DM, Vertical …
- DM, Horizontal …
- KI, Vertical …
- KI, Horizontal …

3.6.9 Signal generation

The Signal Generation DM sub-VI reads the carrier frequency values with their levels from the vectors created in the previous step and sends this data to the SMT, after doing this, it changes the depth from 0 to 90% and a delay of 1 s is used which is the dwell time. Finishing this time, the depth is changed to 0% and a new frequency with its corresponding level value is sent to the SMT again. This process is repeated from 26 MHz to 1 GHz.

The Signal Generation KI sub-VI does almost the same, it sends the frequency and level values to the generator, but instead of changing from 0 to 90% and again to 0%, it turns on and off the pulse modulation. The delay in this sub-VI, that represents the dwell time for this test, is 50 ms. Before turning the pulse modulation on, the pulse width is set to 500 ms.

The generation of both disturbances stops when the last frequency value, 1 GHz, is read from the vector. But, before this, the generation can be paused or stopped if an undesired effect is observed in the EUT by the evaluation engineer.

There is also an option to finish the test before it reaches 1 GHz and it is when the “Finish Test” button located in the front panel of the application is activated.

3.6.10 Pause

When an undesired effect is observed in the EUT due to the radiated disturbance, the evaluation engineer can pause the radiation and write a comment about that phenomenon.

The effects than can be observed are, for example, a change in the mode or function of the EUT, a reset in the function that is tested and even the EUT can be turned off due to the radiated disturbance.

When the radiation is paused a pop-up appears with the question “Do you want to write a comment?” If the answer is YES the evaluation engineer can write the comment in the specified filed for this at the front panel and after that the comment can be saved with the OK button. The comment, the frequency and the level where the radiation was paused are saved in an Excel file. If the answer is NO, the evaluation engineer is not allowed to save the comment.

In order to restart the radiation the RUN option has to be selected at the front panel. The radiation starts in the frequency value that follows the one where the test was paused.

It is important to notice in this pause mode that the values reading is stopped, but all devices are working normally.

Write and save a comment

First the frequency and level values at which the radiation was paused are converted from number to string format using the “Number to Fractional String” function.

As the written comment at the “Comment” field is already in string format, the “Concatenate Strings” function is used to generate a unique string with the frequency value, its level and the corresponding comment which are exported to the Excel file using the “Write to Text File” function.

Such string is only saved when the OK button is activated, if it is not activated the evaluation engineer can write and erase the comments the times that he/she wants.

3.6.11 Stop

The stop mode stops the values reading from the vectors in a similar way as the pause mode does, but also it changes the amplifier mode to standby. And it is used when it is necessary to change the amplifier to the standby mode or when it is necessary to restart the radiation from a specific frequency.

The stop mode is used when the EUT has to be moved or when a connection has to be checked. That is why the amplifier has to be in standby, for preventing accidents. It is important to remember that the max output power is 100 W.

Also this mode is used when the evaluation engineer needs to restart the test in a specific frequency for trying to reproduce the undesired effect which occurred previously.

When the test is restarted, the amplifier is changed to the operation mode.

Select a frequency value

When the radiation is stopped, a pop-up appears with the question “Do you want to continue from the same frequency?” If the answer is YES, the radiation restarts in the frequency value that follows the one where the test was stopped. If the answer is NO, the evaluation engineer can select a frequency in the specified field for that in the front panel.

Because of the frequency values are stored in a vector, it is not possible to restart the test in the exact frequency that the evaluation engineer chooses, so a function has to find the nearest frequency value to the selected one, for this the Select Freq sub-VI is used. What this sub-VI does is to read the frequency vector and compare every element that it has until it finds a vector value which difference between it and the selected frequency is higher than 0.2 but less than 10. Afterwards the sub-VI has selected the frequency value, it is sent to the Generation Signal sub-VI.

In the next chapter are shown the results obtained for the software interfaces by the application of the procedures described here.

4. CHAPTER IV: RESULTS

All the windows presented below were specifically designed throughout this work taking into account the requirements as demanded by the Mabe's test engineers.

4.1 EMI APPLICATION: SUB-VIs

4.1.1 Initialization sub-VI

In Figure 4.1 can be seen that the communication between ESPI and PC was established successfully because the front panel shows the answers to the identification and options queries.

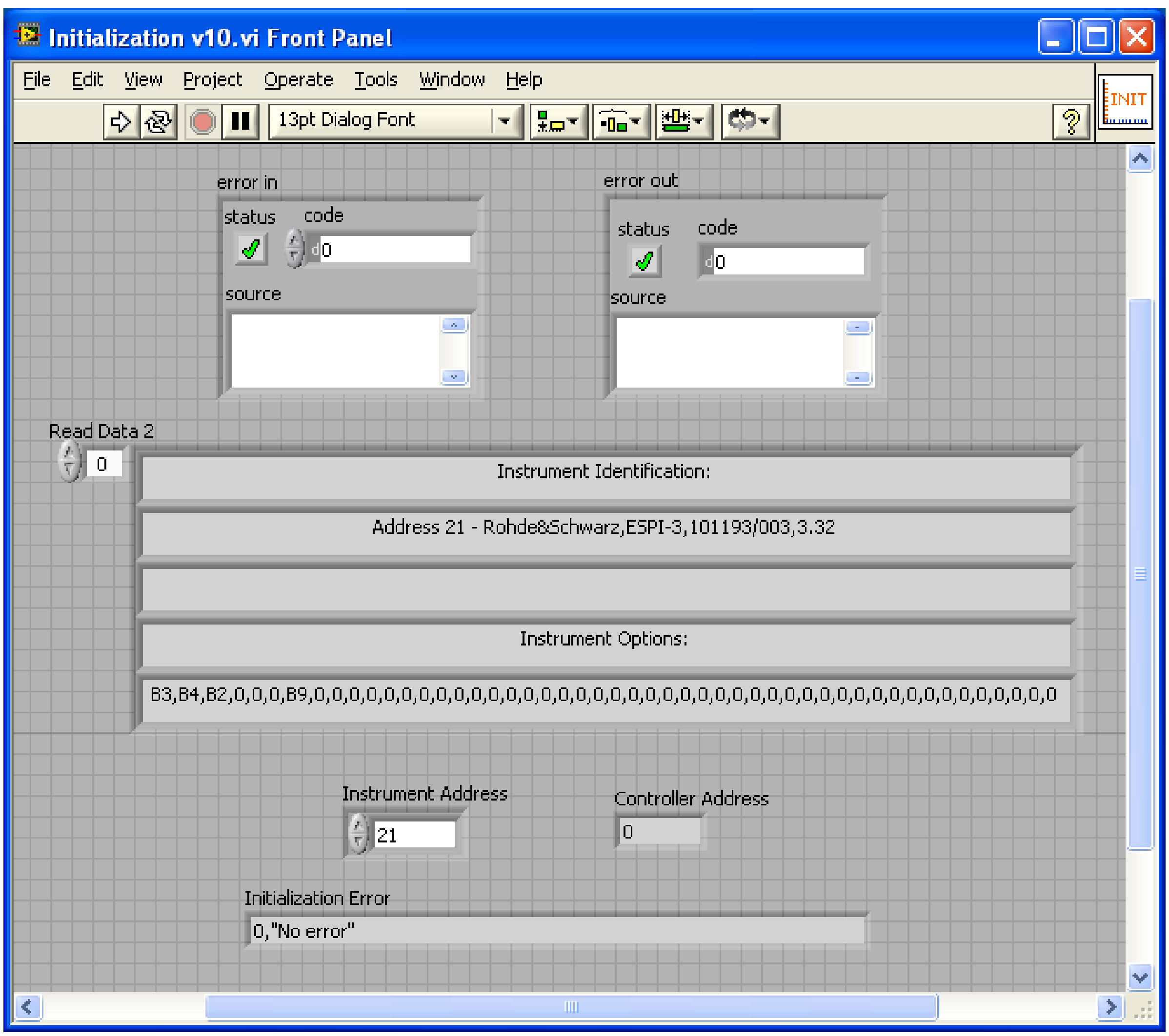

Figure 4.1: *Initialization sub-VI*

Before running the program, the ESPI address which is 21 and the controller address which is 0 are specified as it was explained in section 3.5.1 (Initialization).

The options that the ESPI has according to the answer that was obtained for the identification query are: B3-Audio Demodulator, B4-OCXO (reference oscillator), B2-Preselector (preamplifier), and B9-Tracking Generator 3 GHz. The meaning of the options is not indicated in the front panel because it is not important for the user since they can be checked in the operating manual.

The instrument identification is obtained using the IDN sub-VI shown in Figure 4.2.

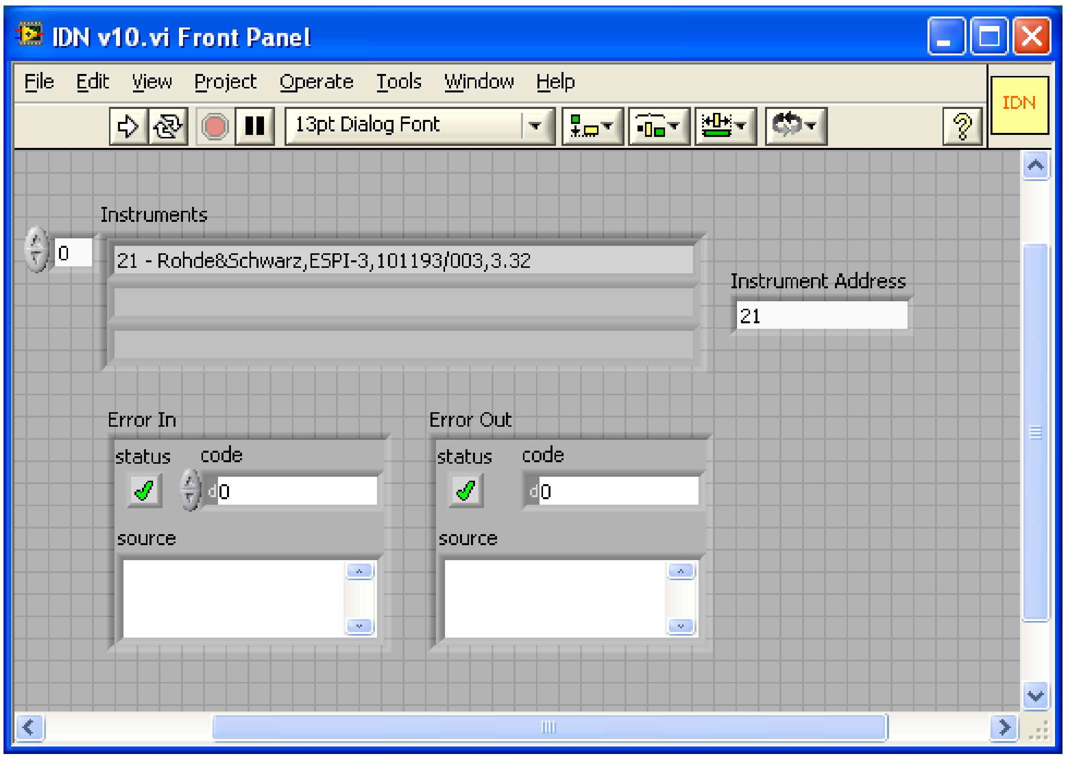

Figure 4.2: *IDN sub-VI*

The answer to the IDN query includes the device address, the name, model, serial number and firmware version:

21 = Address

ESPI – 3 = Device name

101193/003 = Serial number of the instrument

3.32 = Firmware version number

The last command executed in the Initialization sub-VI is the query ":SYSTEM:ERROR?" in order to know if something is wrong. Every time that a query is sent to the instrument the LabVIEW functions "GPIB Write" (for sending the query) and "GPIB Read" (for reading the answer) are used, thus the Write & Read sub-VI was created to simplify the programming. In the sub-VI's front panel which is shown in Figure 4.3 can be seen that there is no error at initialization.

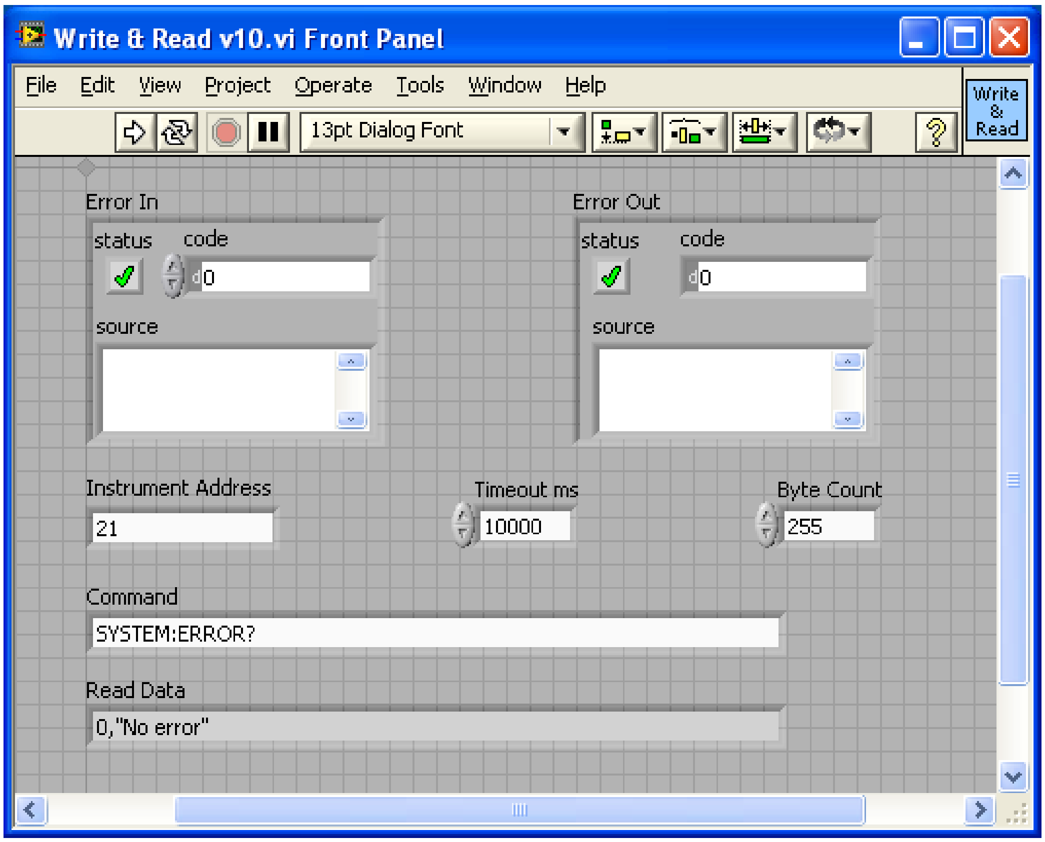

Figure 4.3: *Write & Read sub-VI*

4.1.2 Configuration sub-VI

In this sub-VI the evaluation engineer can set the test parameters according to the EMI test that is going to be performed. The parameters such as frequency, time, units, etc. can be changed using the increment/decrement controls or just writing the desired value in the specific field for each one; the preamplifier and attenuator can be turned on and off using the buttons as is shown in Figure 4.4.

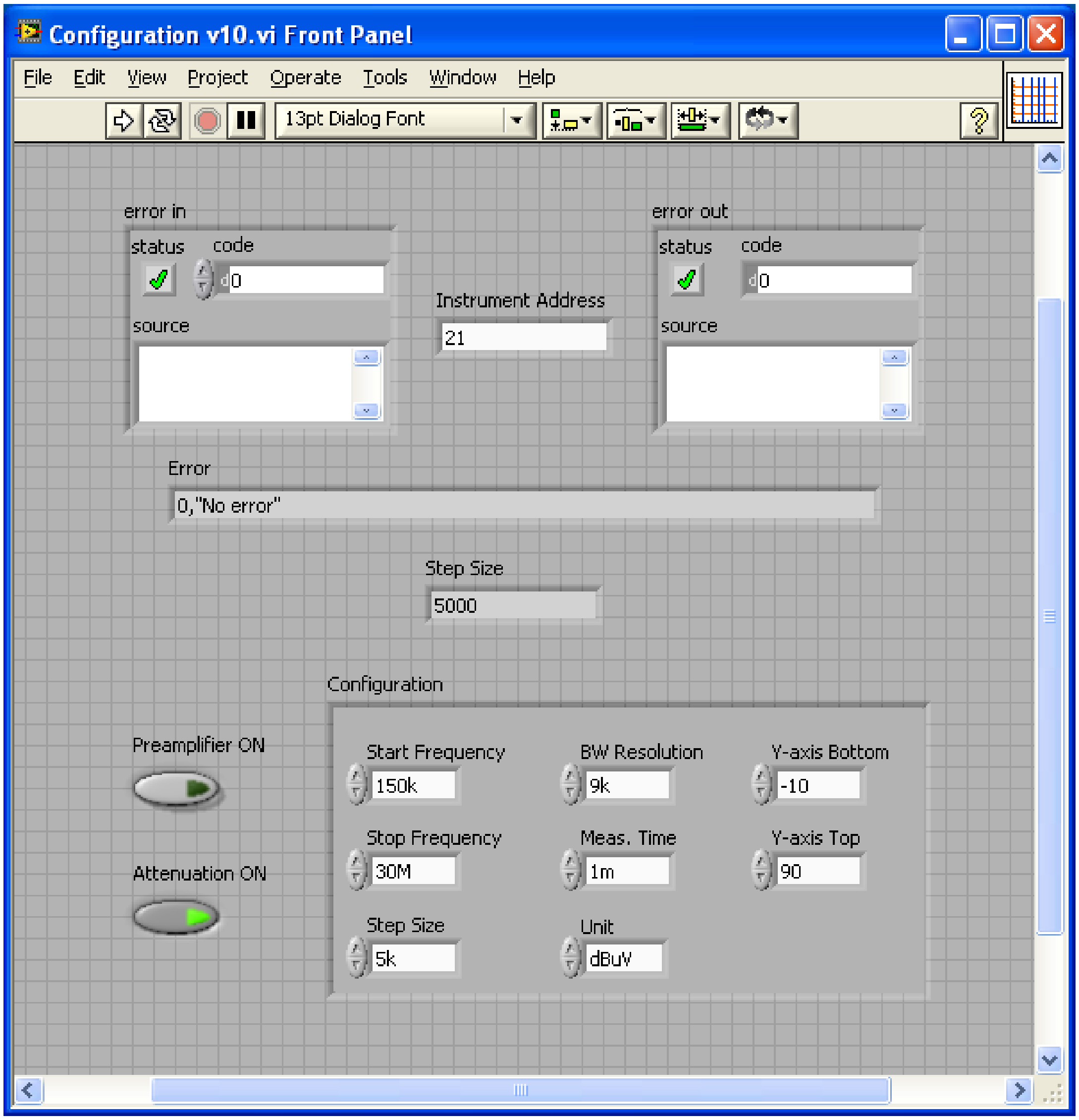

Figure 4.4: *Configuration sub-VI*

The step size is queried as a way to confirm that the ESPI is receiving the commands for setting the parameters. As in Initialization, it is checked if there is an error at the end of the program.

4.1.3 Acquisition sub-VI

Once the scan is finished, the measurement data is queried to the ESPI by the PC. The acquired data is shown in the front panel of Acquisition sub-VI as indicates Figure 4.5.

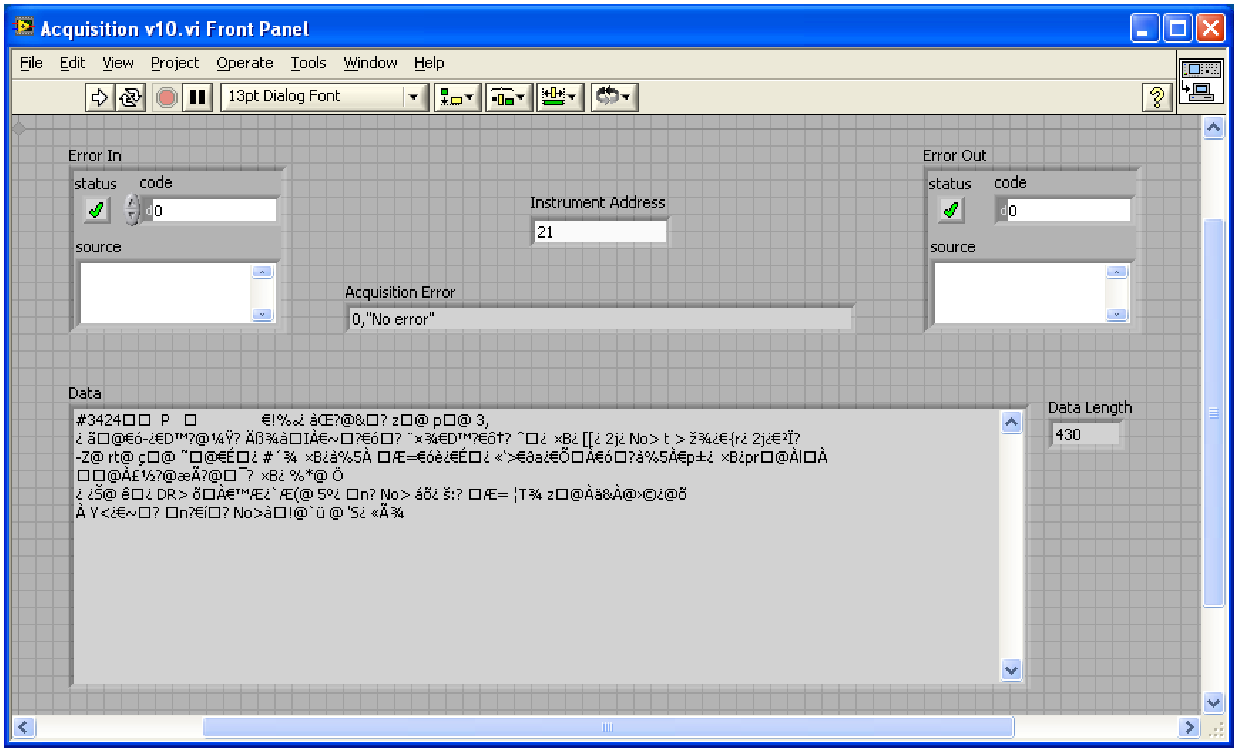

***Figure 4.5:** Acquisition sub-VI*

In Figure 4.6 can be seen clearly the data format that was set in the Configuration step, that is REAL, 32, and how the data block is read as a string where every byte is represented as an ASCII (hex) character.

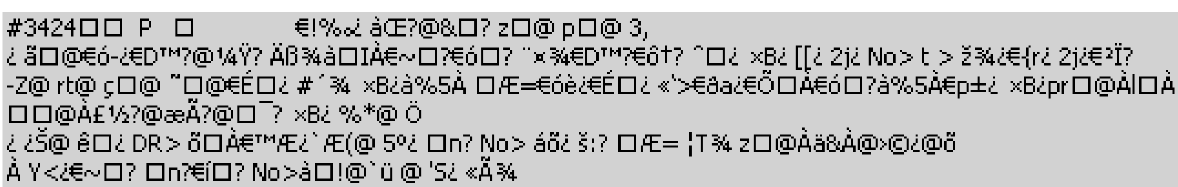

***Figure 4.6:** Data Format*

The total length of the read data for this example is 430 bytes because it includes the data bytes (424), the header bytes (5) and a line feed <LF> (1 byte) to indicate the data block end.

4.1.4 Conversion sub-VI

In the Figure 4.7 can be seen the acquired data without the header in the “Post-Data” field, now the length is 425. This is the data that is converted from REAL, 32 format to decimal number.

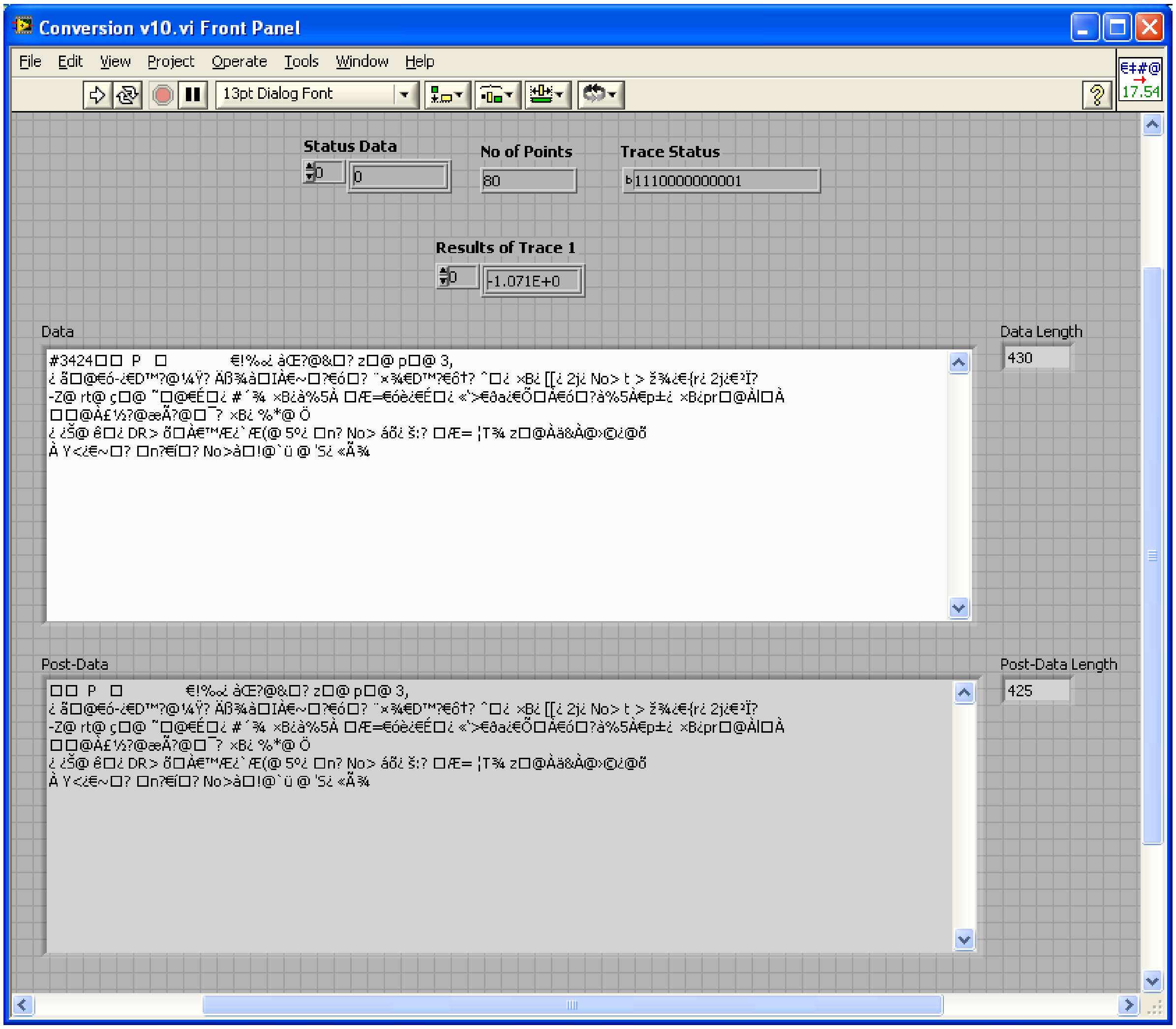

Figure 4.7: *Conversion sub-VI*

After the conversion is done, it can be checked the data structure explained in section 3.5.4 (Data acquisition):

- Trace status (4 bytes) = 7169

  In the front panel it is shown in the “Trace Status” field as a binary number just to analyze every single bit:

  0001 1100 0000 0001

bit 0 = subscan

bit 10 = last block of subscan

bit 11 = last block of last subscan

bit 12 = last of all blocks

Before this last data block, the other ones have a trace status equal to 1.

The result 7169 is used to stop the while loop in the acquisition part.

- Number of transmitted measurement results (4 bytes) = 80

  Which is indicated in the “No of points” field and it is the length of the “Results of Trace 1” vector.
- Trace 1 active (4 bytes) = 1
- Trace 2 active (4 bytes) = 0
- Trace 3 active (4 bytes) = 0
- Reserved (4 bytes)
- Measurement results of trace 1 (80*4 bytes) = -1.071…

  These values are stored in “Results of Trace 1” vector.
- Status data (80*1 bytes) = 0

  Every measurement result has a status information byte which indicates if there is either underrange or overrange for the active trace.

If the number of bytes of each part is added, the sum should be equal to the data length shown in the conversion front panel that is 430 bytes:

Data structure: 4+4+4+4+4+4+320+80 = 424 bytes

Header = 5 bytes

End of data block= 1 byte

Here is an example of one measurement result conversion:

1. Acquired data in string format = A—qì
2. Conversion to long format (32-bit integer) hexadecimal = 41 97 71 EC
3. Conversion to binary format = 0100 0001 1001 0111 0111 0001 1110 1100
4. Conversion to decimal number as it was explained in 3.5.5 = 18.93062591

4.1.5 Read calibration table sub-VI

In Figure 4.8 can be seen the imported calibration table from the Excel file. In the front panel is shown this table first as a string and then as a vector where the values are stored as a numbers. The numeric control “Table Dimension” is for specifying the size of the vector, in this case is 5971 because that is number of elements that are going to be added to the acquired values of the measurement.

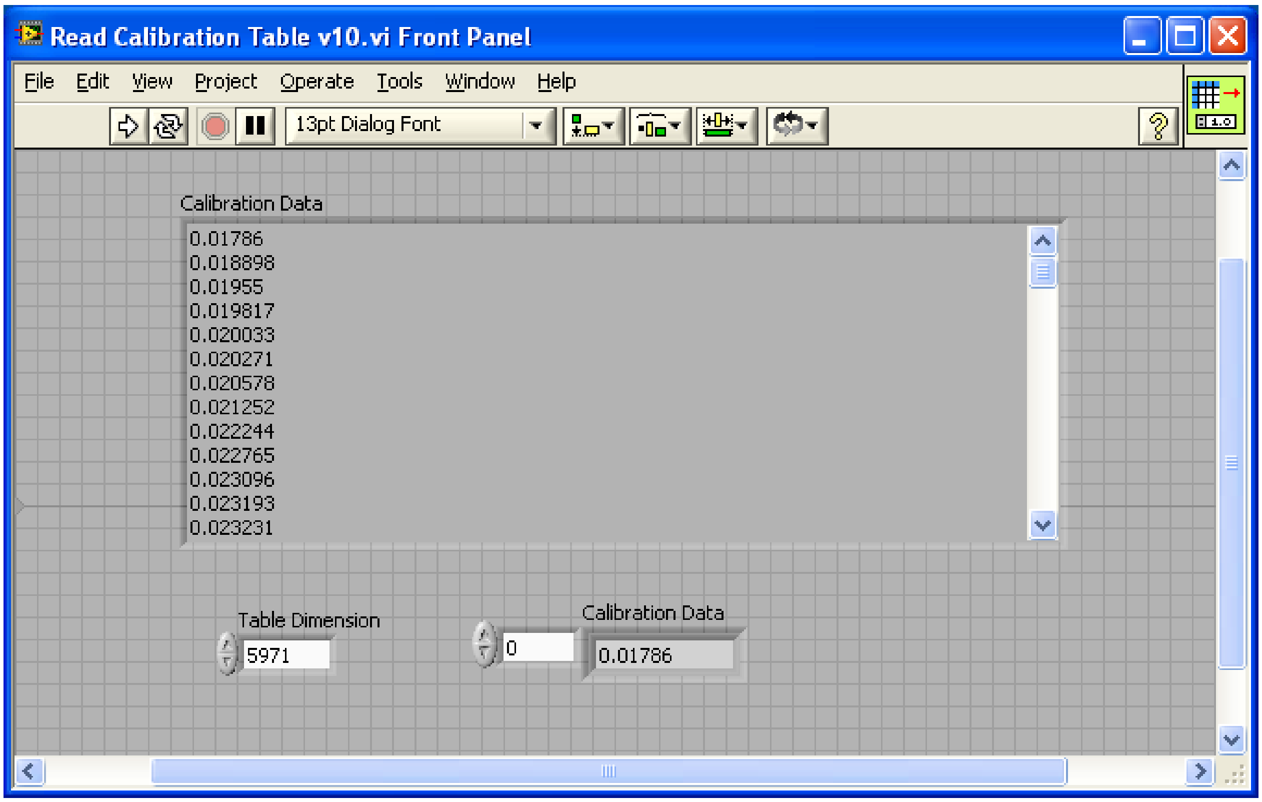

Figure 4.8: *Read Calibration Table sub-VI*

In this part, it is important to remember that for obtaining the 5971 points, an interpolation method was used. Figure 4.9 to 4.11 shows the comparison of the data obtained by the linear, spline and cubic methods against the data given by the EMC32 table, which consists in 110 values represented by circles in the figures.

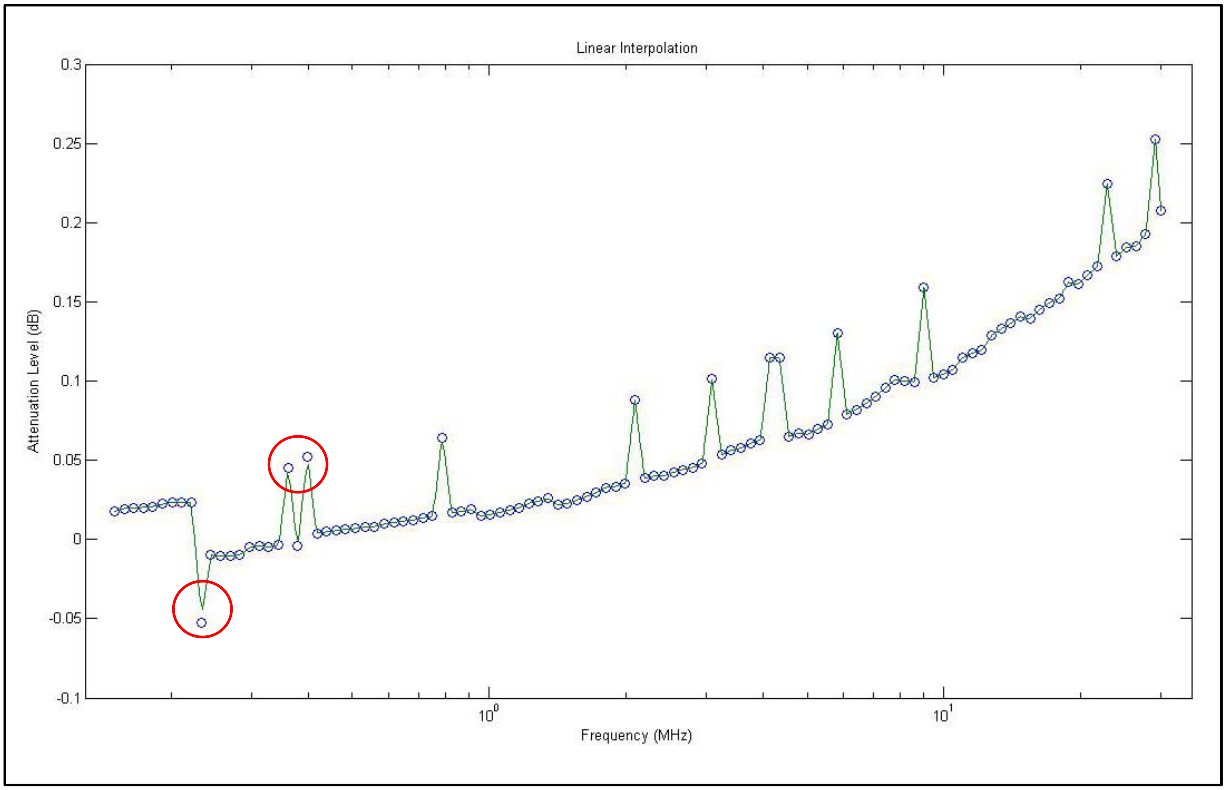

Figure 4.9: *Linear Interpolation*

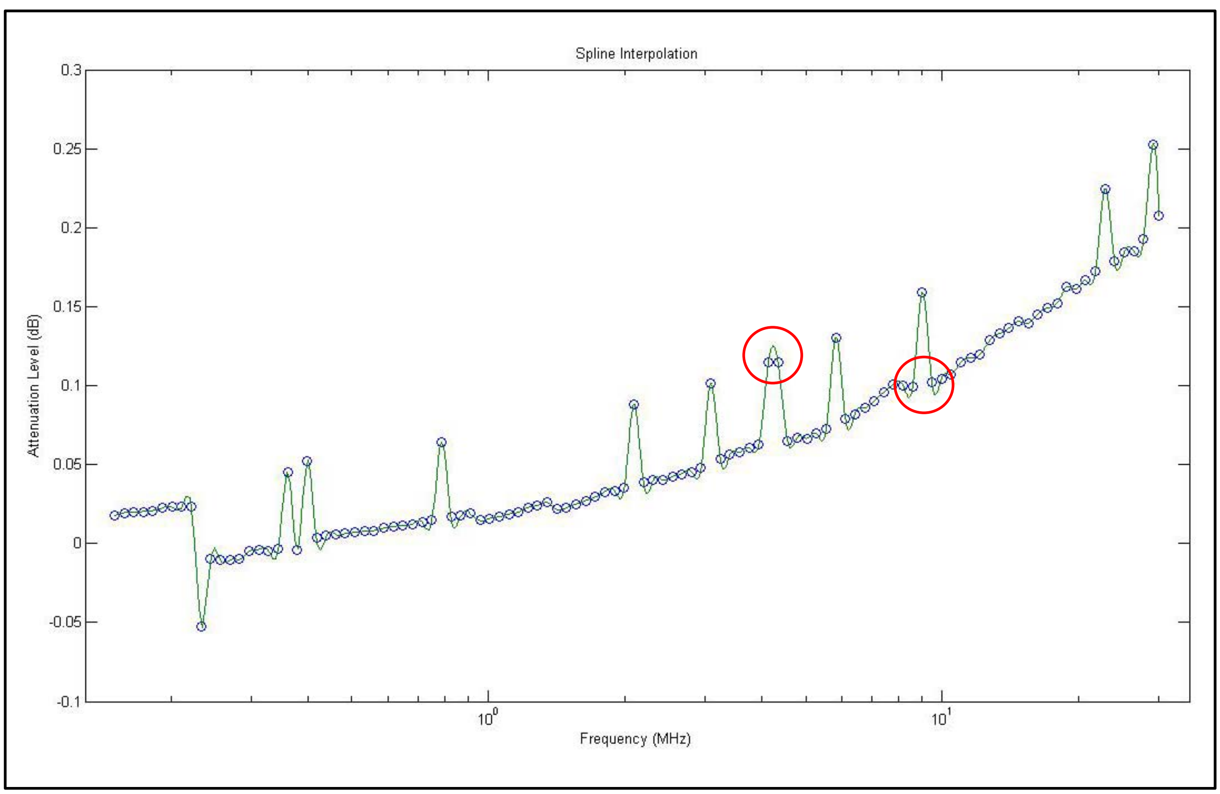

Figure 4.10: *Spline Interpolation*

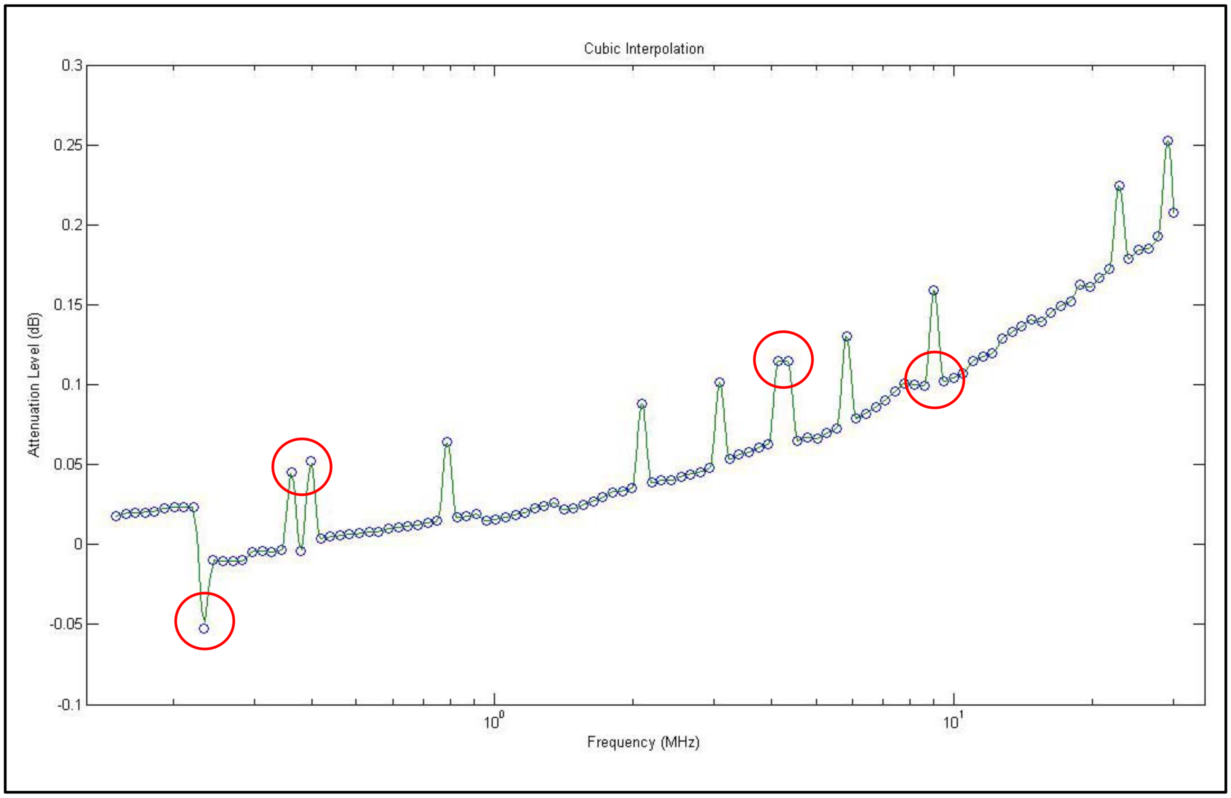

Figure 4.11: *Cubic Interpolation*

As it can be seen in Figure 4.11, the values obtained using cubic interpolation are those that better fit to the values given by the EMC32, so, these values are saved in the Excel file.

4.1.6 Limit check sub-VI

In Figure 4.12 is shown the Limit Check sub-VI. In the front panel are shown three vectors, the “Freq Vector” has the values which are used to calculate the limit lines, the “Limit” vector has the values calculated for the EN55011A line and the “Limit 2” vector has the values for the EN55011Q line.

The “Limit” and “Limit 2” vectors are plotted by the “Waveform Graphs” function.

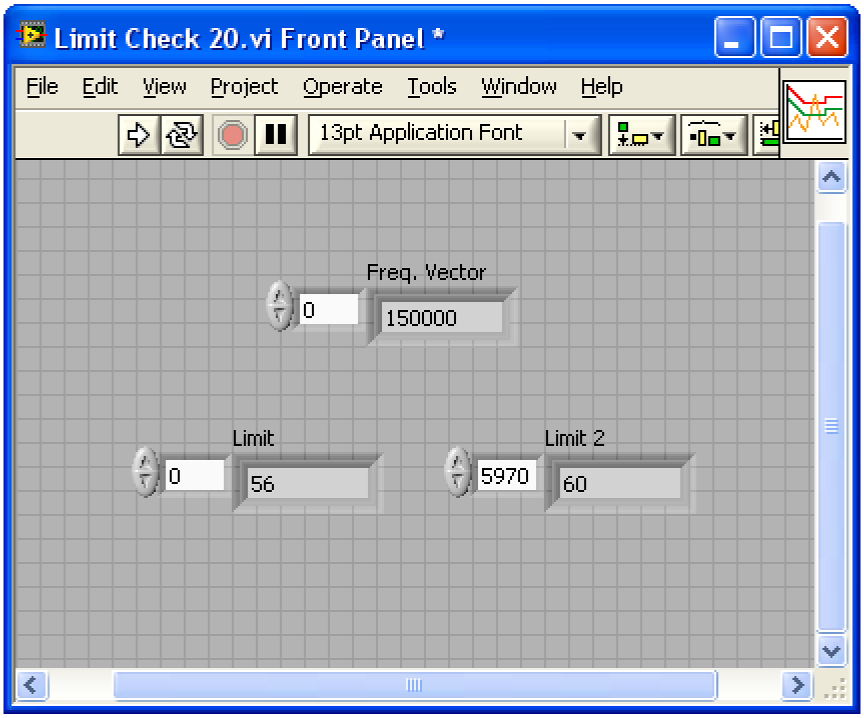

Figure 4.12: *Limit Check sub-VI*

4.1.7 Peaks sub-VI

In Figure 4.13 is shown the Peaks sub-VI, this sub-VI requires the measurement vector and the frequency vector as inputs; both vectors are shown in the front panel. The peak values which were queried to the ESPI has to be found in the "Scan Data" vector in order to find the indexes where that values are stored; once the indexes are found, the frequency values that correspond to the peaks are searched in the "Freq Vector".

The peak values are stored in the "Value FPeak" vector and the frequency value where the peak was found is saved in the "Fpeak" vector.

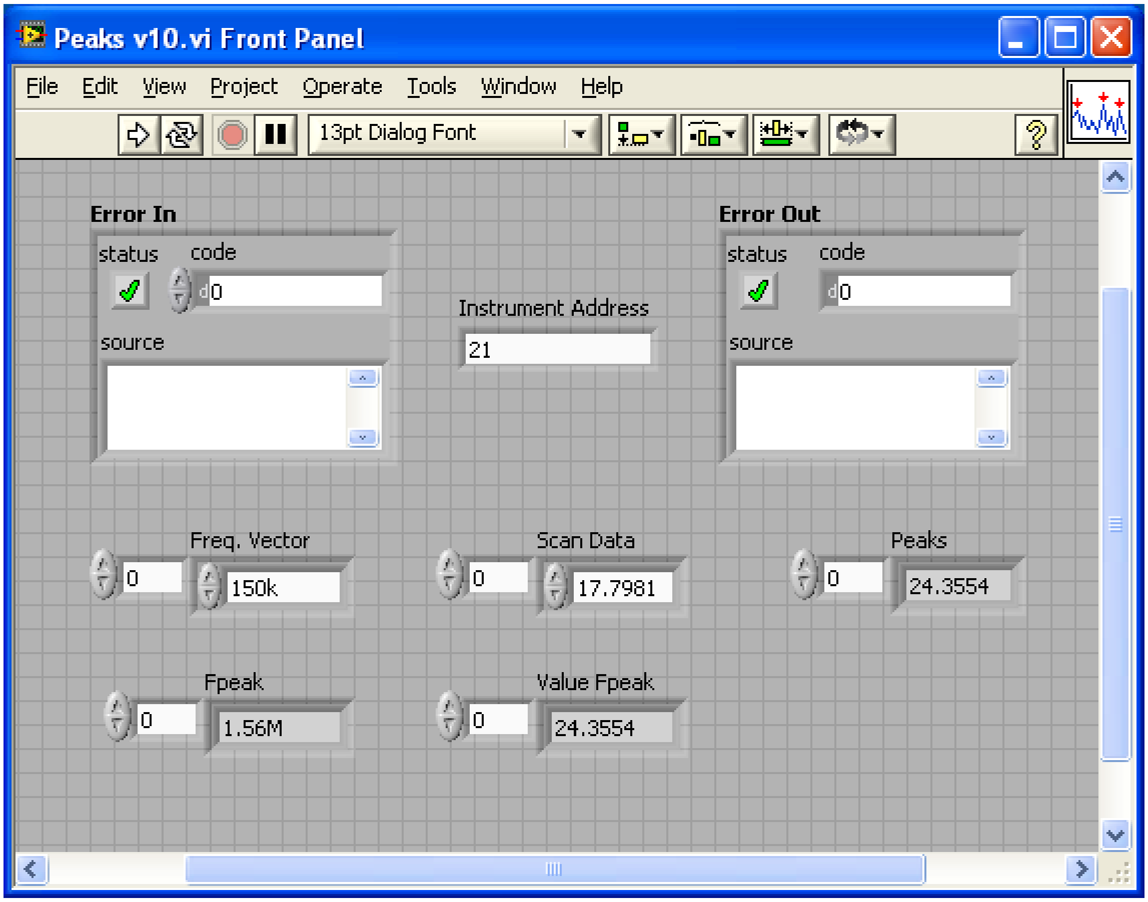

Figure 4.13: *Peaks sub-VI*

4.1.8 Final configuration sub-VI

The Final Configuration sub-VI, shown in Figure 4.14, is where the average and quasipeak detectors are initialized.

Here the evaluation engineer sets the frequency of the peak that is going to be analyzed in the final measurement process and sets the final measurement time.

This sub-VI is executed for every peak frequency that is chosen, this is due to the single scan setting.

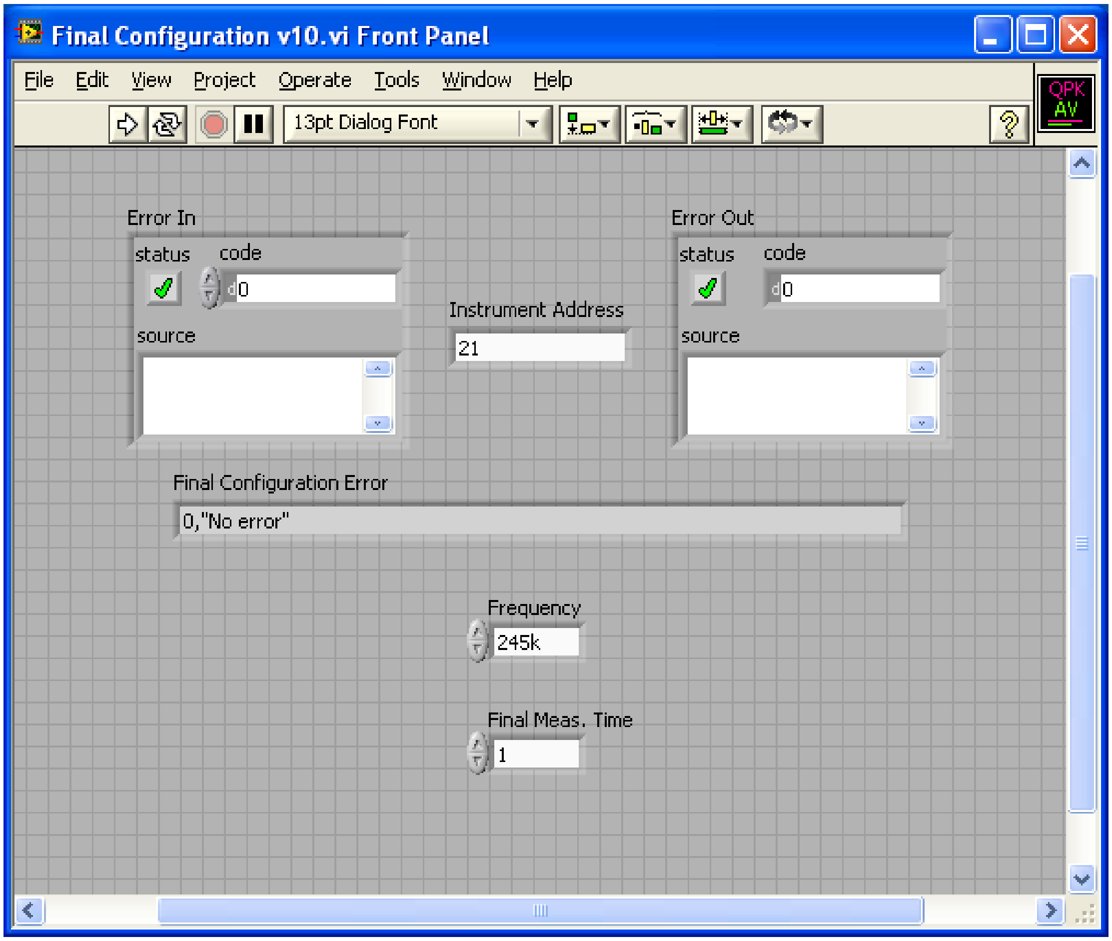

Figure 4.14: *Final Configuration sub-VI*

4.1.9 Final acquisition sub-VI

After choosing the peak frequency, the final measurement is performed and the data obtained by the ESPI is sent to the PC.

In Figure 4.15, can be seen that the acquired data is also in the REAL, 32 format. That data block has no so many values as the measurement data block has, this is because in this part only two values are being acquired, the average and quasipeak results.

This sub-VI is again executed for every peak frequency value.

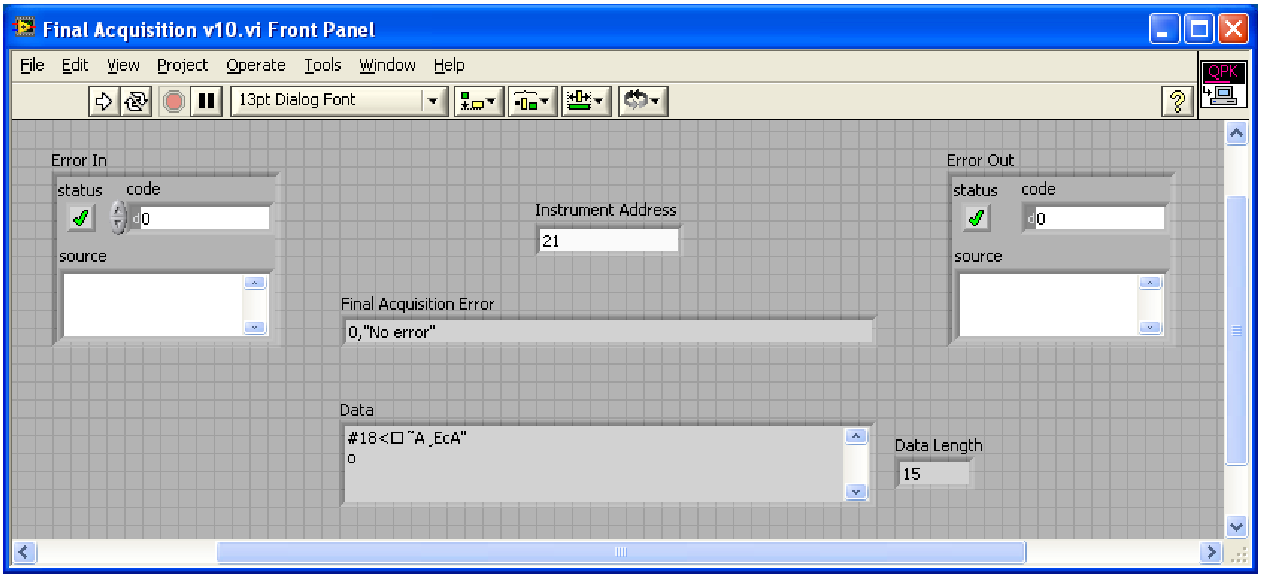

Figure 4.15: *Final Acquisition sub-VI*

4.1.10 Final conversion sub-VI

Once the final measurement data is acquired, the header is separated from the data block and the final conversion process can be started.

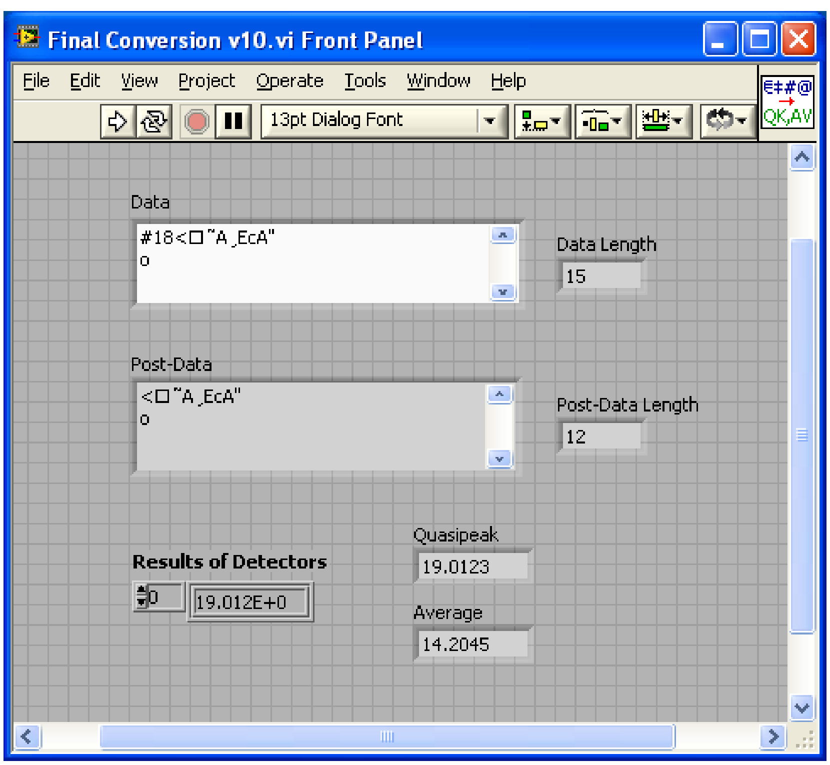

Figure 4.16: *Final Conversion sub-VI*

The values obtained from the final conversion process are stored in the “Results of Detectors” vector. The elements of this vector, that is, the quasipeak and average results are obtained also as single elements as is shown in Figure 4.16.

4.1.11 Write to file sub-VI

The data that appears in the front panel of this sub-VI, shown in Figure 4.17, is the data that is saved in the Excel file. This data includes the scan and final measurement setting parameters, the results obtained in the final measurement and the line where the LISN was connected during the test.

In the field “Data to Write” can be seen the data that is going to be saved in the Excel file by this sub-VI.

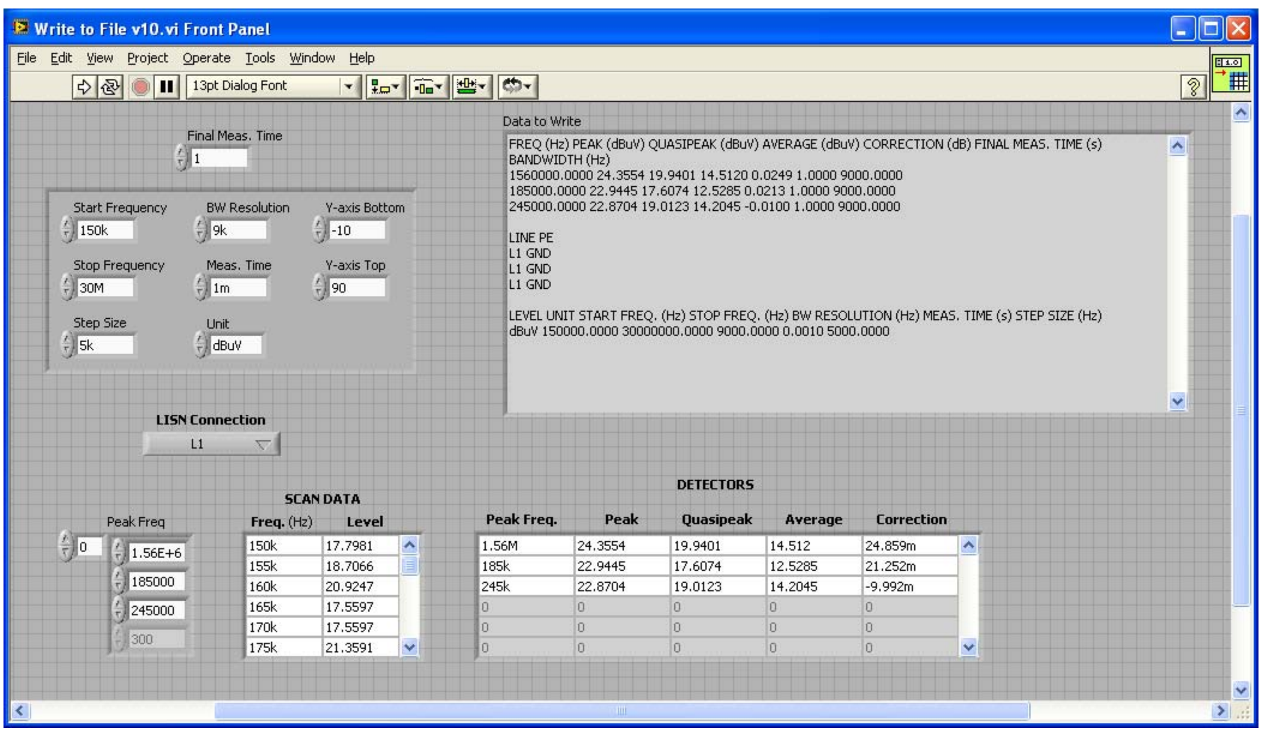

Figure 4.17: *Write to File sub-VI*

4.2 EMI APPLICATION: USER INTERFACE

As it was seen before, the EMI application has a lot of sub-VIs to be controlled and observed by the evaluation engineer at the same time. But that is not a problem since all the important elements of every sub-VI are in the front panel of the principal VI or program.

The main user interface has three sections or screens:

- Configuration
- Run Scan
- Final Measurement

In order to probe that the developed software interface works well, a test was performed using a disturbance generator and the results were compared with the EMC32 results.

The disturbance generator that was used is a COM POWER CGC-255 Comb Generator shown in Figure 4.18.

Figure 4.18: *Comb Generator*

The CGC-255 simulates a EUT generating conducted EMI and its main application is to quickly verify conducted emissions test setups. This Comb Generator was designed to plug directly into the EUT power socket of the LISN. It has two switchable frequency step sizes: 250 kHz and 50 kHz where the peaks are generated.

4.2.1 Configuration screen

In this screen (Figure 4.19) the evaluation engineer can set the test parameters, indicate the line where the LISN is connected, define the ESPI and controller addresses, turn on or off the preamplifier and attenuator and finally select if a calibration test is going to be used. Here are also shown the initialization and configuration errors.

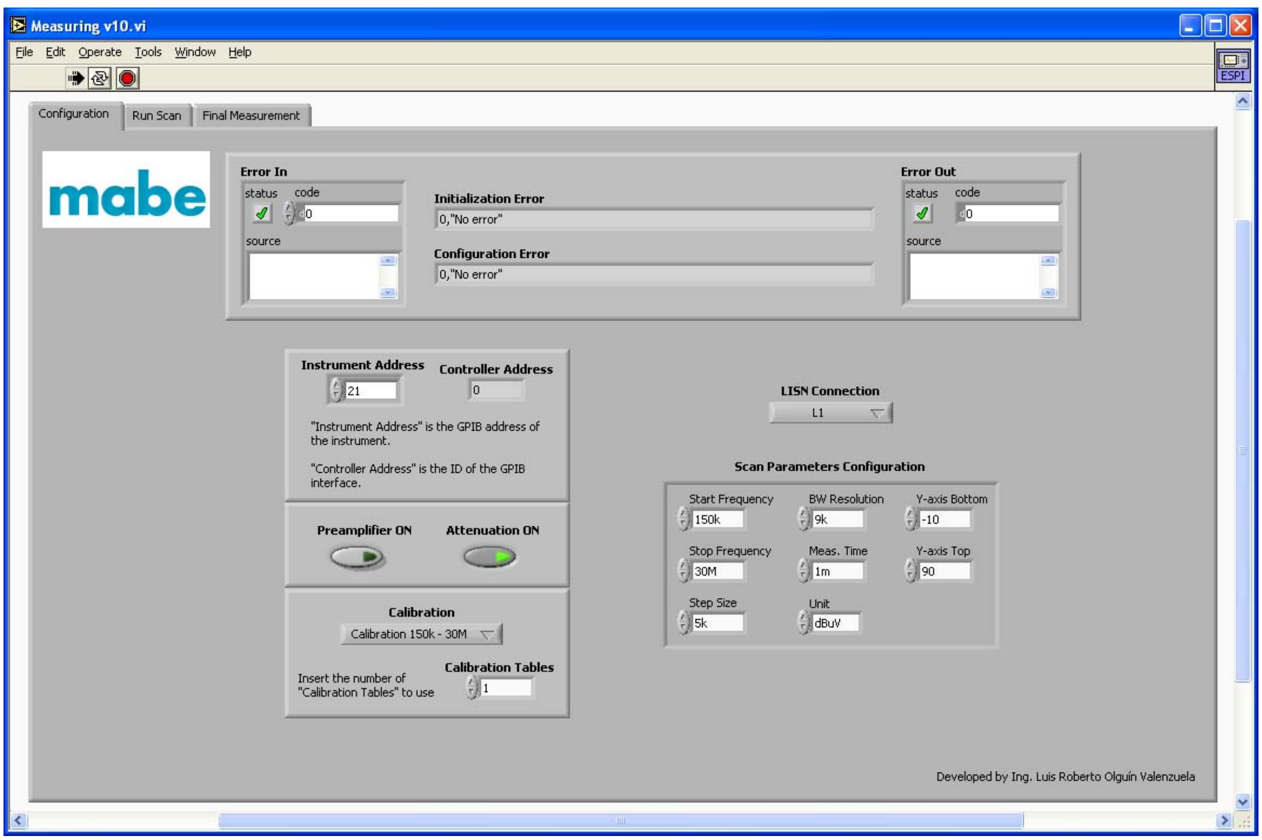

Figure 4.19: *Configuration Screen*

After setting these parameters, the application is ready to start.

The first thing that the software "asks for" to the user is to create a file where the data is going to be saved. For doing this, the name and the path of the file have to be specified in the corresponding fields of the pop-up (Figure 4.20).

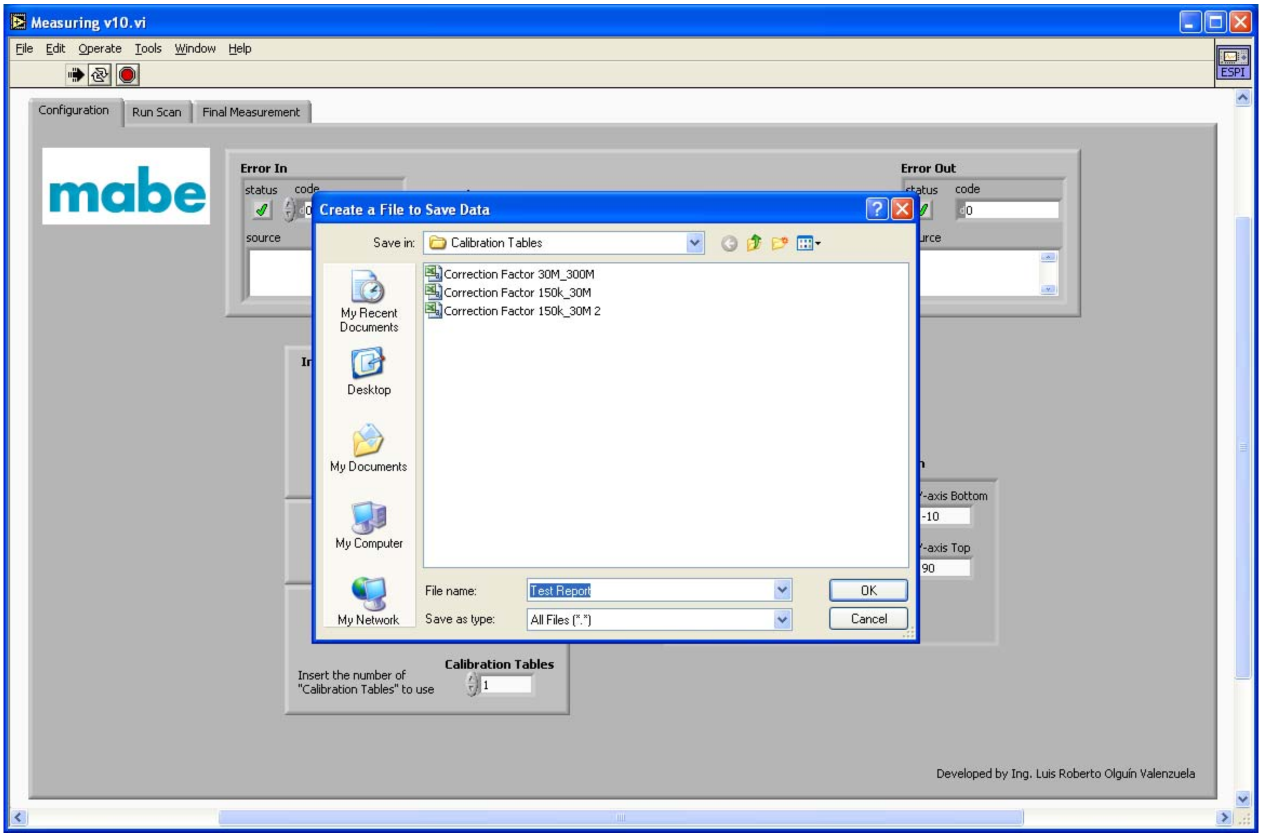

Figure 4.20: *File Creation*

Then the application “remembers” to the user to check the LISN connection (Figure 4.21). Following this, the location of the calibration table is asked for using another pop-up (Figure 4.22).

4.2.2 Run Scan screen

Once the calibration table is read by the application, the scan starts and the measurement results are plotted until all data has been acquired and added to the level values of the calibration table. The measurement data is plotted together with the limit lines (Figure 4.23 and Figure 4.24).

Figure 4.23 shows the obtained data where the peaks are generated every 50 kHz according to the 50 kHz step option of the comb generator and Figure 4.24 shows the obtained data using the 250 kHz step option.

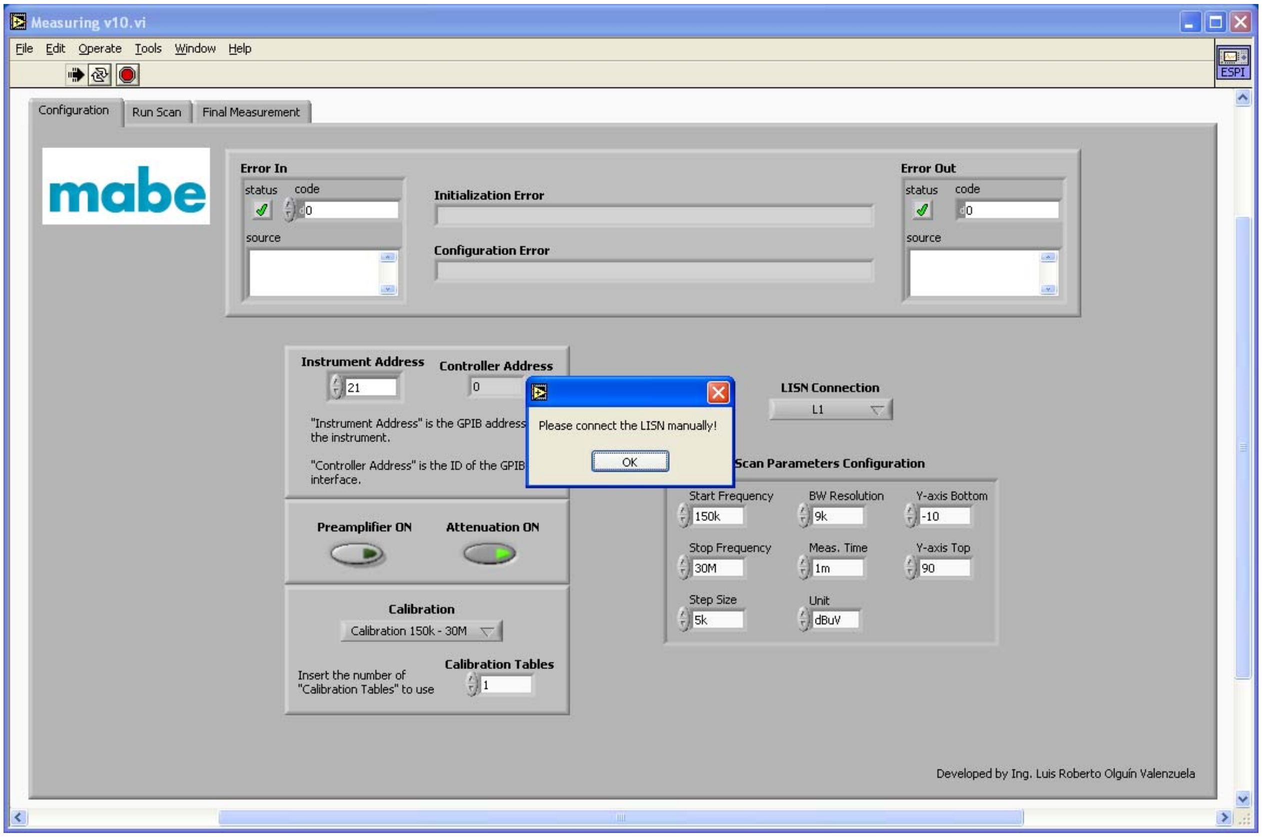

Figure 4.21: *Check LISN Connection*

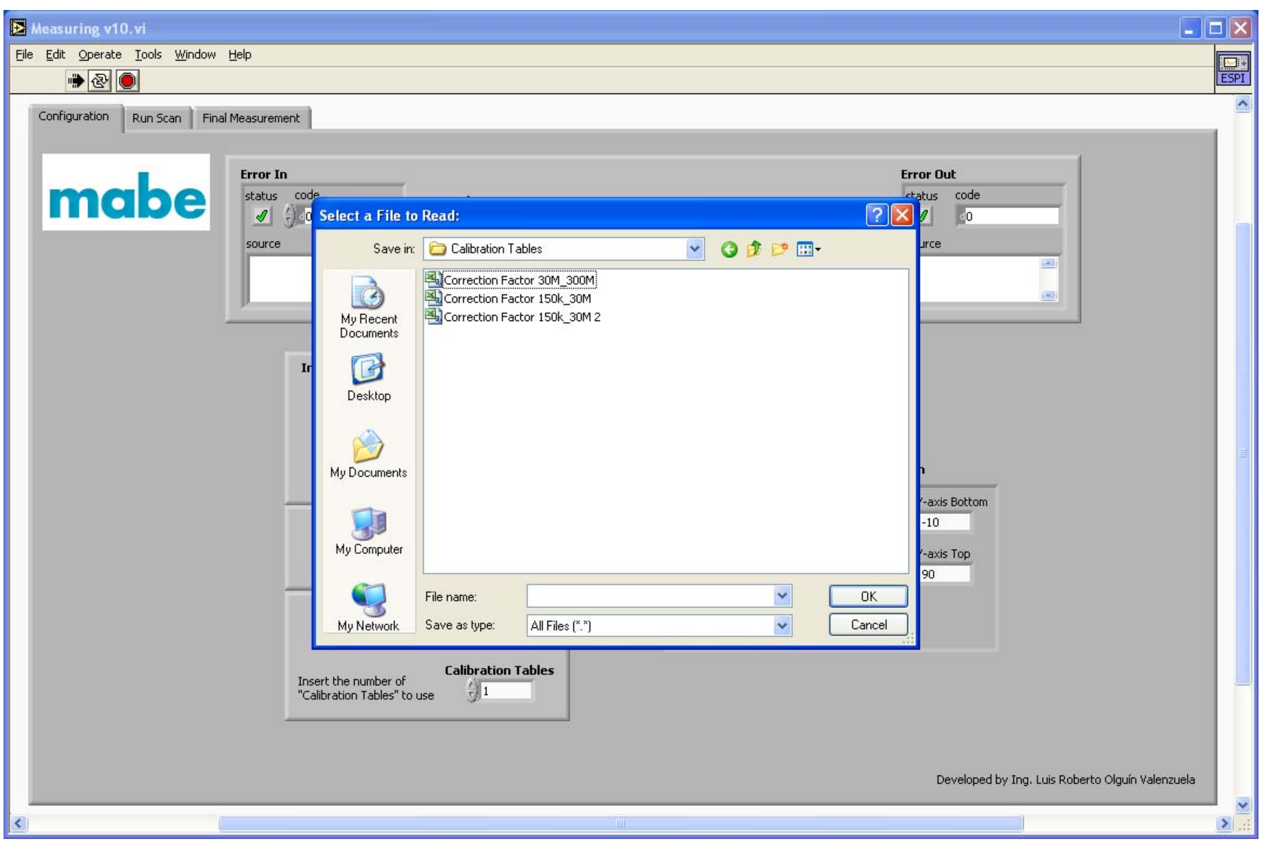

Figure 4.22: *Calibration Table*

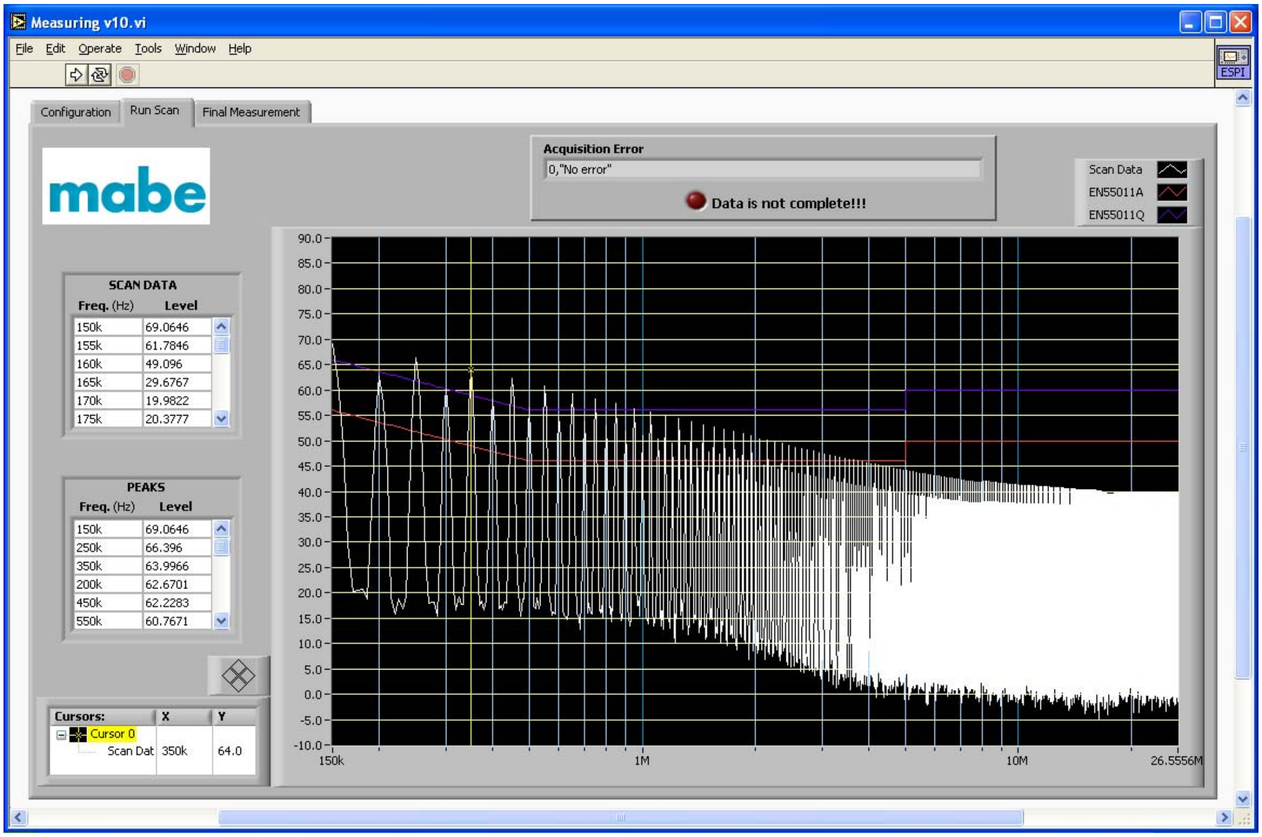

Figure 4.23: *Scan Measurement (50 kHz step option)*

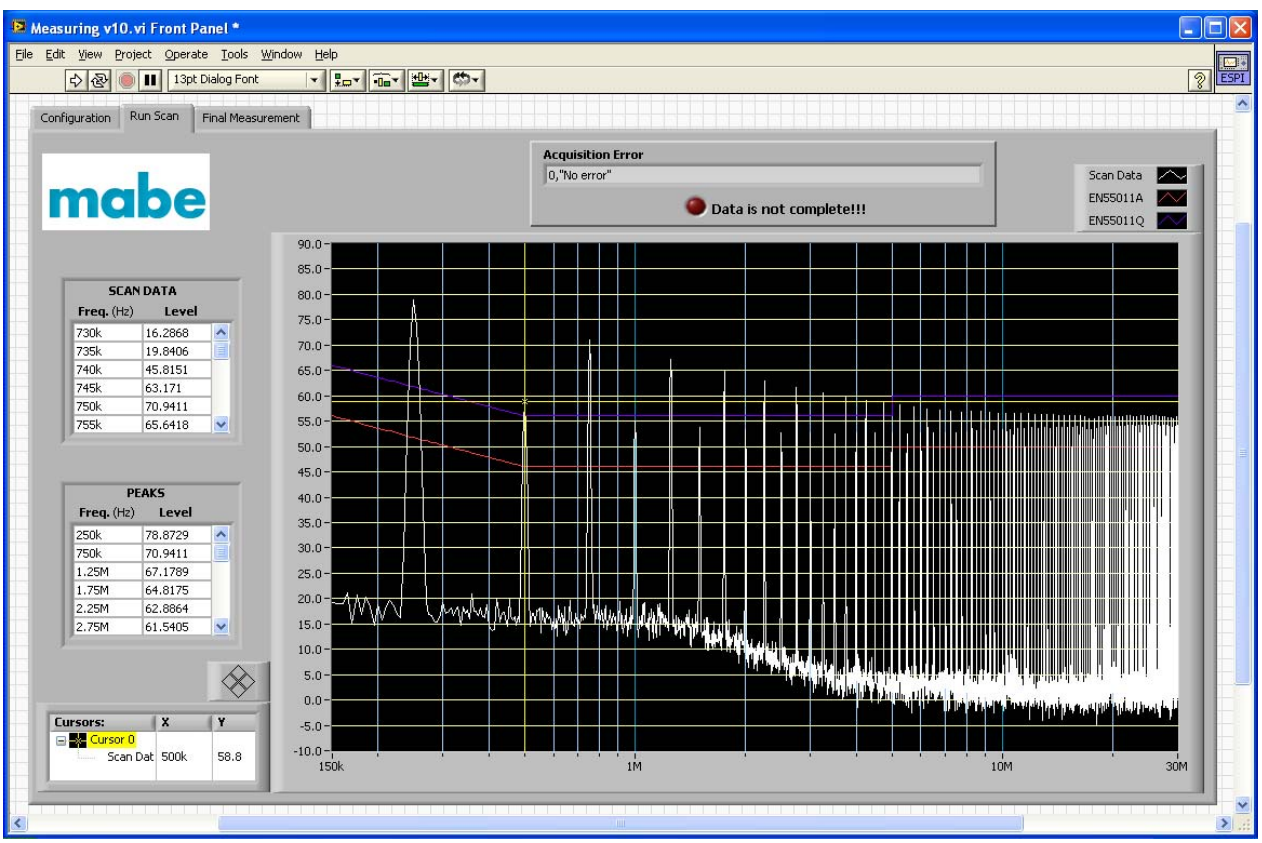

Figure 4.24: *Scan Measurement (250 kHz step option)*

The Run Scan screen shows in the "Scan Data" field all the acquired data, that is, the 5971 level values with their frequencies and in the "Peaks" field shows the peak values and the frequency values at which they were localized.

The user can localize also the peak frequency using a cursor. The X-axis and Y-axis values are shown in the "Cursors" field.

4.2.3 Final Measurement screen

In the Final Measurement screen the user "writes" the frequency values of the peaks that he wants to analyze. After entering the peaks frequencies and setting the final measurement time, the user should run the final scan using the button "Run Final Meas". After doing this, the final scan starts for the first frequency value that is written, and then it will continue with the next values. The final scan loop finishes when it does not find more frequency values in the "Peak Freq" vector.

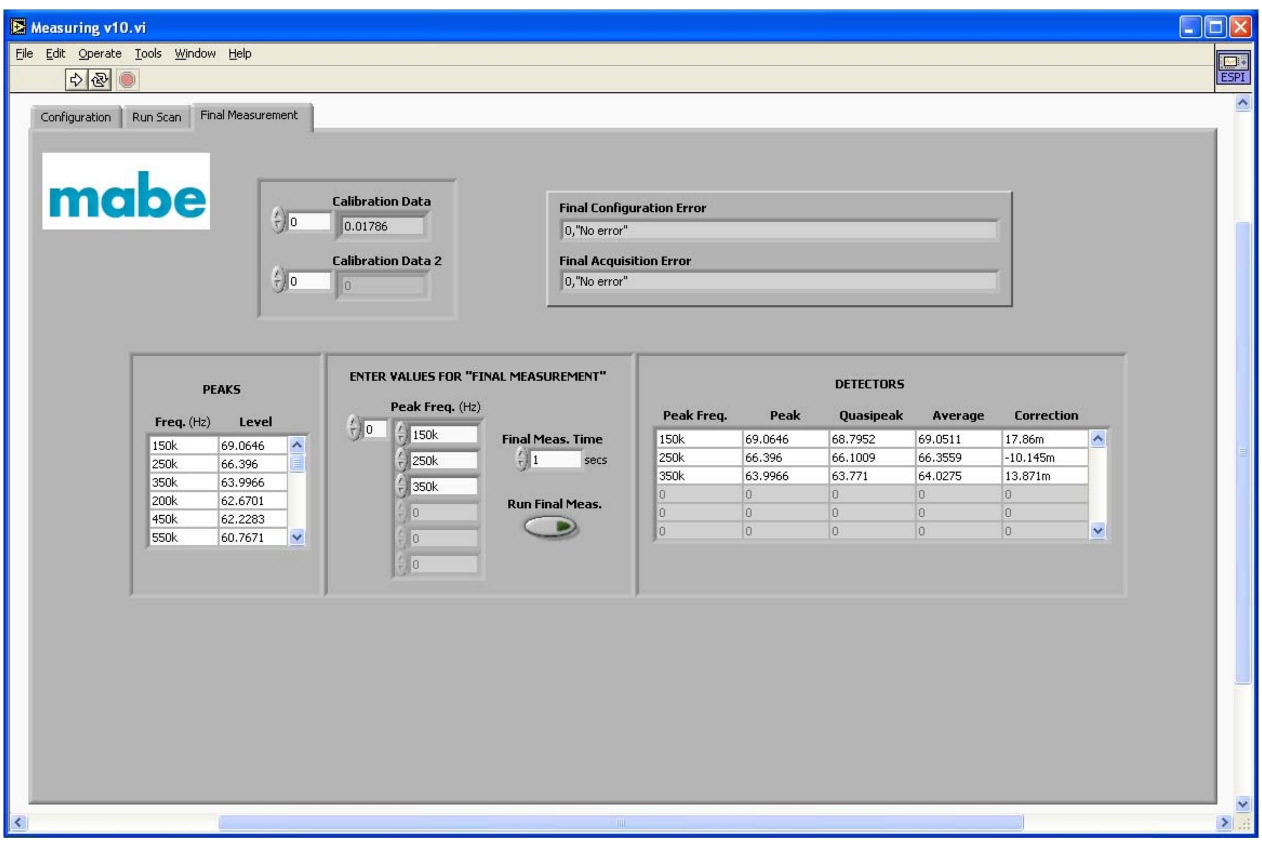

Figure 4.25: *Final Measurement (50 kHz step option)*

In the “Detectors” field are shown the results for the quasipeak and average detectors of the chosen peaks and also the correction values for the peak frequencies. This data with the setting parameters are exported to the Excel file.

In Figures 4.25 and 4.26 are shown the Final Measurement screens for the two options of the comb generator.

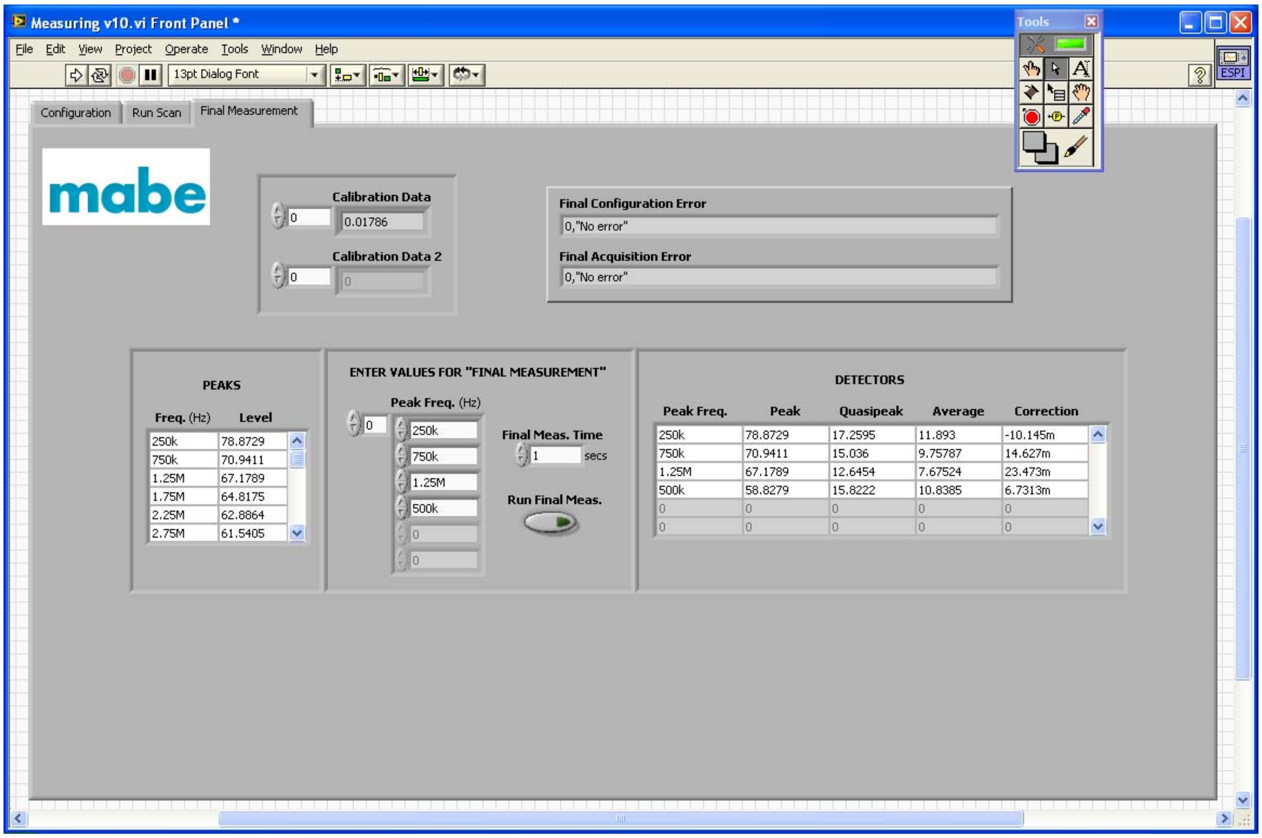

Figure 4.26: *Final Measurement (250 kHz step option)*

4.2.4 Data exported to the Excel File

In Tables 4.1, 4.2, and 4.3 is shown the data that is exported to the Excel file. In Table 4.1 are shown the setting parameters for the EMI test.

In Table 4.2 are shown the results obtained for the 50 kHz option of the comb generator, and in Table 4.3 are shown the results obtained for the 250 kHz option of the comb generator.

LEVEL UNIT	START FREQ. (Hz)	STOP FREQ. (Hz)	BW RES (Hz)	MEAS. TIME (s)	STEP SIZE (Hz)
dBuV	150000	30000000	9000	0.001	5000

Table 4.1: *Setting Parameters*

FREQ (Hz)	PEAK (dBuV)	QUASIPEAK (dBuV)	AVERAGE (dBuV)	CORRECTION (dB)
150000	68.372	68.3266	68.5211	0.0179
350000	63.3184	63.0329	63.2431	0.0139
250000	65.5186	65.4983	65.7092	-0.0101

Table 4.2: *Final Measurement Results (50 kHz step option)*

FINAL MEAS. TIME (s)	BANDWIDTH (Hz)	LINE	PE
1	9000	L1	GND
1	9000	L1	GND
1	9000	L1	GND

Table 4.2 (cont.): *Final Measurement Results (50 kHz step option)*

FREQ (Hz)	PEAK (dBuV)	QUASIPEAK (dBuV)	AVERAGE (dBuV)	CORRECTION (dB)
250000	78.2334	78.0269	78.2347	-0.0101
750000	70.4865	70.0134	70.223	0.0146
1250000	66.2281	66.1905	66.4044	0.0235
500000	57.9776	57.7521	57.9968	0.0067

Table 4.3: *Final Measurement Results (250 kHz step option)*

FINAL MEAS. TIME (s)	BANDWIDTH (Hz)	LINE	PE
1	9000	L1	GND
1	9000	L1	GND
1	9000	L1	GND
1	9000	L1	GND

Tables 4.3 (cont.): *Final Measurement Results (250 kHz step option)*

4.2.5 Comparison between EMC32 and EMI application

In Figures 4.27 and 4.28 and Tables 4.4 and 4.5 are shown the results obtained using the EMC32 software. As it can be seen in Tables 4.6 and 4.7, the results obtained with the EMI application developed in this project are correct due to the quasipeak and average values of the selected frequencies correspond to the results obtained with the EMC32 for the same detectors.

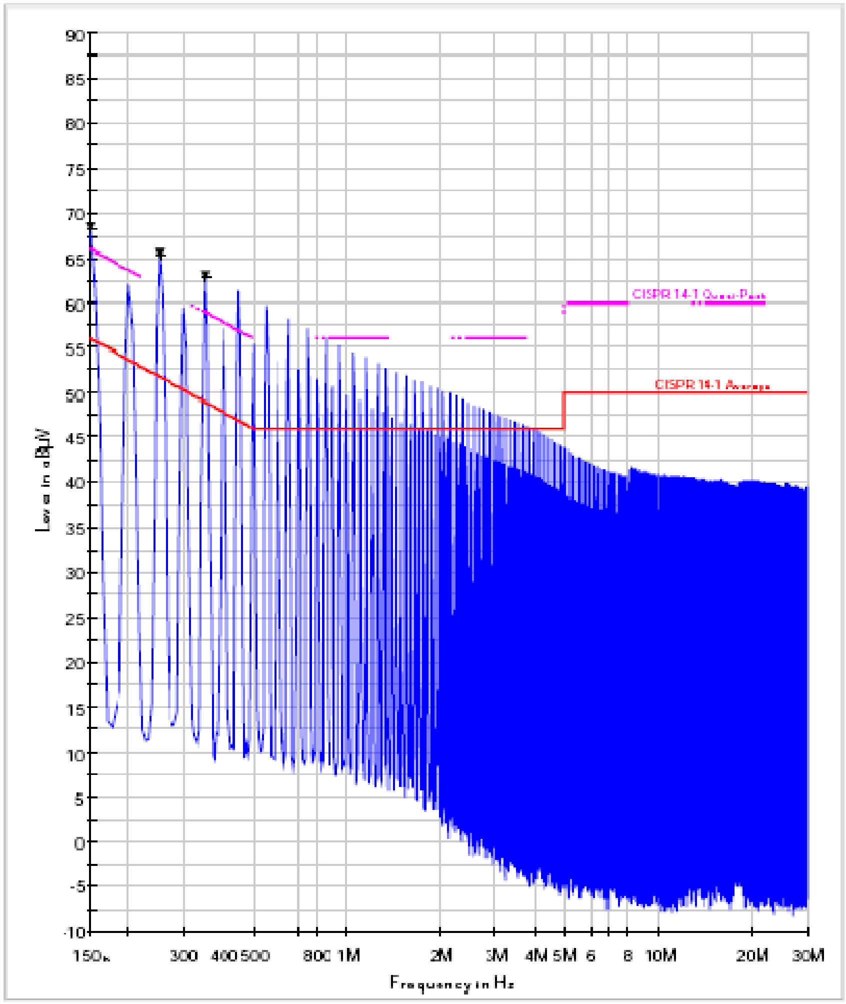

Figure 4.27: *Scan Measurement with EMC32 (50 kHz step option)*

Frequency (MHz)	QuasiPeak (dBµV)	Average (dBµV)
0.150000	63.3	68.5
0.350000	62.9	63.2
0.250000	65.4	65.6

Table 4.4: *EMC32 Results for Quasipeak and average detectors (50 kHz step option)*

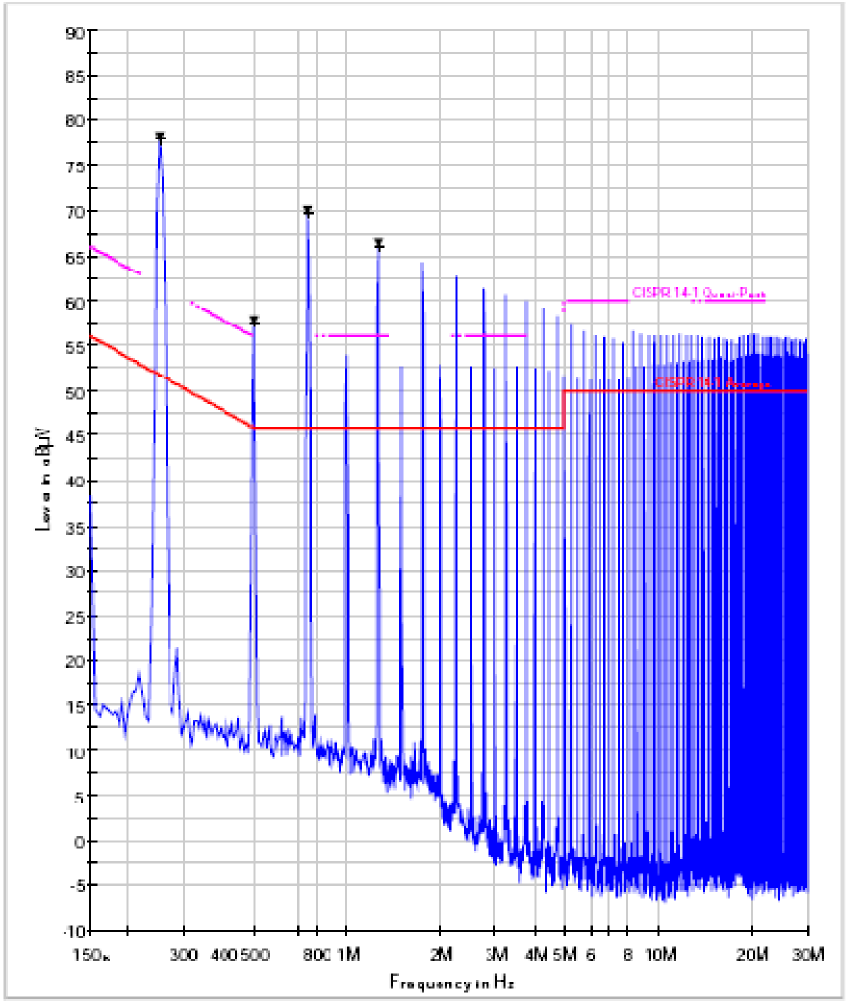

Figure 4.28: *Scan Measurement with EMC32 (250 kHz step option)*

Frequency (MHz)	QuasiPeak (dBµV)	Average (dBµV)
0.250000	77.9	78.1
0.750000	69.9	70.1
1.250000	66.1	66.3
0.500000	57.7	57.9

Table 4.5: *EMC32 Results for Quasipeak and average detectors (250 kHz step option)*

Frequency (kHz)	Quasipeak (dBuV) EMC32	Quasipeak (dBuV) EMI Application	Average (dBuV) EMC32	Average (dBuV) EMI Application
150	68.3	68.3266	68.5	68.5211
350	62.9	63.0329	63.2	63.2431
250	65.4	65.4983	65.6	65.7092

Table 4.6: *Comparison between EMC32 and EMI Application Results (50 kHz step option)*

Frequency (kHz)	Quasipeak (dBuV) EMC32	Quasipeak (dBuV) EMI Application	Average (dBuV) EMC32	Average (dBuV) EMI Application
250	77.9	78.0269	78.1	78.2347
750	69.9	70.0134	70.1	70.223
1250	66.1	66.1905	66.3	66.4044
500	57.7	57.7521	57.9	57.9968

Table 4.7: *Comparison between EMC32 and EMI Application Results (250 kHz step option)*

4.3 EMS APPLICATION: SUB-VIs

4.3.1 Amplifier initialization sub-VI

The amplifier initialization is done using the Power IAR and Reset IAR sub-VIs. Their front panels are shown in Figures 4.29 and 4.30. Since in Reset IAR is sent only a command, it only has a numeric control for setting the address and the Power IAR has the same numeric control and a push button for turning on and off the amplifier.

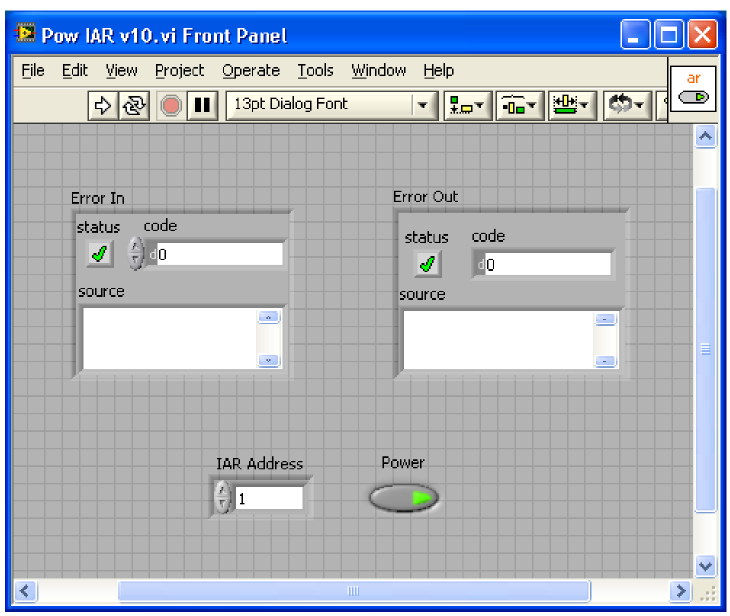

Figure 4.29: *Power IAR sub-VI*

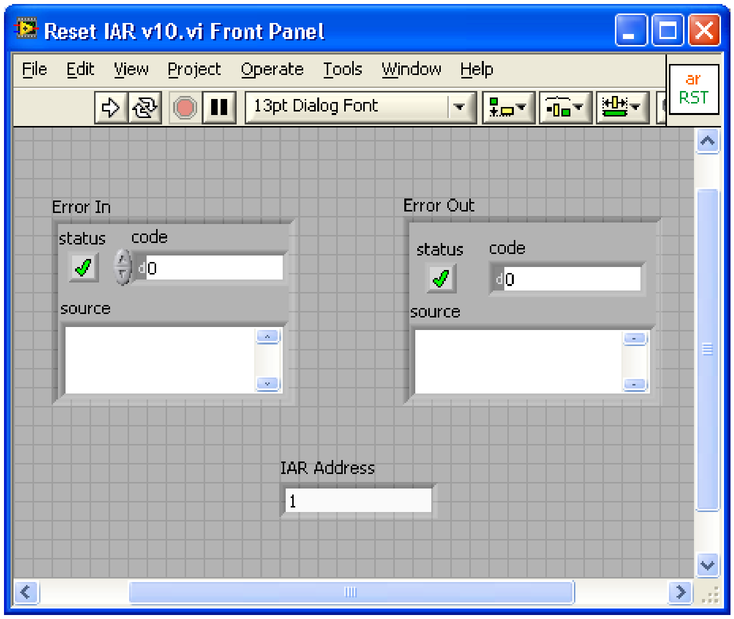

Figure 4.30: *Reset IAR sub-VI*

4.3.2 Signal generator initialization sub-VI

As it was mentioned in the Procedure chapter, the Initialization sub-VI developed for the ESPI was used for the initialization of the SMT signal generator.

In Figure 4.31 is shown how the communication between the SMT and the PC was established without problems because the “Read Data” field shows the instrumentation identification and their options and the “Initialization Error” field indicates that No error occurred during the program execution.

The answer to the IDN query is as follows:
28= Address
SMT03 = Device name
100429/003 = Serial number of the instrument
4.66 = Firmware version number

The options that the SMT includes according to the obtained answer are: LF generator for sine, triangle and square waves (SM-B2), and pulse modulation (SM-B4 and SM-B8).

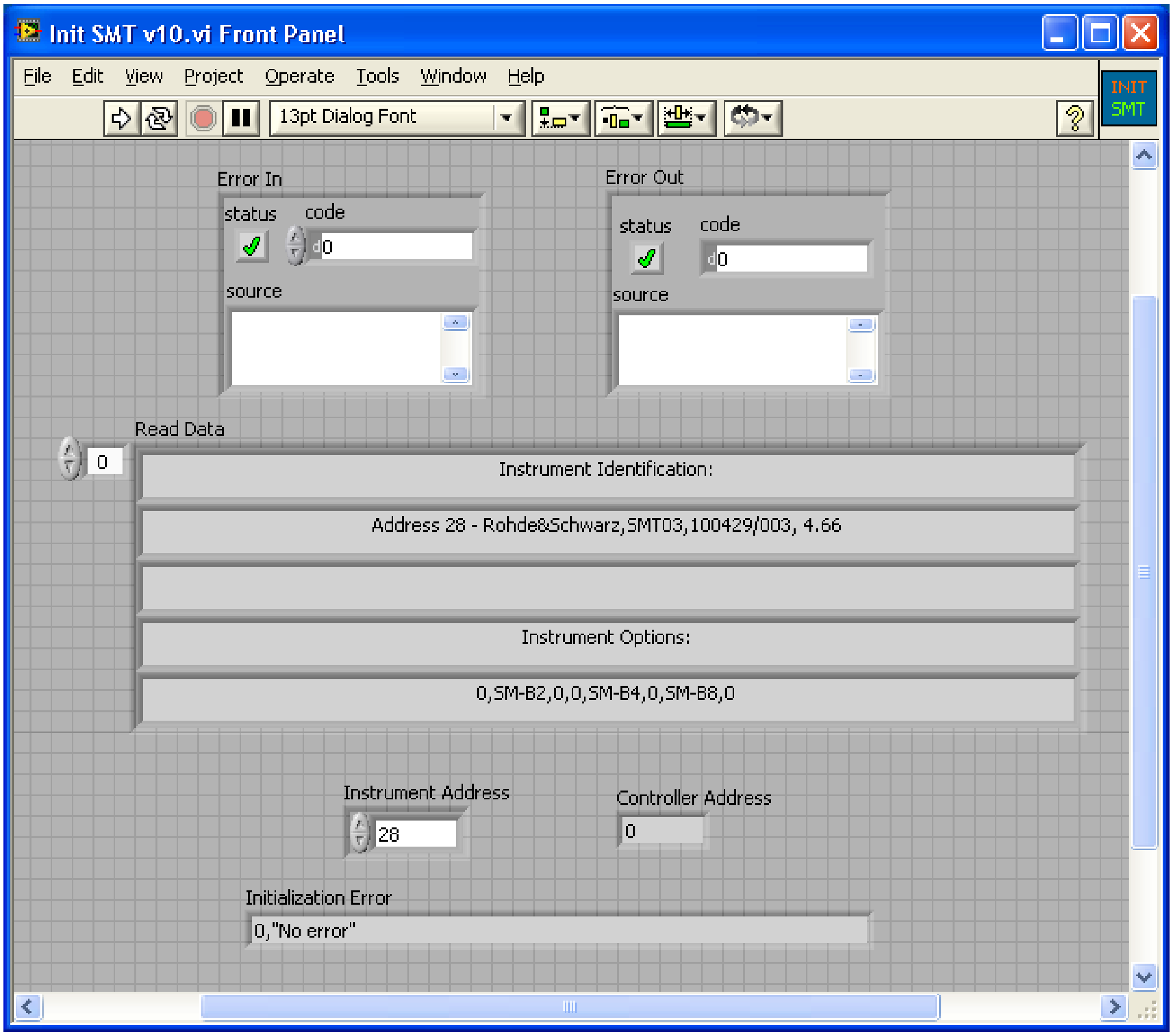

Figure 4.31: *SMT Initialization sub-VI*

4.3.3 Power meter initialization sub-VI

Once again the ESPI initialization sub-VI was used successfully but now for the NRVD power meter. For this instrument the option identification query was changed by the “INP1|2:SENS:INFO?” query. Thus in the “Read Data” field is indicated the type of sensors that are connected to the NRVD as is shown in Figure 4.32.

The answer to the information query for input 1 contains the next data:

1 = Status: sensor connected

1 = Channel A (2 = Channel B)

URV5-Z2 / 50 = Designation of sensor

0395.1019.02 = R&S stock no.

100607/722 = Serial number

ME1B = Calibration center

23.05.05 = Data of calibration

The answer to the identification query was:

20 = Address

NRVD = Device name

101262.002 = Serial number of the instrument

V1.52 V1.40 = Firmware version number

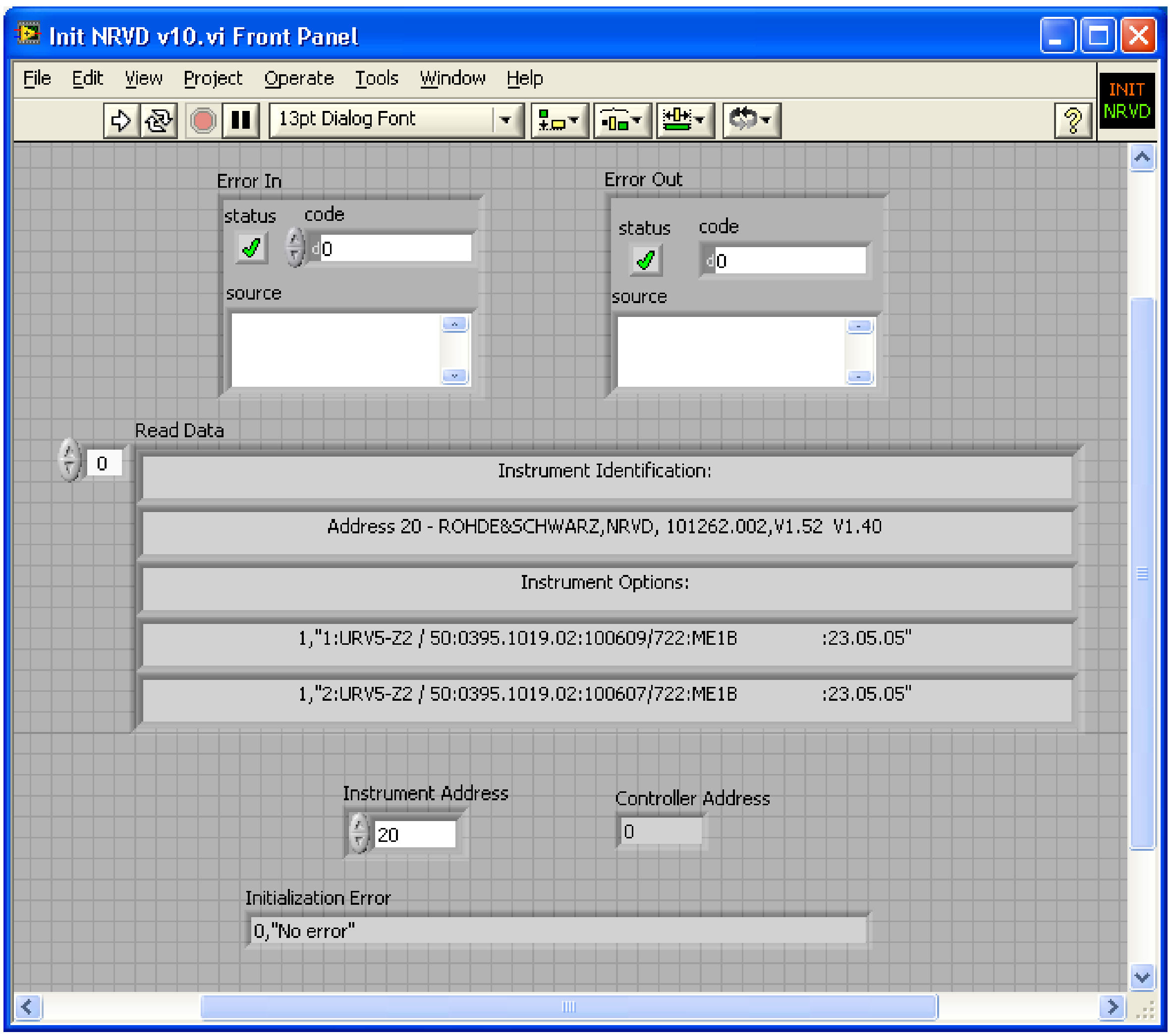

Figure 4.32: *NRVD Initialization sub-VI*

4.3.4 Signal generator configuration sub-VI

The EMS application handles two sub-VIs for setting the signal generator parameters according to the test selection, one sub-VI is for DM test and the other one is for KI. Although different commands are used for setting the necessary parameters for both modulations, the front panel is the same for each sub-VI as it can be seen in Figure 4.33 and Figure 4.34.

In both front panels are shown only the attenuator level indicators and the error status. Since the level value in these sub-VIs is set to -100 dBm, the low and upp attenuator levels are set automatically by the SMT to -110 dBm and -87 dBm.

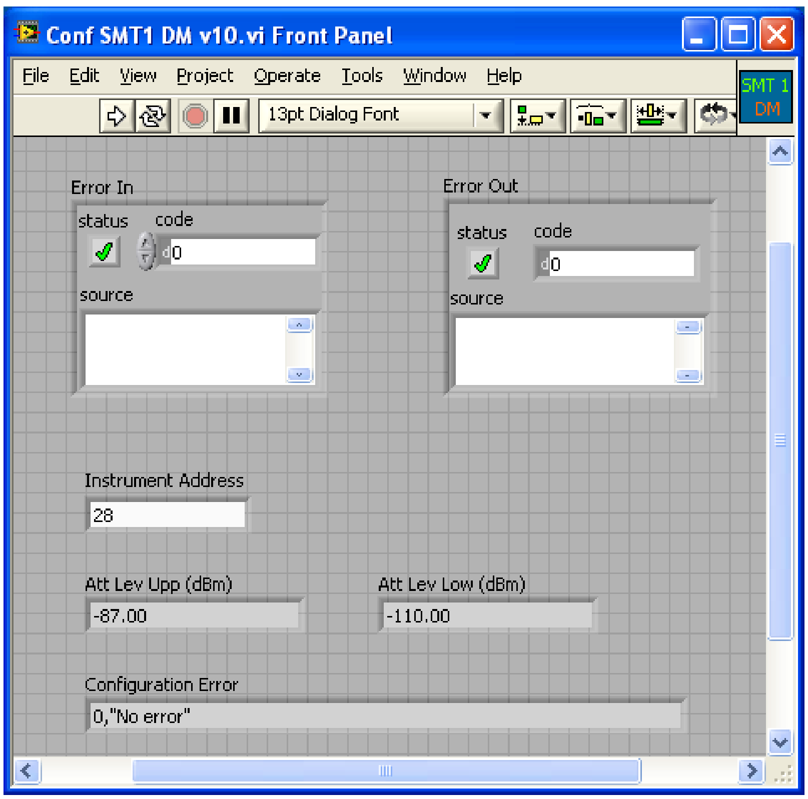

Figure 4.33: *SMT Configuration – DM sub-VI*

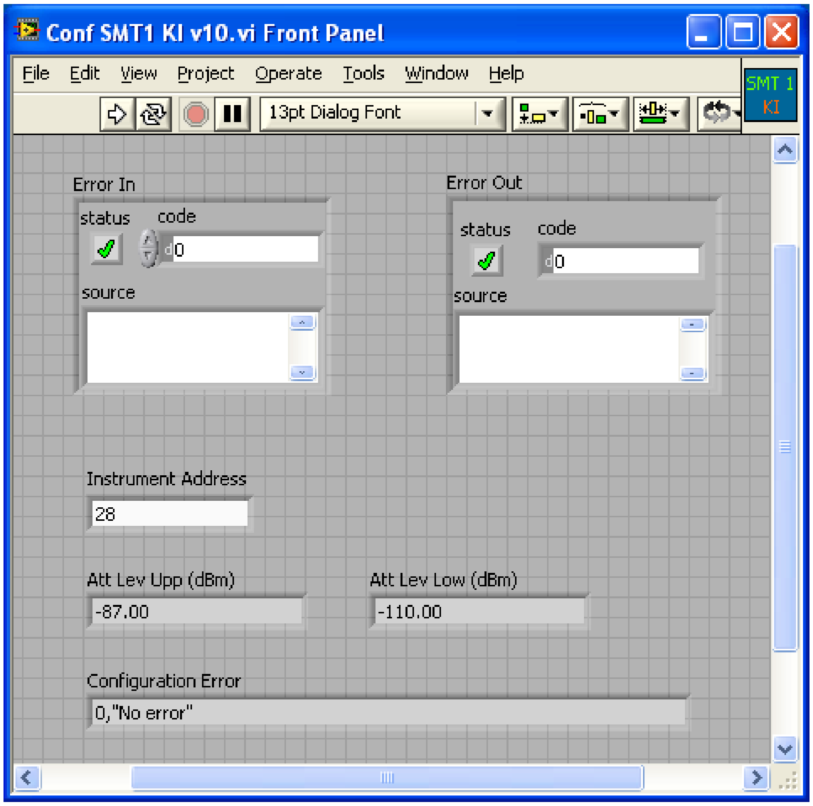

Figure 4.34: *SMT Configuration – KI sub-VI*

4.3.5 Power meter configuration sub-VI

In the front panel of the NRVD configuration sub-VI is checked the sensors status, that is, if the URV5-Z2 heads are connected to the power meter. The answer to the “:INP1:SENS?” and “:INP2:SENS?” queries is 1, as is shown in Figure 4.35, so the sensors are connected.

Also in this sub-VI, as in the previous ones, is checked if an error occurs during the configuration. Here can be seen that no error occurred in the filter and units setting.

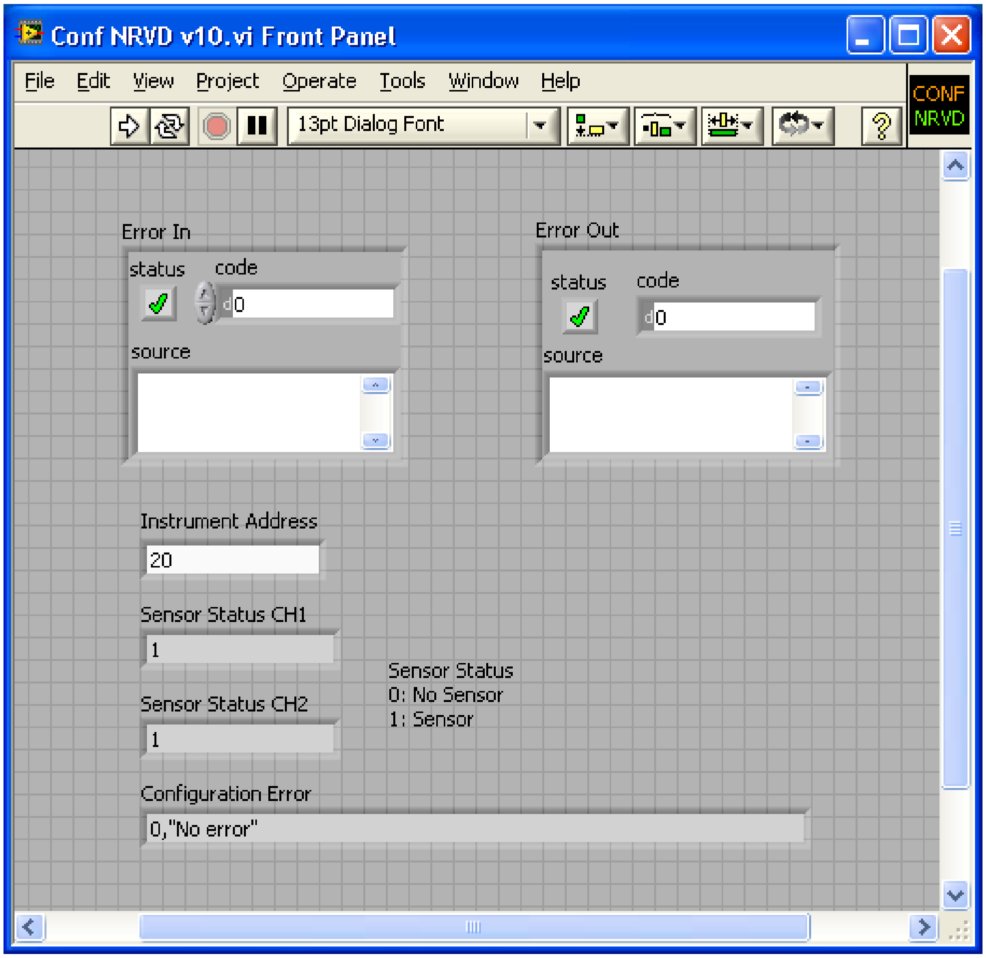

Figure 4.35: *NRVD Configuration sub-VI*

4.3.6 Amplifier operation sub-VIs

Once the SMT and NRVD are initialized and set, the amplifier gain is selected and then the amplifier is changed from standby mode to operation mode. For doing this, the Gain IAR and Operate IAR sub-VIs are used.

In the Gain IAR sub-VI, shown in Figure 4.36, the evaluation engineer sets the amplifier gain using the numeric controls “Gain 4 to Gain 1”. To confirm that the command for setting the gain was received correctly by the amplifier, the gain is queried. For doing this, the Query IAR sub-VI has a control menu to choose between two queries, gain and identification. In Figure 4.37 can be seen that the selected option was Identification and the answer obtained is “G4095” which is shown in the “Read Data” field.

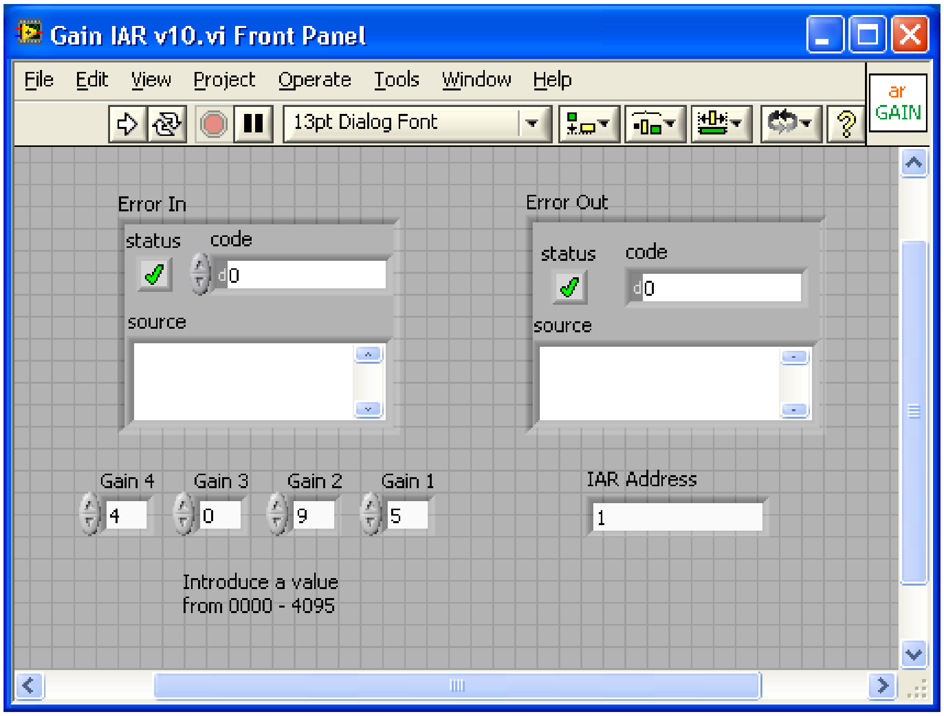

Figure 4.36: *Gain IAR sub-VI*

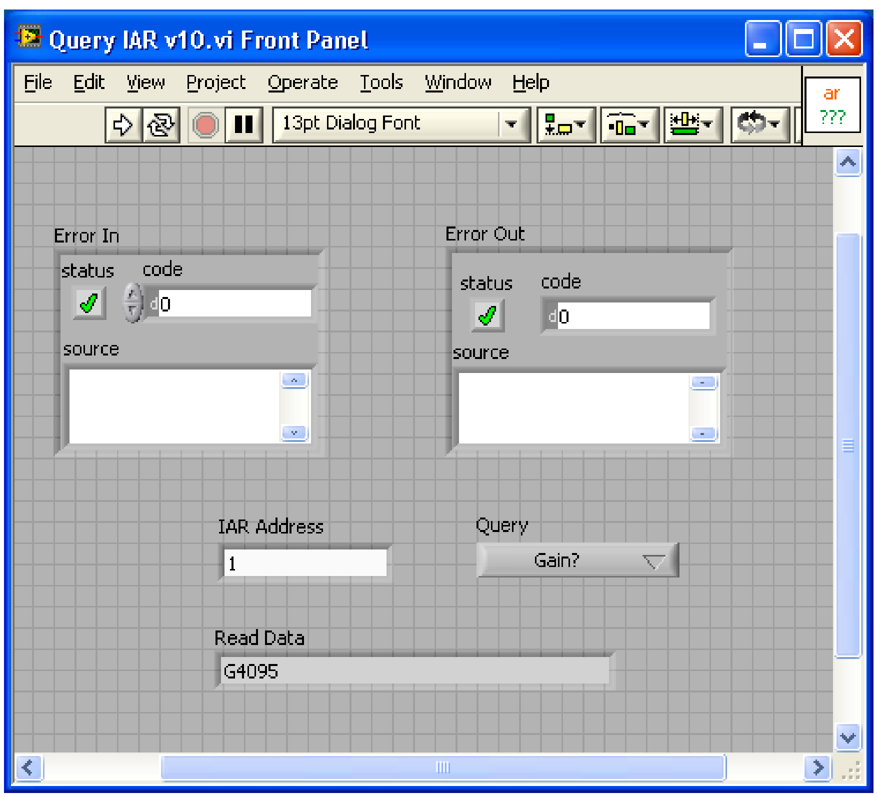

Figure 4.37: *Query IAR sub-VI*

In the Operation IAR sub-VI is sent only one command, so the user only has to run it after setting the address in order to operate the amplifier (Figure 4.38).

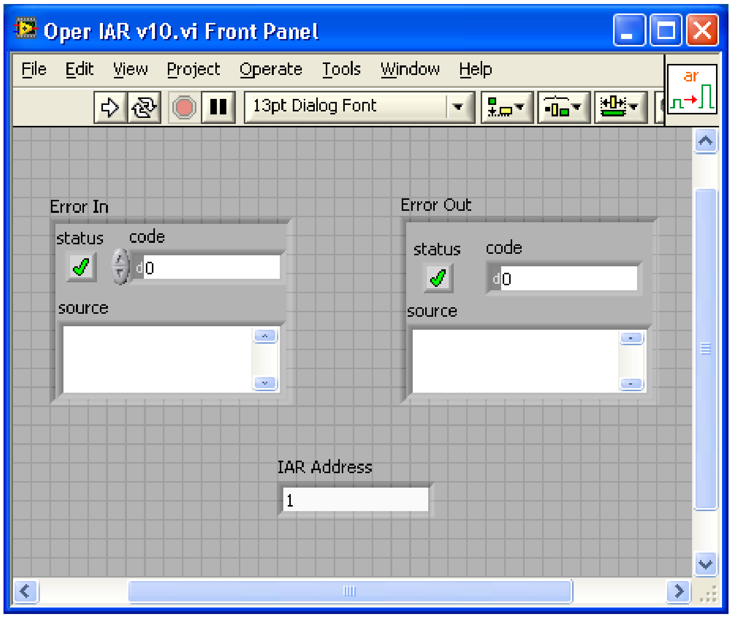

Figure 4.38: *Operation IAR sub-VI*

4.3.7 Power measurement sub-VI

Every time that the user runs this sub-VI, the NRVD starts the measurement in both inputs. In Figure 4.39 can be seen that the value obtained for channel A is higher than the value for B, so the antenna is connected.

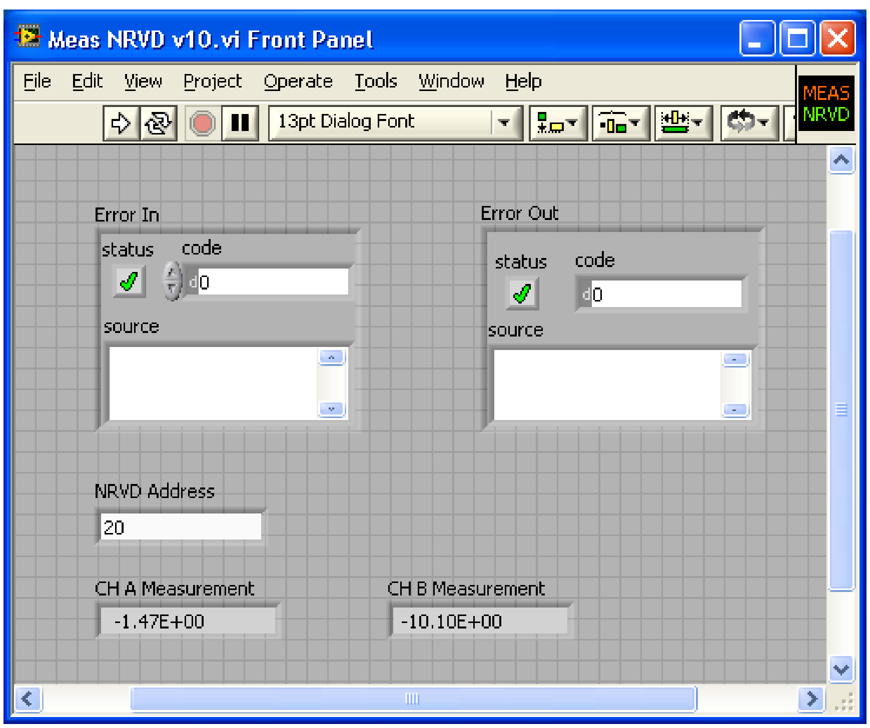

Figure 4.39: *NRVD Measurement sub-VI*

4.3.8 Read calibration sub-VIs

In Figure 4.40 can be seen the pop-up that appears when the Read Calibration and Polarity sub-VI is activated. There, the evaluation engineer selects the calibration table according to the test. After choosing the calibration table, the sub-VI scans the path where the calibration table is located and looks for the words KI or DM and Vertical or Horizontal depending on the test.

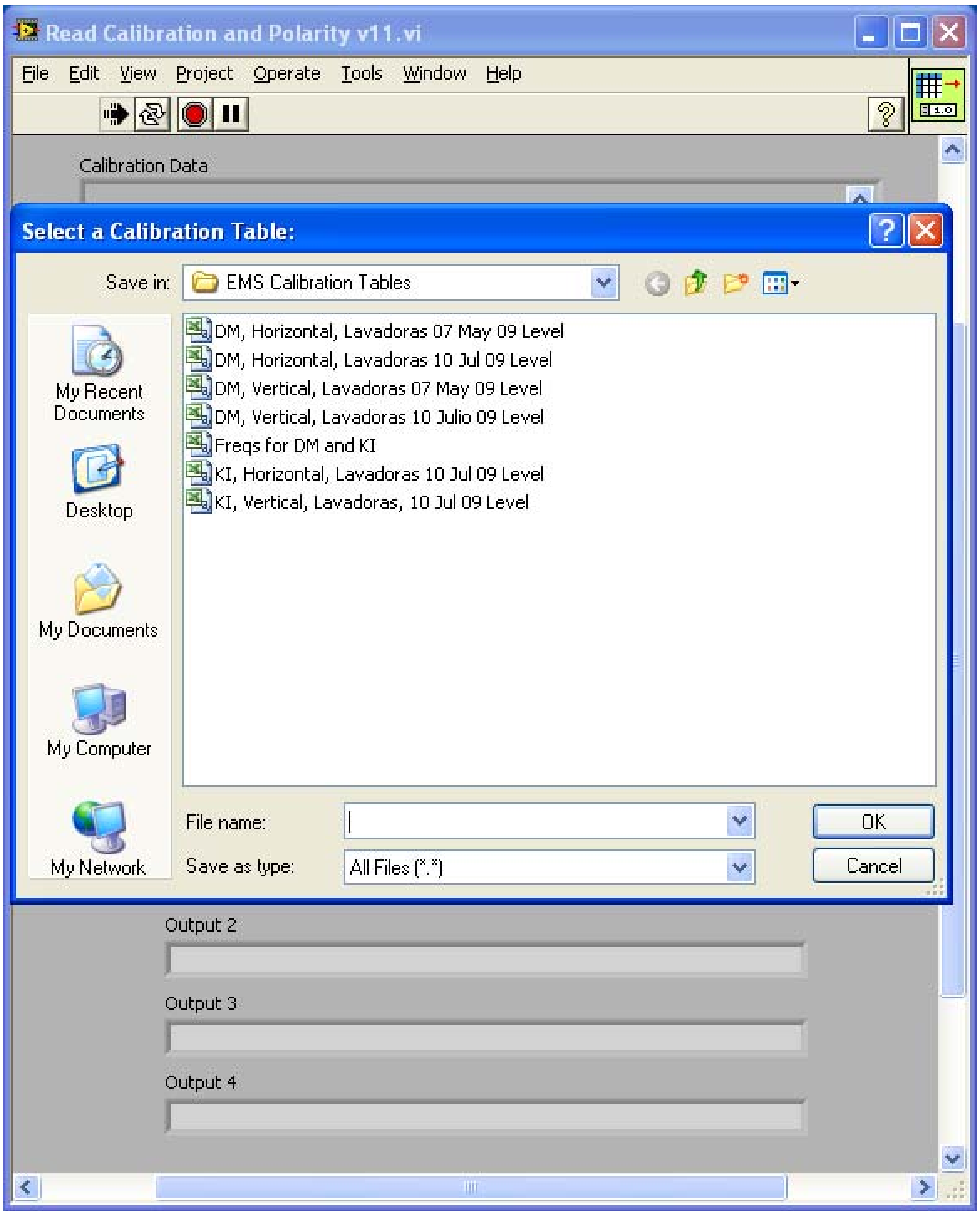

Figure 4.40: *Read Calibration and Polarity sub-VI (pop-up)*

In this case, it was chosen a KI test with vertical polarization for the antenna using the buttons located in the front panel. The “Path” field shows that the file that the user selects is for DM, Vertical, so the selection does not agree with the file and an error message appears to notice about that to the user as is shown in Figure 4.41.

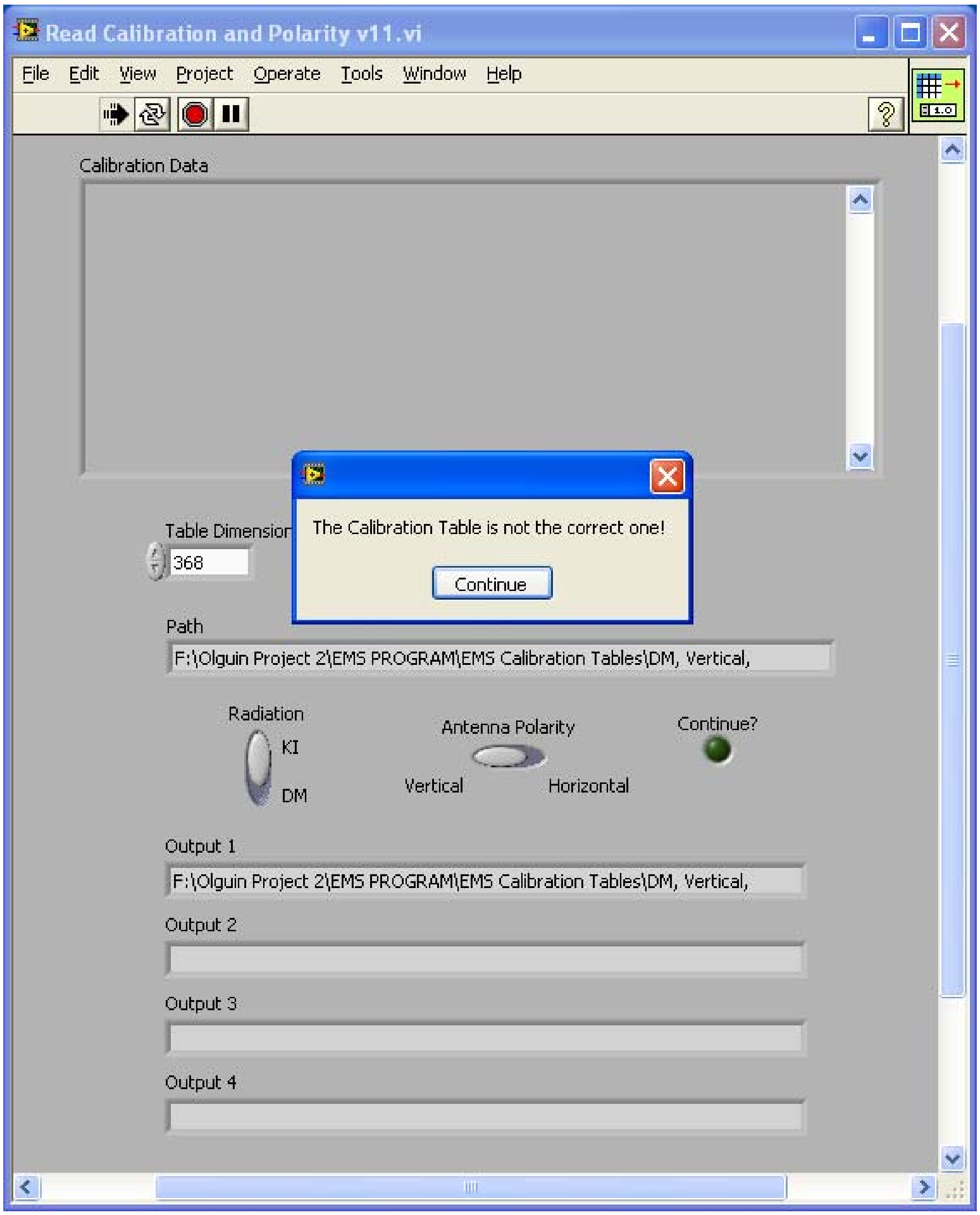

Figure 4.41: *Read Calibration and Polarity sub-VI (Test Error)*

In Figure 4.42 can be seen now that the selected file is for KI as is shown in the "Output 1" field, but the polarization is not the correct, so another error message appears on the screen.

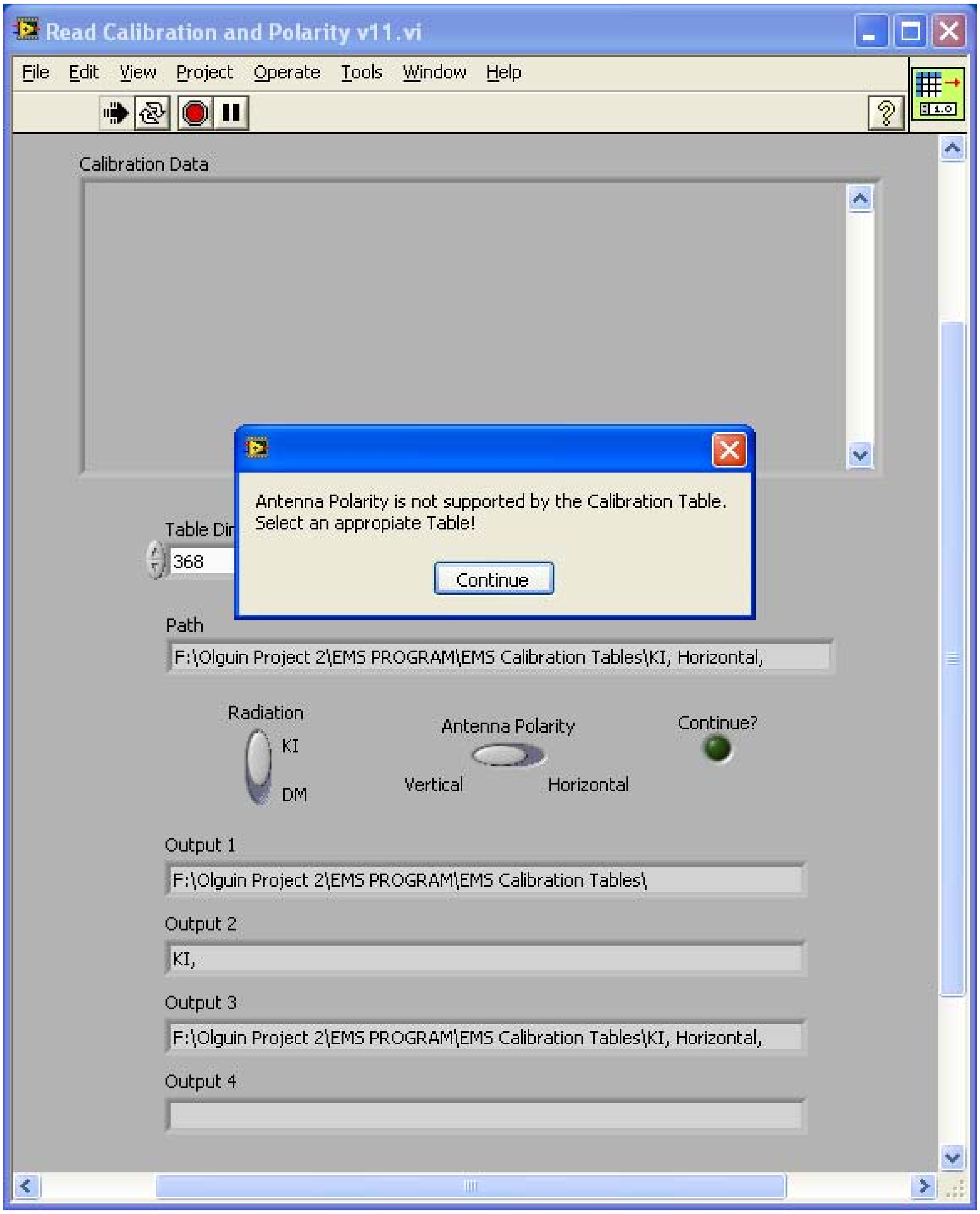

Figure 4.42: *Read Calibration and Polarity sub-VI (Polarization Error)*

Finally in Figure 4.43 is shown in the "Path" field the location for a DM, Horizontal file which agrees with the test selection indicated by the buttons in the front panel. In fields

"Output 1" to "Output 4", which are the "Scan from String" outputs, are shown the key words that this function looks for in order to assure that the read file is the correct one. In this figure is also shown the read data as a string and as a vector.

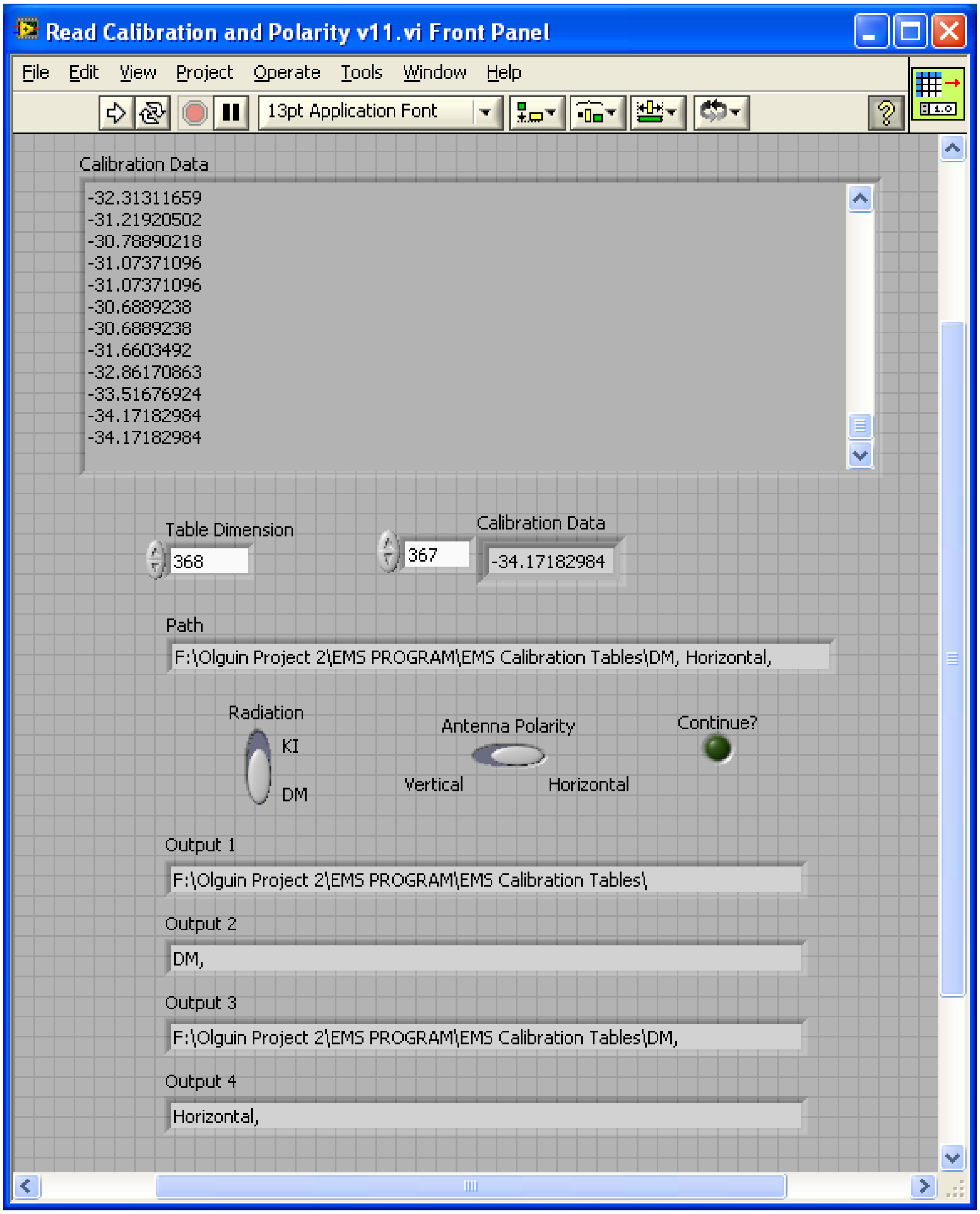

***Figure 4.43:** Read Calibration and Polarity sub-VI*

In Figure 4.44 is shown the sub-VI that reads the frequency values. As it was explained in the Procedure, the Read from File sub-VI developed for the EMI application was used, but the only difference between them is that in this sub-VI the path is written in the front panel before running the program.

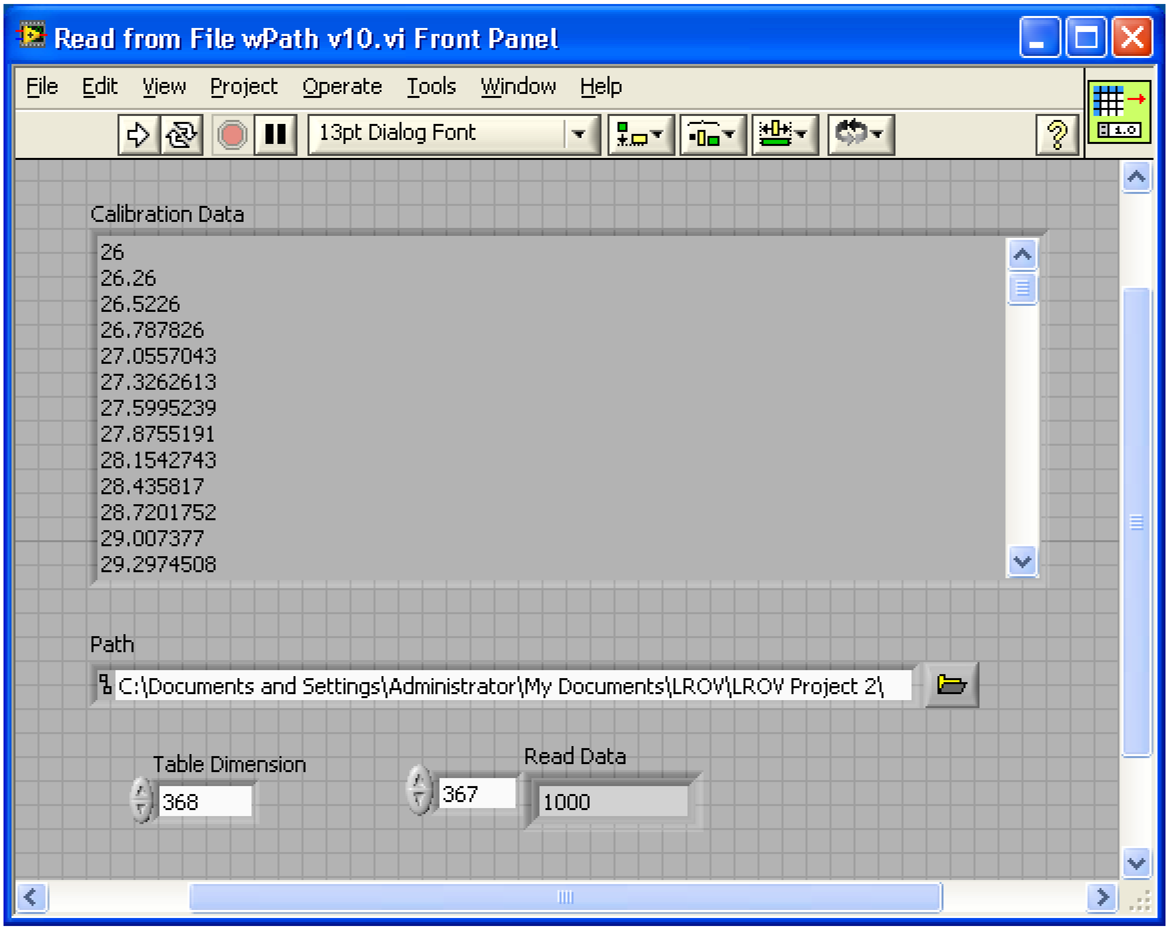

Figure 4.44: *Read from File with Path sub-VI*

4.3.9 DM and KI generation sub-VI

Once the calibration values are read and stored in a vector, the signal generator sub-VIs for DM or KI use this data for generating the disturbances. With the numeric controls “Freq” and “Level” the user can set manually the frequency and level, but in the EMS application this is done automatically using the frequency and level vectors. In the front panels of both sub-VIs is shown the power measurement for each channel of the NRVD.

The dwell time is set also in these sub-VIs as is shown in Figures 4.45 and 4.46.

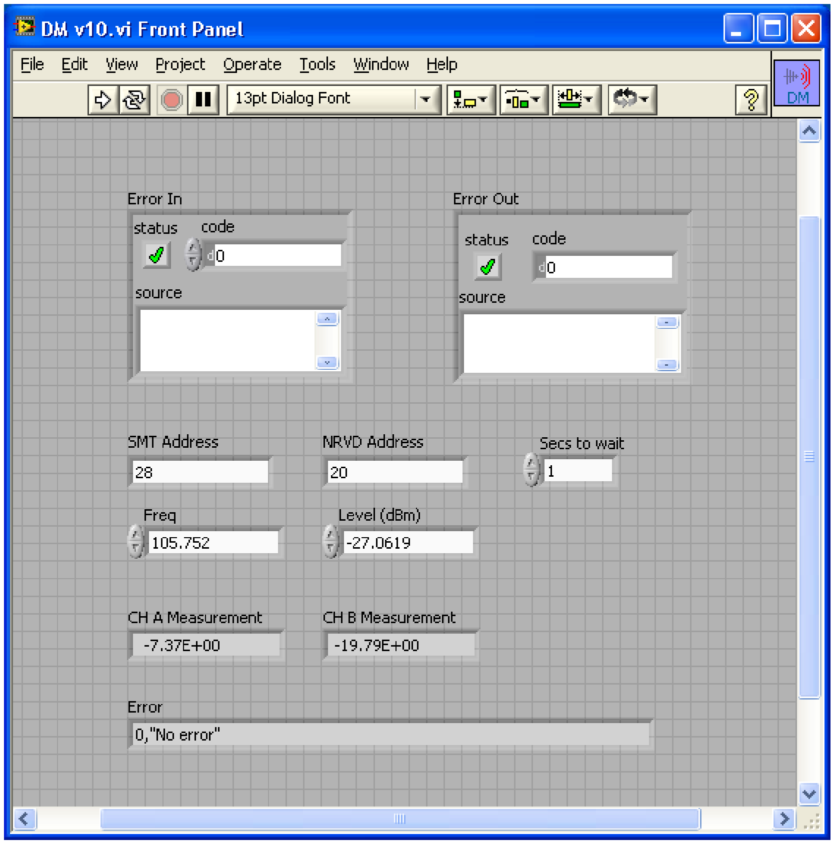

Figure 4.45: *DM Generation sub-VI*

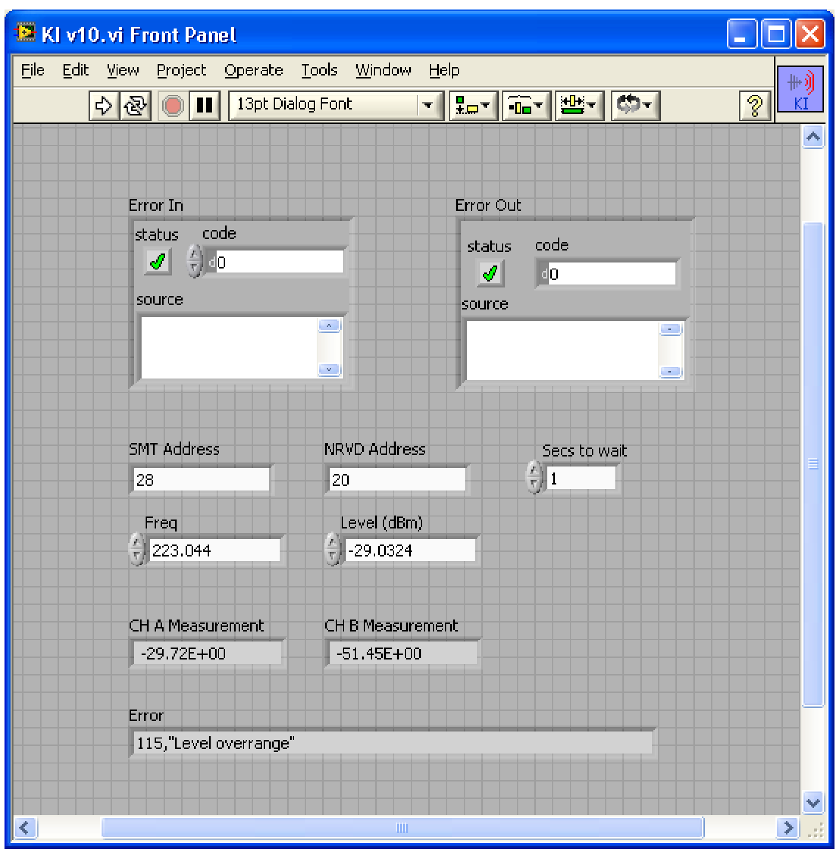

Figure 4.46: *KI Generation sub-VI*

In Figure 4.46 can be seen that an error occurred during the execution of the KI sub-VI. This error message means that the level sent to the SMT is under the attenuator low level set previously by the generator in the configuration step.

4.3.10 Frequency selection sub-VI

The Select Freq sub-VI is used when the application is stopped and the option for restarting in another frequency is selected. In Figure 4.47 is shown in the “Selected Frequency” field that the frequency that is going to be searched in the frequency vector is 100 MHz. After executing this program the frequency that was found is 100.619 MHz. In the Freq Vector can be seen that this the closest value to the selected.

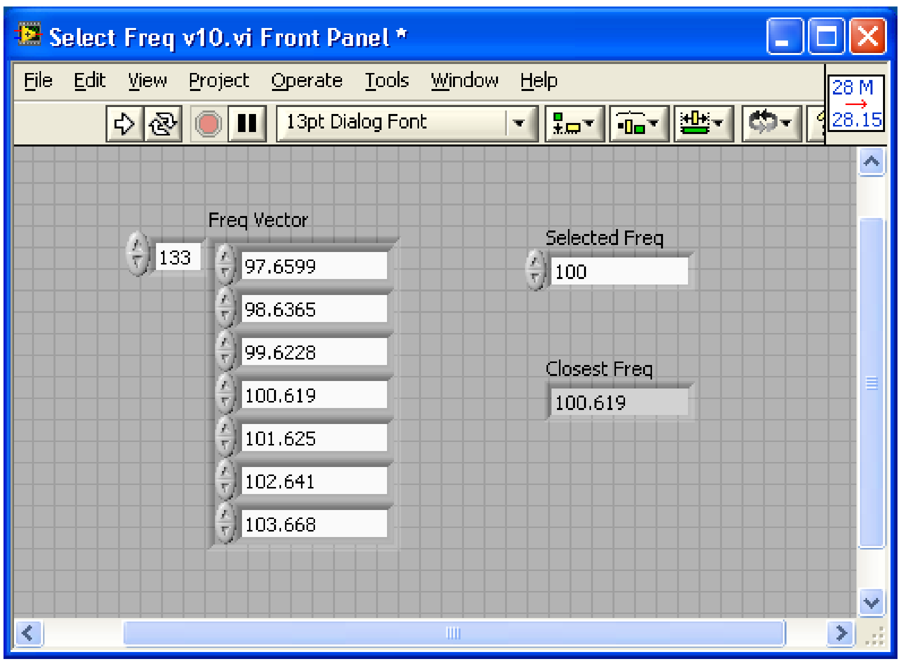

Figure 4.47: *Frequency Selection sub-VI*

4.4 EMS APPLICATION: USER INTERFACE

The user interface has two screens, the principal that is called Radiation, shown in Figure 4.48, where the radiation type is selected and the device addresses, dwell time and amplifier gain are set. The other one, shown in Figure 4.49, is called Error Window and there the errors, if they occur during the device initialization, configuration or generation, are shown.

The Radiation screen has the control menu to pause, stop or run the radiation, a numeric control to choose the frequency where the radiation will continue after stopping it, a string control where the evaluation engineer can write a comment when the radiation is paused, another string control for writing the path where the frequency file is, and finally a button to finish the test at any time that the user considers.

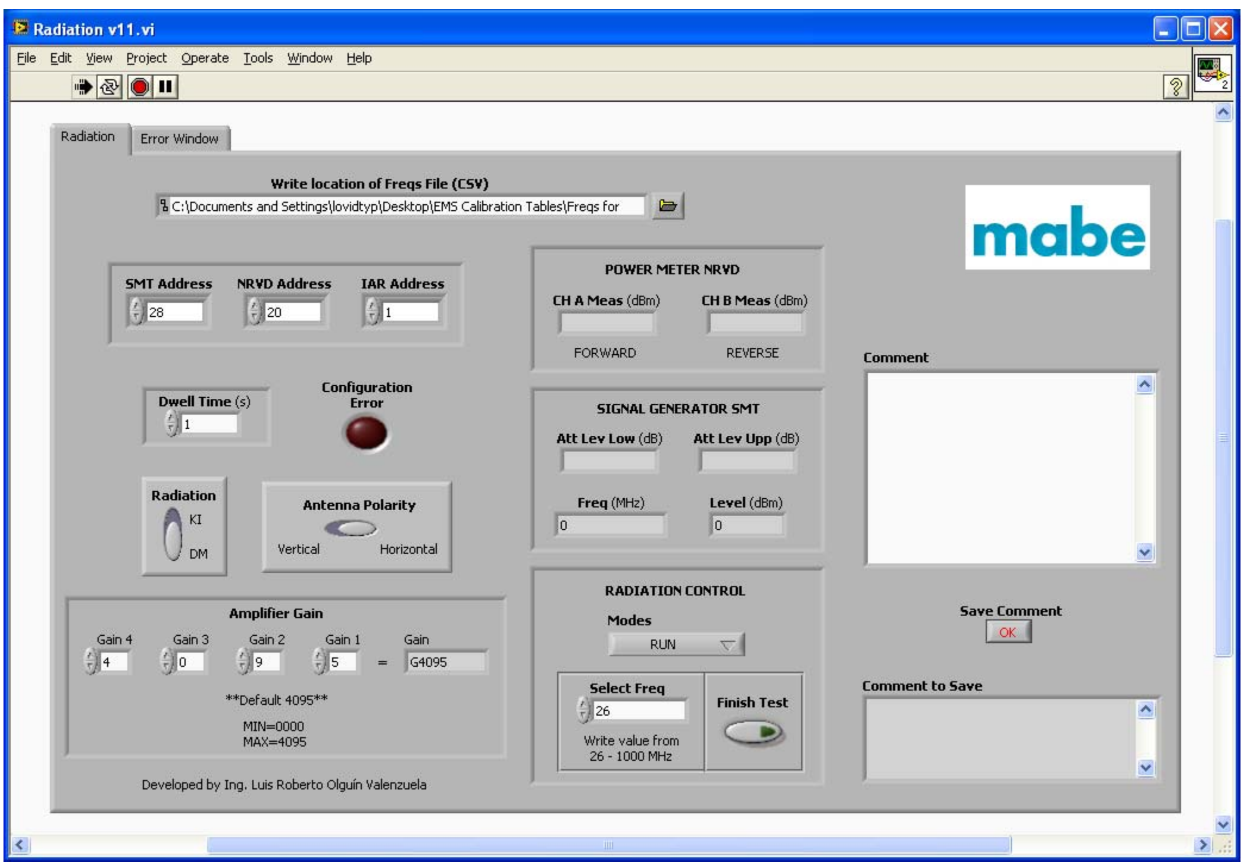

Figure 4.48: *EMS Application User Interface – Radiation Screen*

The principal screen also displays the measurements performed by the NRVD, the frequency and level values that are sent to the SMT and the attenuator levels that the SMT sets.

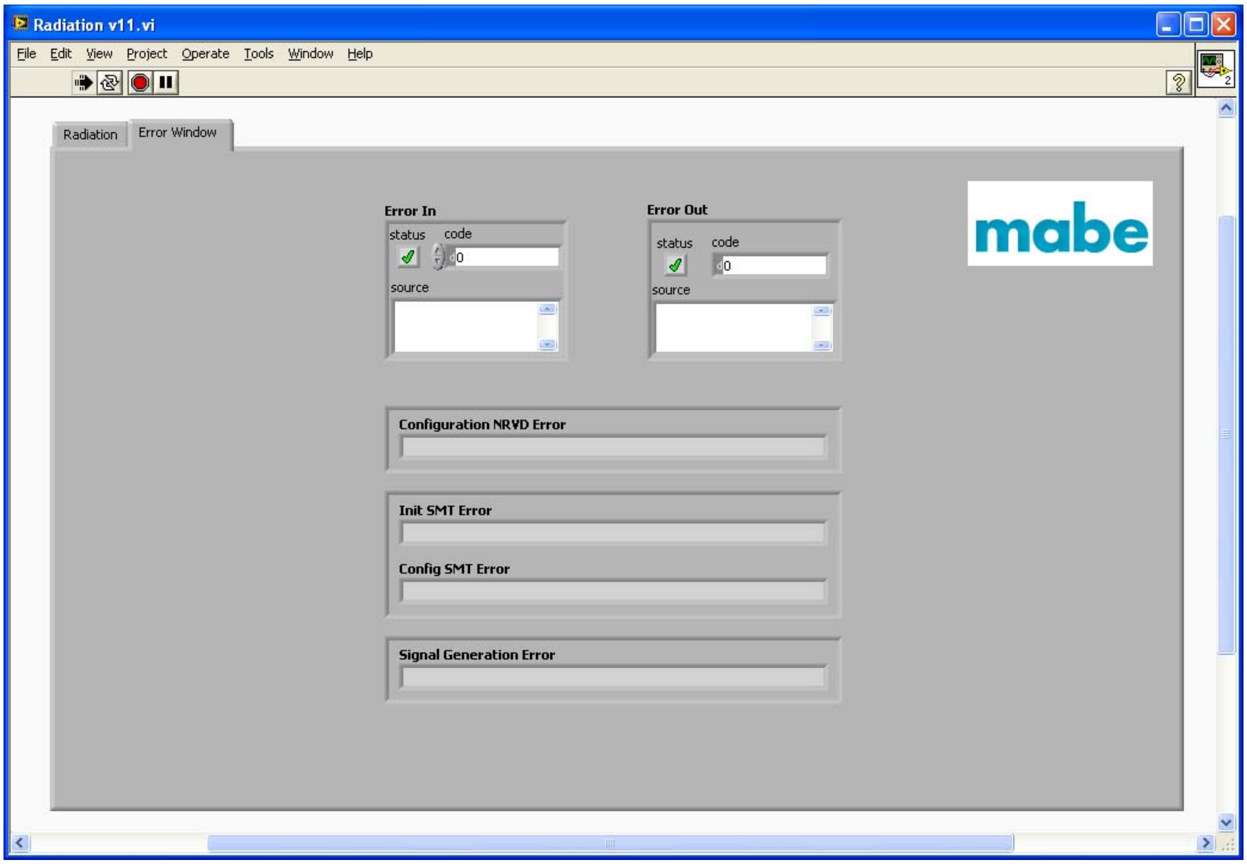

Figure 4.49: *EMS Application User Interface – Error Screen*

4.4.1 Initialization

The initialization part of the EMS application has the following steps:

- Address setting for the signal generator, power meter and amplifier.
- Test selection.
- Amplifier gain setting (optional).
- Frequency file path specification.
- Dwell time setting.

Once these parameters are set and the application is started, it "remembers" to the evaluation engineer to check the antenna polarization (Figure 4.50).

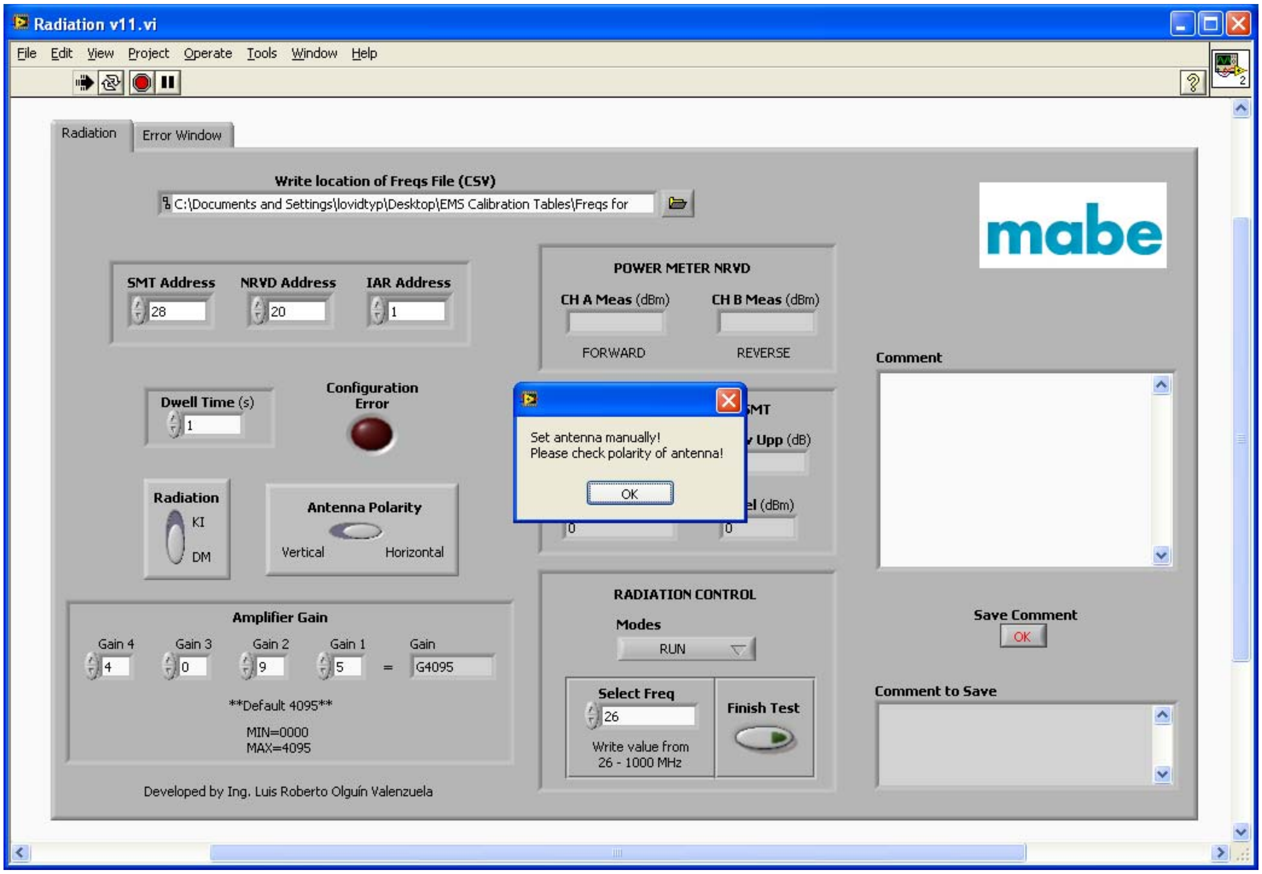

Figure 4.50: *Asking for Checking Antenna Polarization*

After the user confirms that the antenna is collocated as the selected test requires, the application asks to the user to create an Excel file for saving all the comments that are written during the test execution (Figure 4.51).

Then the calibration table is chosen (Figure 4.52). If the name of the selected file does not agree with the test selection, an error message appears and the evaluation engineer has to select the correct file as it was demonstrated in Read calibration sub-VIs section.

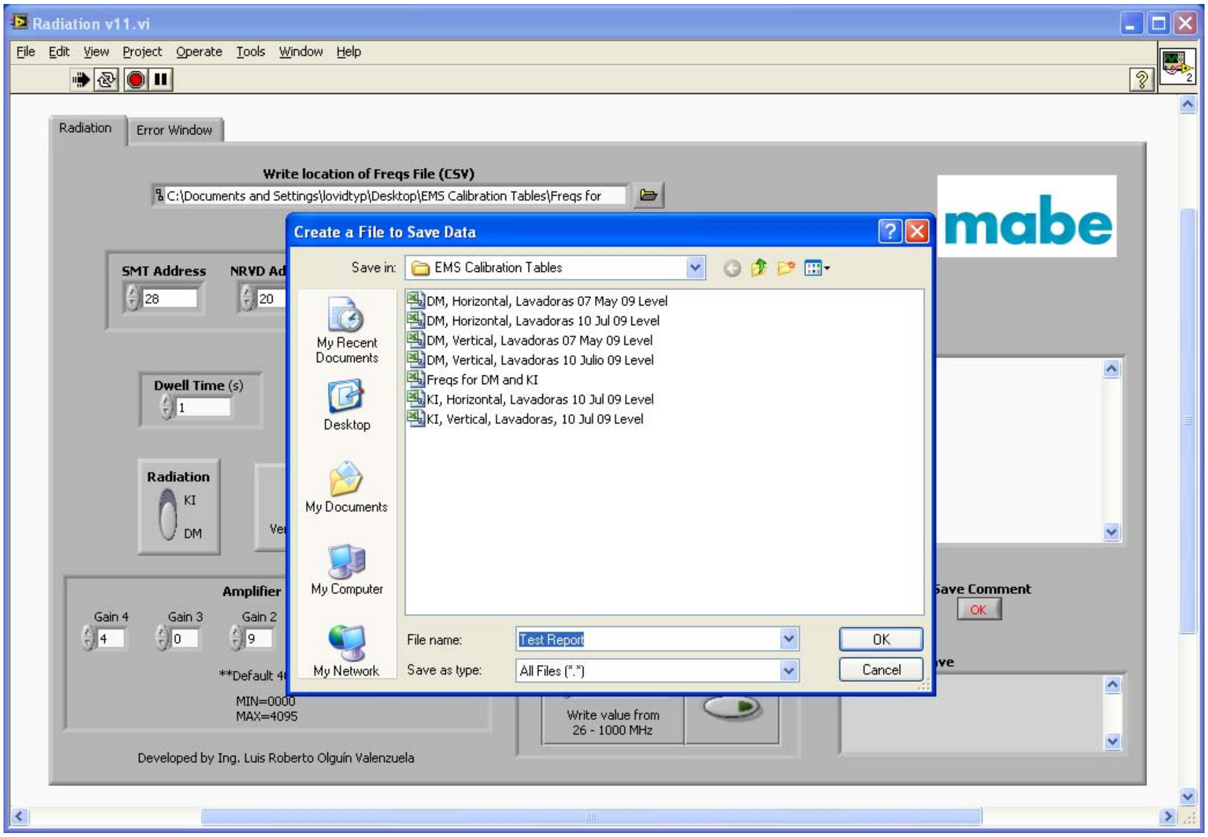

Figure 4.51: *Creation of the Excel File*

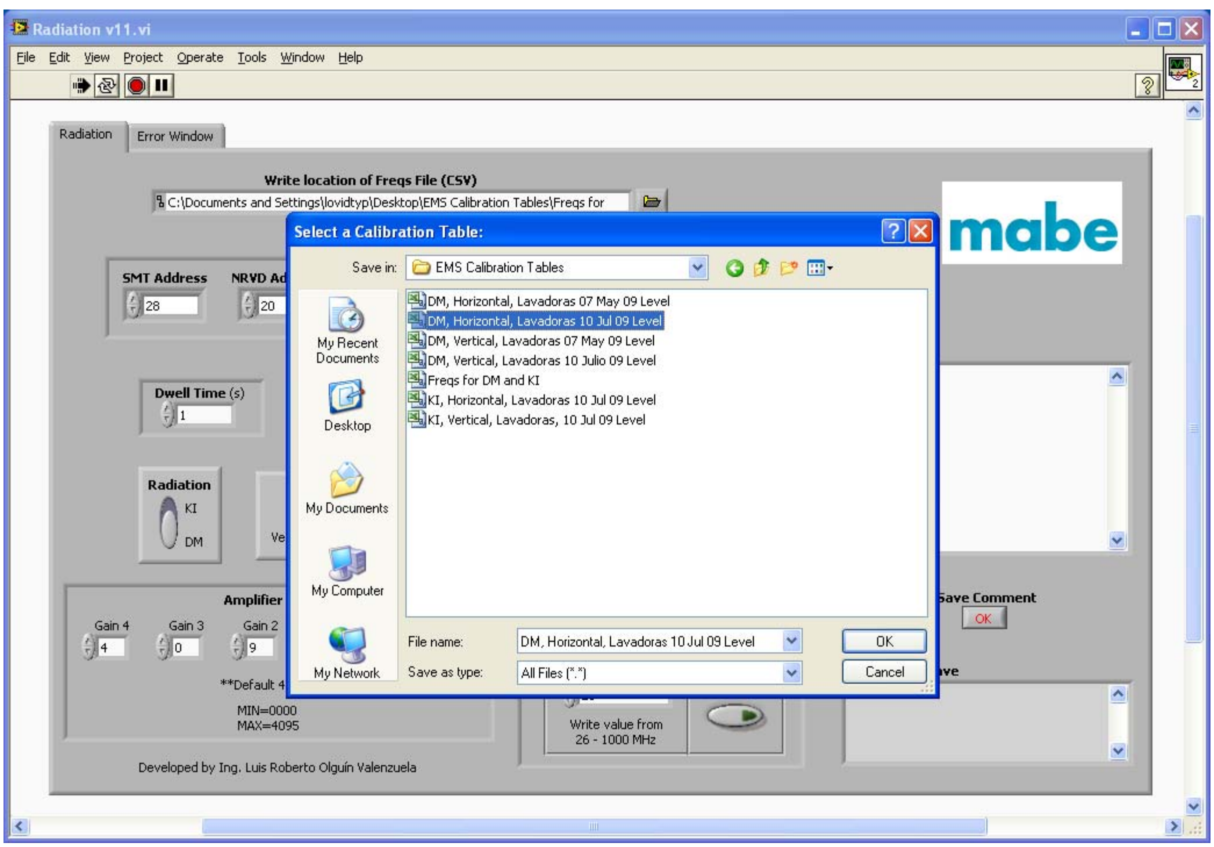

Figure 4.52: *Selection of the Calibration File*

4.4.2 Generation/Radiation

Once all parameters were set and the corresponding files read and created, the devices are initialized and configured. At this moment the program checks if the antenna is connected, if it is not, a message appears on the screen as is shown in Figure 4.53 and then the application is stopped.

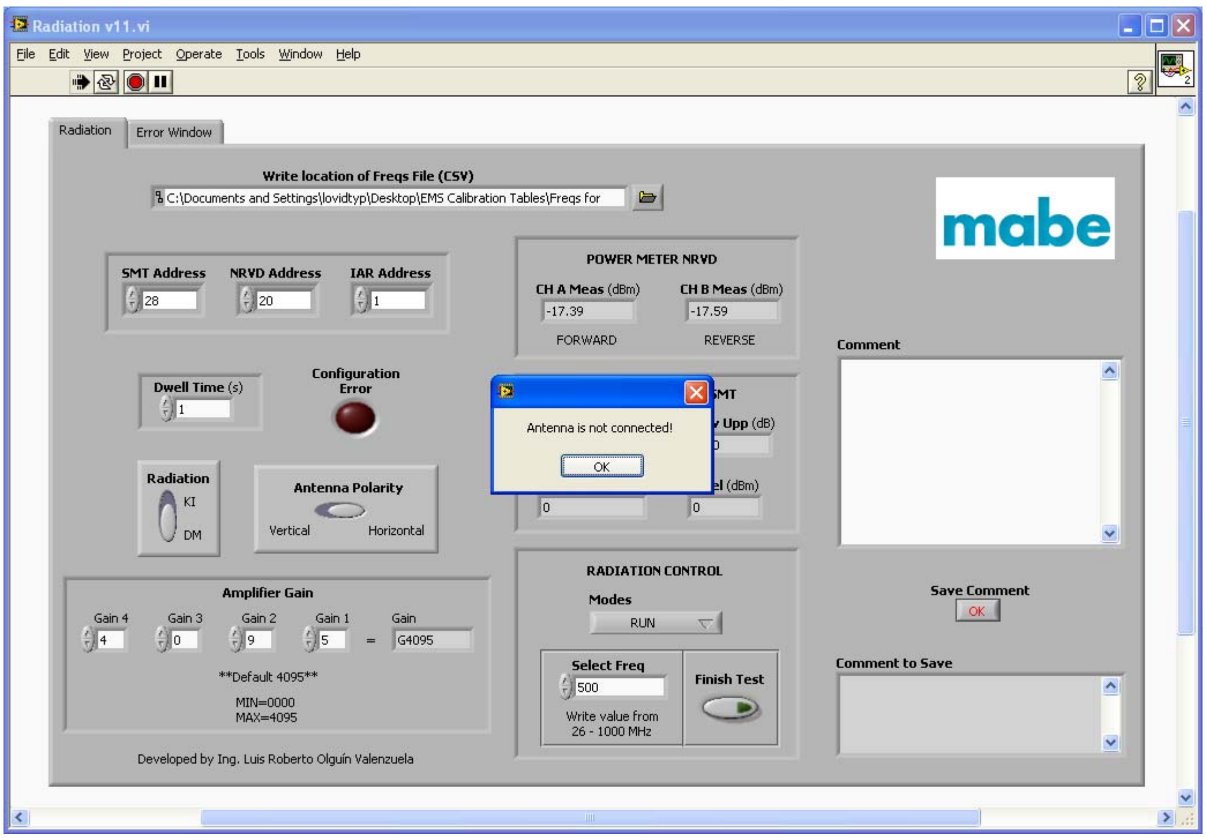

Figure 4.53: *Antenna Not Connected Warning*

After connecting the antenna, the application can be started again. Since everything works well as is shown in Figure 4.54, the signal generator sub-VI starts to send the frequency and level values from the vectors that stores the data of the Excel files to the SMT.

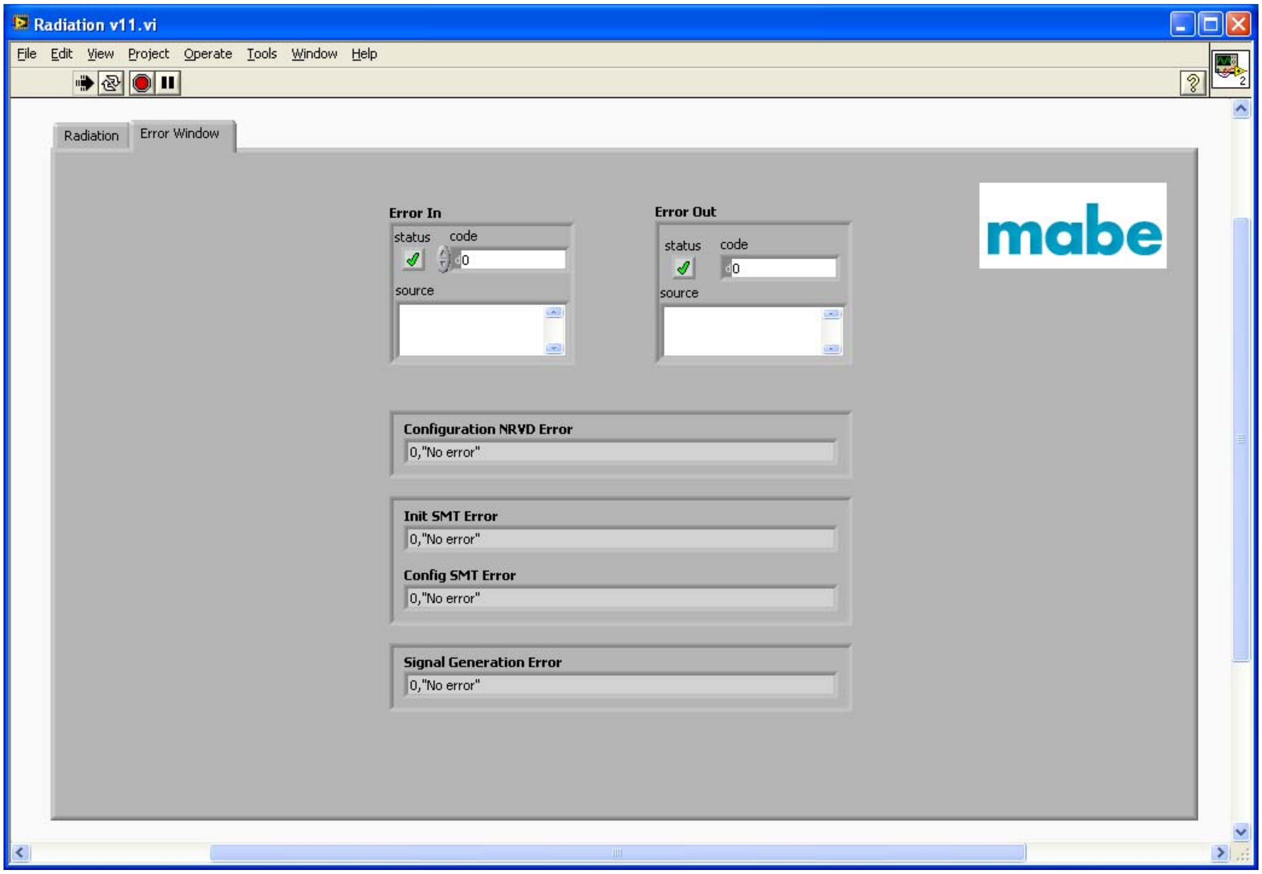

Figure 4.54: *Error Screen after Initialization*

In Figure 4.55 is shown the Radiation window for a DM, Horizontal test. There can be seen the frequency and level values that are sent to the generator, the attenuator levels that the SMT sets, and the forward and reflected power that are being measured by the NRVD at that moment. In this case, the level that is sent is within the attenuator range. The signal generated that is radiated by the antenna to the EUT is shown in Figure 4.56, the frequency of the carrier signal is 41.01193 MHz and the level is -20.9721 dBm.

In Figure 4.57 is shown the front panel for a KI test and Figure 4.58 shows the signal generated with a frequency of 33.0131008 MHz and a level of -21.7052 dBm.

The signals that are shown in Figure 4.56 and 4.58 were obtained with a digital oscilloscope.

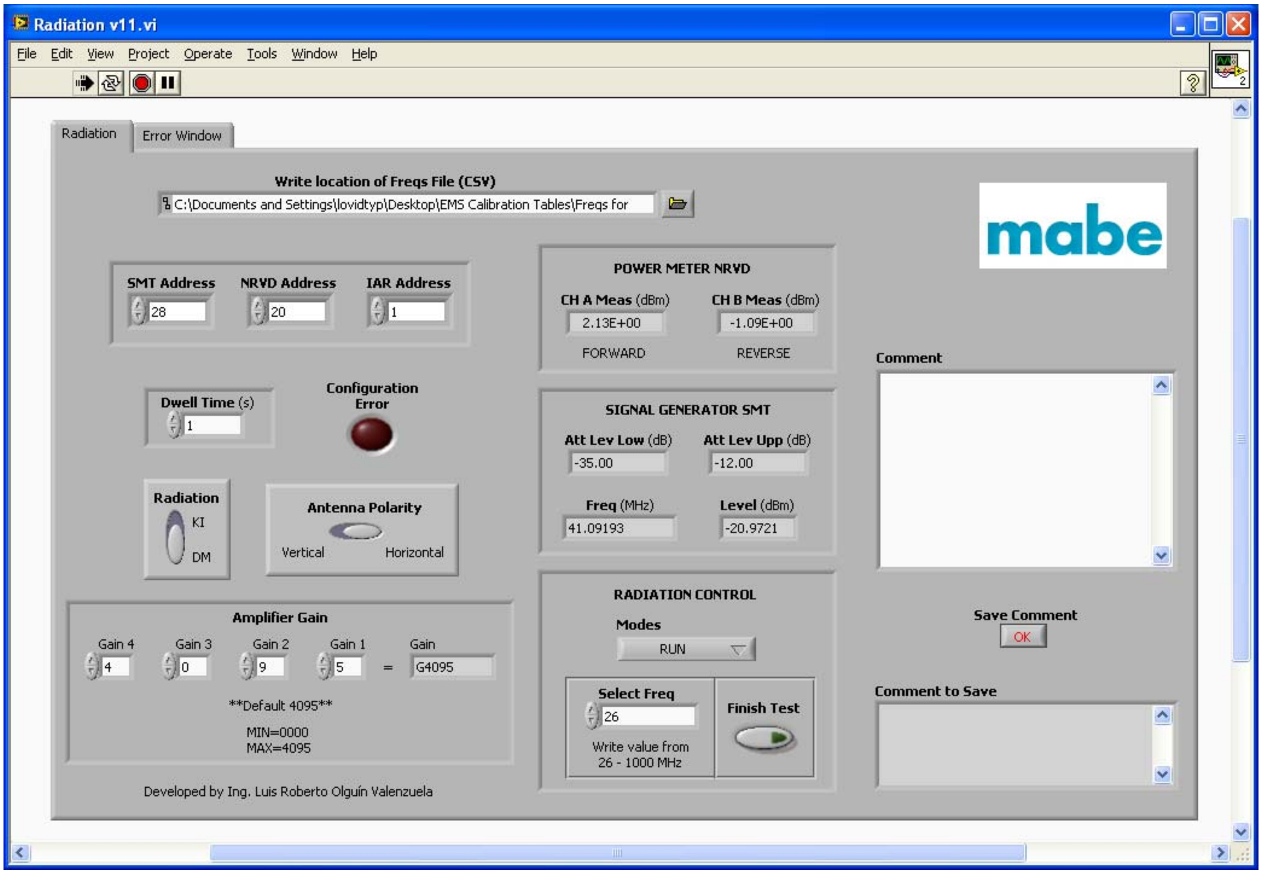

Figure 4.55: *Radiation Screen for DM Test*

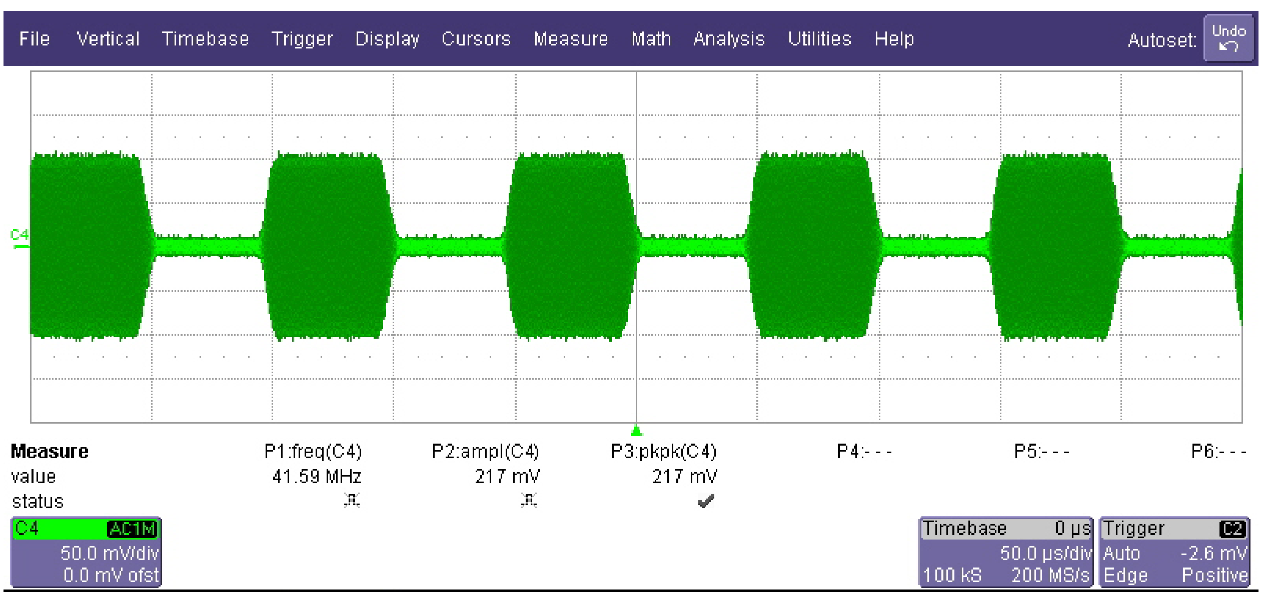

Figure 4.56: *Radiated Signal for DM Test*

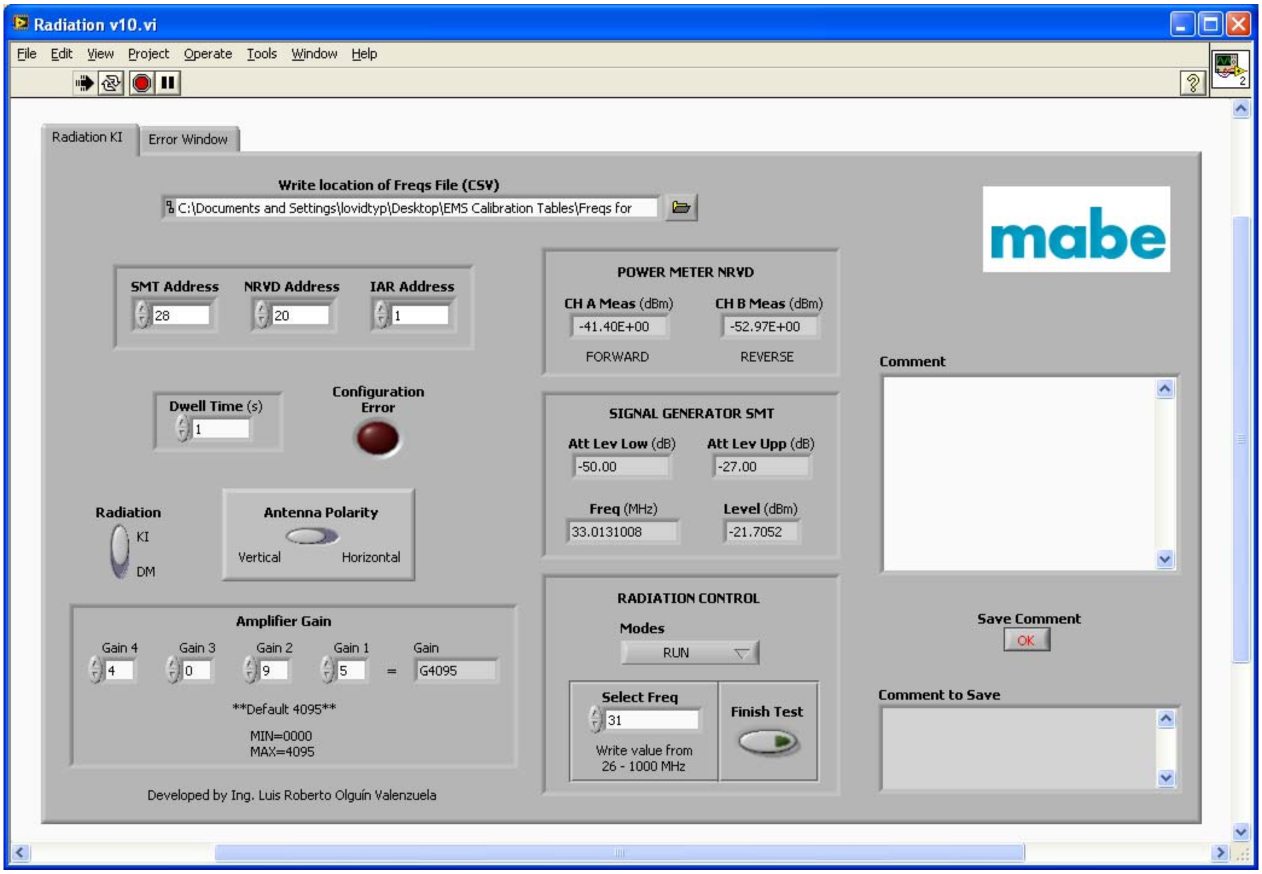

Figure 4.57: *Radiation Screen for KI Test*

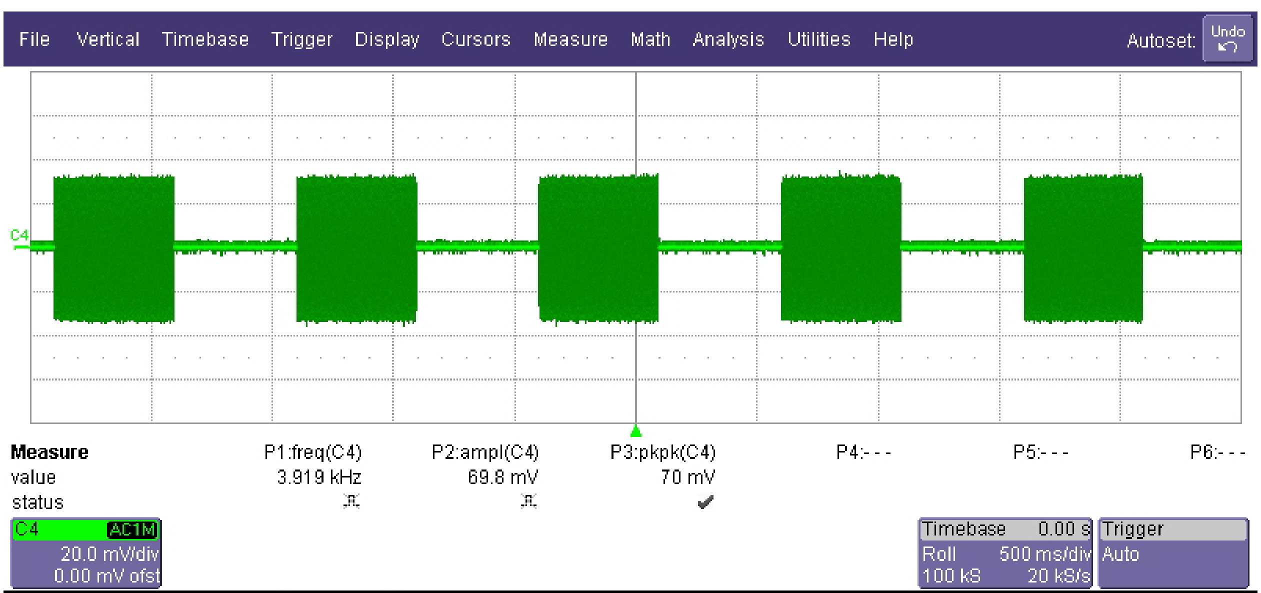

Figure 4.58: *Radiated Signal for KI Test*

4.4.3 Pause

If the EUT presents a behavior that is not expected during the disturbance radiation, the evaluation engineer pauses the application using the menu control “Modes” and immediately a message appears asking to the user if a comment is going to be written as is shown in Figure 4.59. In this case the answer was YES, so the user writes the comment in the string control “Comment”. In order to save the comment that the user wrote to describe the behavior or effect that was observed, the “Save Comment” button is clicked. The evaluation engineer can see the comment, the frequency and the level of the signal where the failure occurred in the “Comment to Save” field, Figure 4.60.

The information that is shown in the “Comment to Save” indicator is the data that is exported to the Excel file. Every comment that the user writes is saved in the same file, so later for writing the report the data can be copied and pasted in the Excel template that Mabe has for its reports. In table 4.6 is shown how the EMS application exports the data to Excel.

After writing and saving the comment, the evaluation engineer can restart the radiation throughout the Run option in the “Modes” menu.

FREQUENCY	LEVEL
51.147777 MHz	-22.776870 dBm
Reset in washing function	
286.038461 MHz	-34.369616 dBm
LEDs are blinking	
963.012742 MHz	-31.660349 dBm
Function changes from washing to stand by	

Table 4.8: *Comments Exported to the Excel File by the EMS Application*

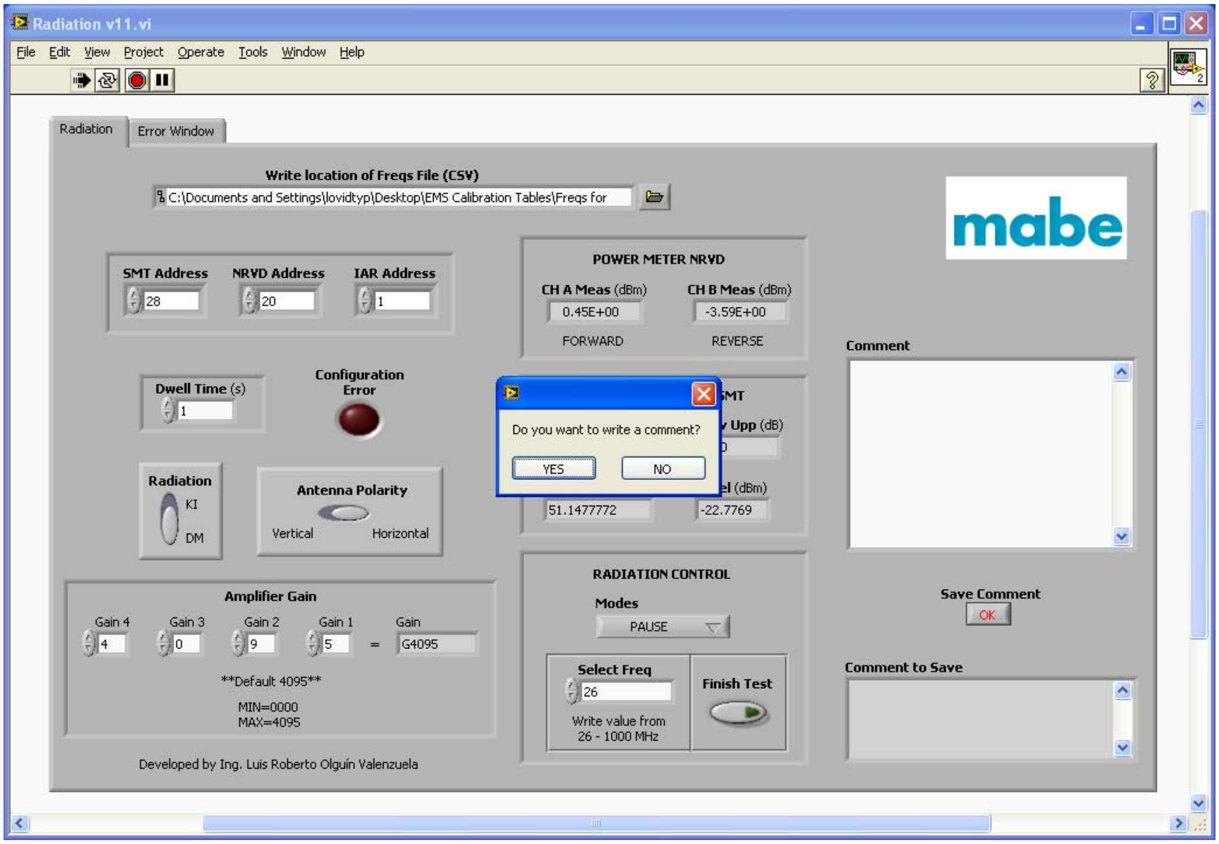

Figure 4.59: *Pause Mode*

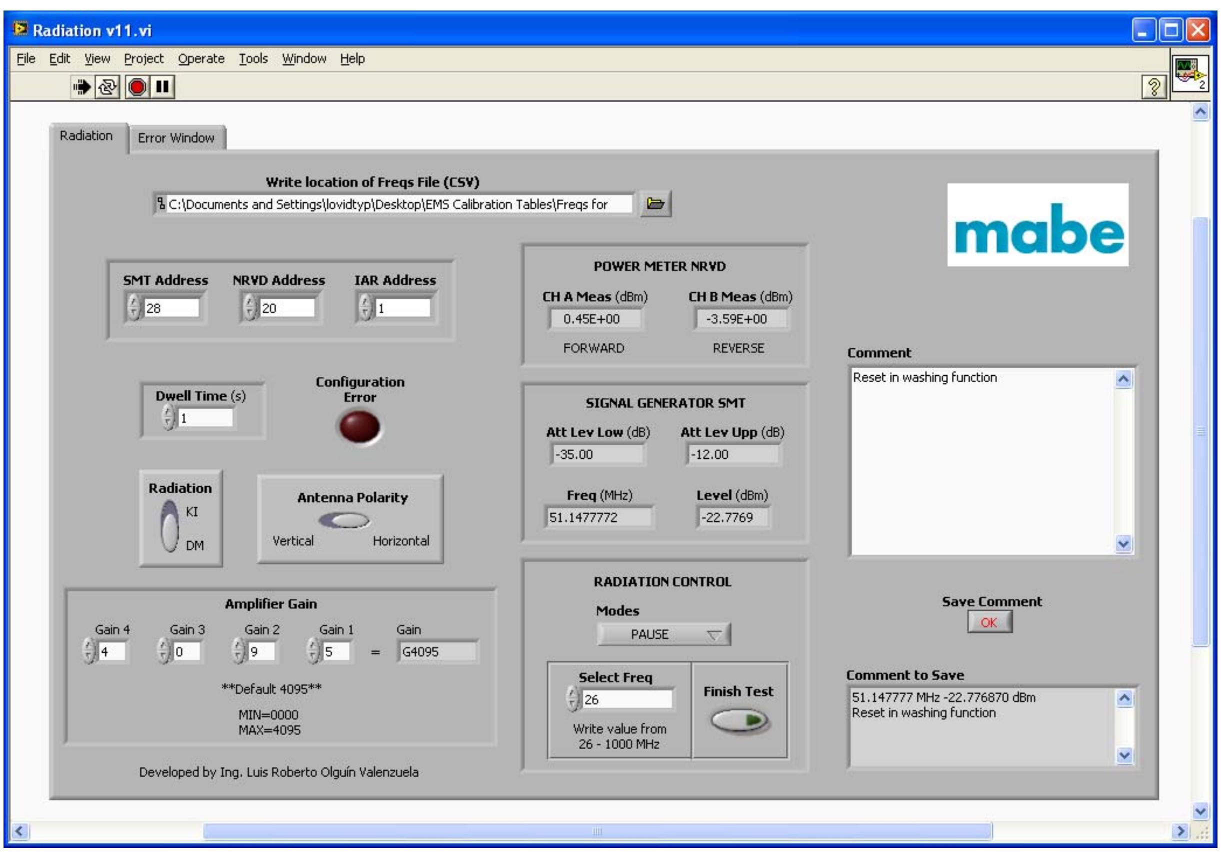

Figure 4.60: *Exporting a Comment to Excel*

4.4.4 Stop

Another option that this application handles with the "Modes" control menu is the Stop option. When it is selected a message appears asking if the radiation will restart in the same frequency where it was stopped or if another frequency value will be chosen, as is shown in Figure 4.61.

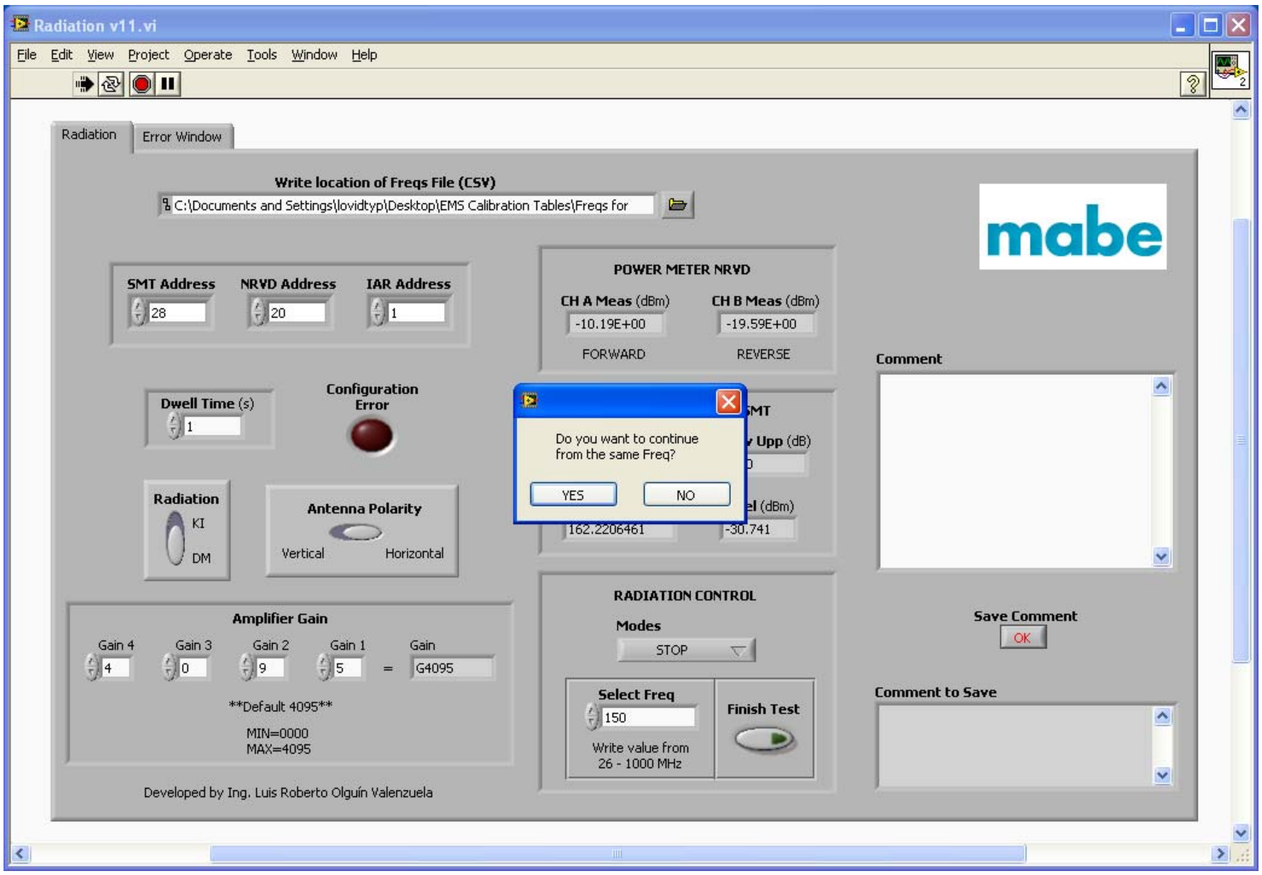

Figure 4.61: *Stop Mode*

In this case the selected option was NO, so the frequency where the radiation restarted was indicated in the numeric control "Select Frequency". In Figure 4.62 can be seen that the selected frequency is 500 MHz, and the radiation started in 504.3624405 MHz, which is the closest value that the Select Freq sub-VI found. As in the Pause mode the radiation was restarted with the Run option included in the "Modes" menu.

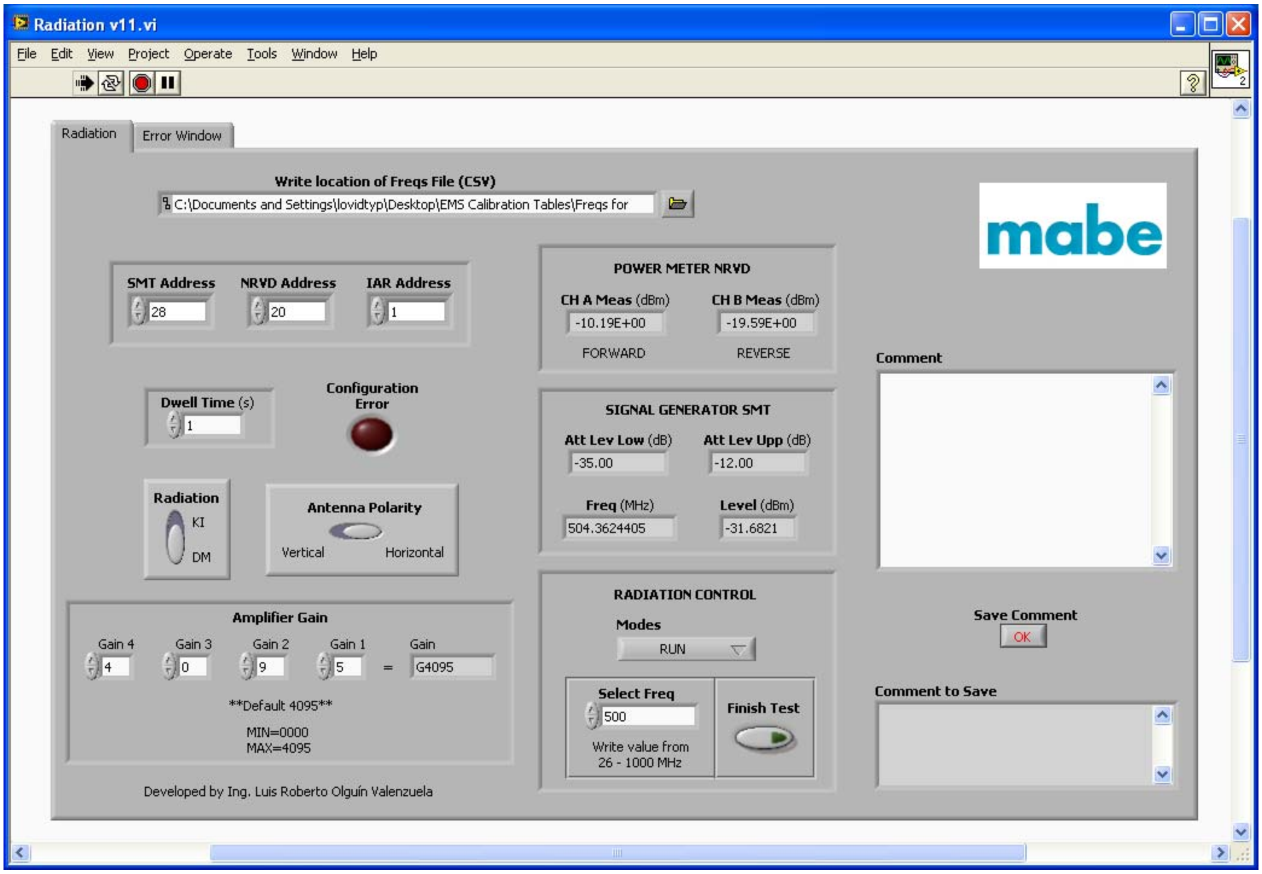

Figure 4.62: *Restarting in the Selected Frequency*

Finally, the radiation finishes when the user clicks the “Finish Test” button or when the last frequency value, that is 1 GHz, is sent to the SMT.

5. CONCLUSIONS

The software interface developed in this project for the emissions and susceptibility tests will allow to the Mabe's evaluation engineers to perform those tests in an easier way than using the EMC32.

Among the advantages presented by the new software interface are:

- The possibility to initialize the devices.
- The facility to set parameters.
- To acquire, convert and display measurement results.
- To import information from files to perform the tests.
- To export results to an excel file to generate reports.

Moreover, the necessary parameters to perform the tests can be set easily in the front panels of the EMI and EMS applications throughout buttons, menus, numeric controls, etc. These options are used not only for setting the required parameters for the conducted emissions tests and susceptibility to electromagnetic radiations test; but they also allow the user to set these parameters for different tests. For example the EMI application can be used for measuring the emissions radiated by the power supply cables of the appliances; for this, the frequency range, the frequency step, bandwidth resolution and units have to be modified in the front panel of the user interface. In order to perform this test the LISN is replaced by an absorbing clamp for measuring the radiated electromagnetic field and it is connected to the ESPI, so the scan can be started and then the final measurement is performed as it is done with the conducted emissions test.

As well, both applications allows to the user to change the program commands since they are divided in sub-VIs or subprograms. For example, in the EMS application can be modified the signal that is radiated to the appliance just by changing some commands related to the waveform. Instead of using a square wave in the DM option, a sinusoidal wave can be used. This kind of modifications cannot be directly done from the front panel because the way that the test has to be performed will not change, unless the test procedure changes. It should be kept in mind that the waveform is a parameter that is not usually modified; hence their modification is only possible in the block diagram.

Therefore with these new two options created to modify the test parameters, one can carry out the tests even if the procedures require new modifications in the way that the tests need to be performed.

Also the EMI and EMS applications can control the new equipment that exists in the laboratory just by setting the device addresses. This is possible because the new acquired equipment is from the same suppliers, so there will be no problems due to the specific commands although they are not the same model. For example the EMI application was developed for the R&S ESPI 3 but it can be also used with the R&S ESPI 7.

As a result of this, both test receivers can be used at the same time just by installing the EMI application in two different PCs with LabVIEW licenses, which is not a problem because of the relationship between Mabe and National Instruments.

Finally the development of these software interfaces should be considered as the basis for future projects in order to complement them and maybe should be considered as a convenient custom platform for the creation of a complete EMC tests tool.

6. RECOMMENDATIONS

As it was mentioned in the conclusions these work should be considered as the beginning for upcoming projects. One of these possible projects can be the creation of a database for the tests.

This is possible because the developed software application stores the measurement results in vectors that can be exported to an Excel file. So a failure historical file of a determined appliance can be saved. Then this information can be used in order to analyze the results from similar appliances and when a failure occurs the software application could suggest why this is happening.

For example, the washing machines can have up to three principal components that can produce the emission of conducted interferences:

- the motor,
- the power supply circuit and
- the control circuit.

So every time that a washing machine is evaluated and it does not pass the test, that is, it presents peaks over passing the accepted limit lines, the measurement should be saved and identified in the data base. After the designers inform to the evaluation engineers the reason of the failure, that information should be added to the corresponding measurement results in the database.

Then if a washing machine that is being evaluated, presents some peaks in a frequency range, the measurement results can be compared with the information previously stored in the database, thus the software application can “suggest” that the disturbance is produced by the motor or the control section or the power section, because the peaks found in that frequency range occurred in the previous tests due to a specific element. Finally a solution can be also proposed due to the cause of the failure is well identified.

This kind of database can be used also for the susceptibility to electromagnetic radiation tests.

Another point to be considered for complementing this work is to develop a subroutine for the calibration processes, so this part could be performed not only for the EMC32 but also for the new software interface.

7. BIBLIOGRAPHY

[1] Atmel Corporation. 2000. Application Note. “AVR040: EMC Design Considerations”. Rev. 1619A–01/00.

[2] Maxim Integrated Products. 2006. Application Note. “EMI/EMC Suppression in Audio/Video Interfaces”. AN3882.

[3] KODALI, V. Prasad. Engineering Electromagnetic Compatibility. IEEE Press. New York, USA, 1996.

[4] McCulley, Bill. 2007. Web seminar. “Reducing EMI in Class D Audio Applications: The Basics”. Americas Audio & LV/LP. National Semiconductors.

[5] BALCELLS, Josep; DAURA, Francesc; ESPARZA, Rafael. Electromagnetic Interference in Electronic Systems. Alfaomega – Marcombo. Barcelona, Spain. 1992.

[6] European Directives 82/499 EEC and EN336/89.

[7] VIOLETTE, J. L. Norman; WHITE, Donald R. J.; VIOLETTE, Michael F. Electromagnetic Compatibility Handbook. New York, USA. 1987.

[8] IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from external Sources. IEEE Std 518-1982.

[9] Don White Consultants. 1988. Course. “EMC Design and Measurement for Control of EMI: A two Parts, Five-Day Training Course”. Interferences Control Technologies. Virginia, USA.

[10] ELLIS, Norman. Electrical Interference Handbook. Spanish edition. Paraninfo Ed. Madrid, Spain. 1999.

[11] IEEE Guide on Electrostatic Discharge Characterization of the ESD Environment. IEEE C62-47-1991.

[12] "Chemistry – Triboelectric Effect". Webpage. 2005. http://www.chemistrydaily.com/chemistry/Triboelectric_effect. (July 6, 2009).

[13] HIGGINS, D. F. H.; LEE, K. S. H.; MARTIN, L. System Generated EMP. IEEE Trans EMC, vol. EMC 20. 1978.

[14] LONGMIRE, C. L. On the Electromagnetic Pulse Produced by Nuclear Explosion. IEEE Trans EMC, vol. EMC 20. 1978.

[15] WHITE, D. R. J. A Handbook Series on Electromagnetic Interference Compatibility, Vol. 5, EMI Prediction and Analysis. Don White Consultants. 1988.

[16] BARNES, F. S. Typical Electric and Magnetic Field Exposure at Power Line Fequencies and Their Coupling to Biological Systems. In "Biological Effects of Environmental Electromagnetic Fields (Ed. M. Bland) Washington, USA. 1995.

[17] DING, Haiqiang; ZHOU, Jolly; WANG, Tong. 2004. "EMI/EMC Design in V/UHF Communication Receiver". Ansoft China.

[18] The Clemson University Vehicular Electronics Laboratory. "Clemson Vehicular Electronics Laboratory: Introduction to EMC". Webpage. http://www.cvel.clemson.edu/emc/tutorials/Introduction_to_EMC/Introduction.html (July 3, 2009).

[19] Missouri University of Science and Technology. "Electromagnetic Compatibility Laboratory". Webpage. http://emclab.mst.edu/emcdef.html (July 3, 2009).

[20] Rhode & Schwarz. “EMI Measurements, Test Receiver vs. Spectrum Analyzer”. Systems Support Center. Texas, USA.

[21] Tektronix. 1999. Brochure. “27120B EMI Measurement System with EMC120 Windows Software”. USA.

[22] Rohde&Schwarz. 2008. Brochure. “R&S EMC32-EB EMI Measuremnt Software”. Version 1.0. Germany

[23] EP5 Series. Brochure. “Automatic EMI Measurement Software”.

[24] Summitek Instruments. Brochure. “OASIS Spectrum Monitoring & Interference Analysis”. Englewood, USA.

[25] DHANASERKARAN, R.; RAJARAM, M.; SIVANANDAM S. N. Mixed Mode EMI Noise Level Measurement in SMPS. College of Technology, Coimbatore,TN, India 2006.

[26] Rohde&Schwarz. 2004. Operating Manual. EMI Test Receiver. Germany.

[27] Rohde&Schwarz. 2004. Operating Manual. Signal Generator SMT. Germany.

[28] Amplifier Research. 2005. Operating and Service Manual. 100W1000B. USA.

[29] Rohde &Schwarz. 2004. Operating Manual. Power Meter NRVD. Germany.

[30] LAJARA VIZCAINO, José Rafael; PELEGRI SEBASTIA, José. LabVIEW Entorno Gráfico de Programación. Alfaomega – Marcombo. Barcelona, Spain 2007.

[31] National Instruments Corporation. Tutorial. “GPIB Tutorial”. www.natinst.com

[32] National Instruments Corporation. 1998. Manual. “LabVIEW User Manual”. Part Number 320999B-01. Texas, USA.

[33] National Instruments Corporation. 2000. Manual. “LabVIEW Basics 1, Course Manual”. Part Number 320628G. Texas, USA.

[34] National Instruments Corporation. Brochure.” GPIB Interfaces for PCMCIA”. Texas, USA.

[35] KLEIN KEANE, Justin C. “Converting a Decimal Digit to IEEE 754 Binary Floating Point”. Webpage. 2007. http://justin.madirish.net/node/171
(August 8,2009)

[36] The MathWorks, Inc. MATLAB 7.0 (R14) Help.