EMC Design - First Time Right

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Abstract:

With the development of electronic devices, the high technology industry has an increasing need to deal with the problems of EMC. It is well known that finalised products can fail the EMC requirements therefore bringing them back to the designing process. These failures are very costly. Thus it is very important to be able to design a product that will pass the EMC regulations at the first design.

In order to address this problem, we have created a program that calculates the far-fields that radiate from a source using the measured near-fields of this source. We have validated this program and then compared the results to some measurements.

The comparison between the calculated far-fields and the measured ones has proven to be imperfect. Therefore some hypothesis have been made to improve the matching between the calculations and the measurements.

Keywords:

EMC, near to far field, field intensity distribution

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Chapter 1

Introduction

1.1 Introduction

Electrical products are used in every aspect of our lives, communications, entertainment, life support and luxury equipments for example. They often, unexpectedly, produce radio-frequency (RF) energy. Each of these digital devices has the potential to interfere with its neighbour and to possibly affect its functions. But even inside one of those devices, the different modules that compose it are prone to be affected by the module next to it.

Most of those interferences are unfortunately discovered late in the design of a product. When the different modules of the device are put together, even if each of those modules is within the criteria for radio-frequency emissions, they can affect each other in ways that were completely unforeseen. This will force the designer of the product either to try and understand the cause of the malfunction or to try and correct it with copper grounding or walls. Each of these solutions being very costly in time, resources and money.

This is why control of these interferences is primordial. The field known as Electro-Magnetic Compatibility (EMC) is dedicated to understand the causes of these interferences and to create the adequate solutions. But most importantly it is used before the problem appears, in the development phase of the product to ensure that no interference will affect the quality of the product. Good understanding of the EMC and correct application of its design methods would ensure considerable gain of time and money as the first design will be the correct one.

Figure 1.1 gives an idea of how many measures are available to us at all the stages of the design and how much these measures cost in all the different stages of production.

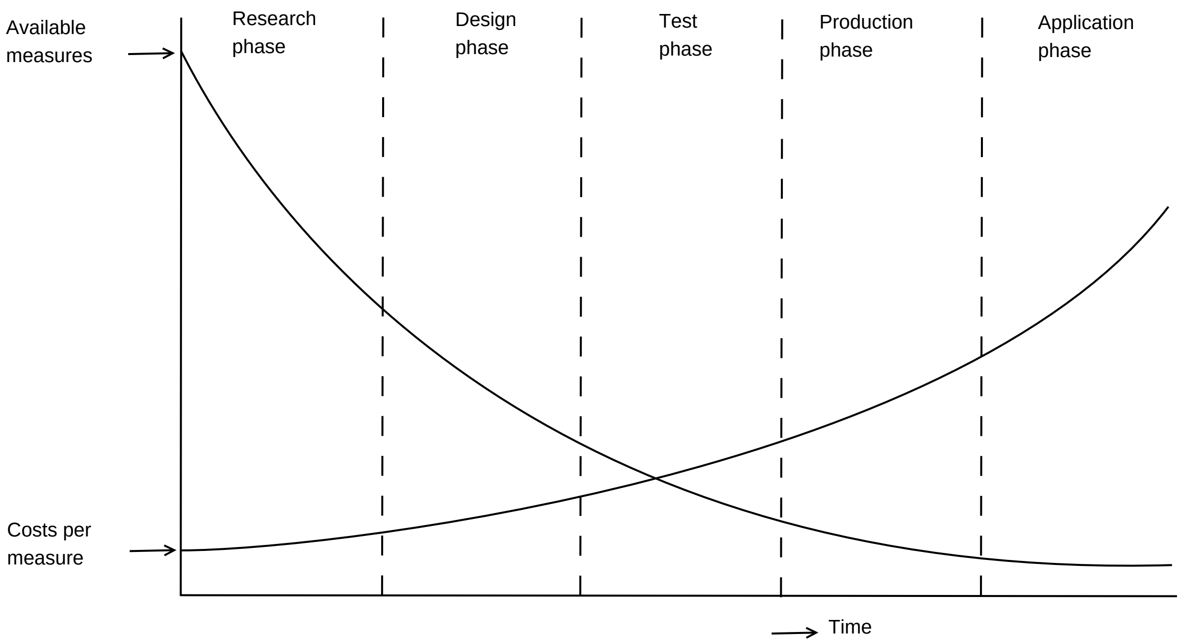

Figure 1.1: Measures and their costs in function of time and design phase [11]

EMC problems could appear in a wide range of frequencies outside of the band of interest. Therefore the prevention of EMI (Electromagnetic Interference) has become critical in situations where EM (Electromagnetic) compatibility is imperative.

1.2 History

In the early twentieth century, when electronic devices started to appear, engineers had only to ensure that their devices would function in the presence of natural noise and sometimes lightning. Indeed, the first radio receivers could interfere with each other but then simply changing frequencies or moving the receptor would be enough to eradicate the problem.
However, in the years that followed, we witnessed the appearance of radio, radars, television and telephones which would transmit more and more information in more and more complex ways and the proliferation of non natural noise sources as power lines, motors or relays. The first conflicts began to appear. In 1933 the CISPR (International Special Committee on Radio

Interference) was created and produced a document on Electro-Magnetic Interference (EMI). In world War II, it became evident that vehicles using radio or radars could be easily detected. Plus their instruments could be disrupted by other emissions. Therefore the US military became interested in reducing emissions and shielding their devices against other emissions. Governments became involved with the appearance of the first computers that introduced complex electronic devices in the houses.

Chapter 2

Problem description and goals

2.1 Problem description

The project proposal came from our supervisors Gert Frølund Pedersen and Ondrej Franek from the University of Aalborg (Denmark). It is focused on the Electro-Magnetic Compatibility design and the methods that can be used to help the first design of an electronic device to pass the EMC standards that are set for it.

Nowadays, with the multiplication of electronic devices in our everyday life, we are more and more surrounded by electromagnetic fields. These fields have an effect on the electronic devices that we use. This is why we need to be able to minimize the emissions of electromagnetic fields but also protect the electronic devices from the influence of these shields. This part becomes very complicated when an electronic device is composed of different electronic modules that are supposed to interact with each other. Indeed, more often than not, the modules create unintended emissions that will perturb the whole device. This is why it is necessary to apply EMC rules even inside an electronic device. However, the emissions being unintended, it is very complicated to foresee what complications will arrive. Therefore, completed products will sometimes not pass these EMC characteristics. Thus returning the product to earlier stages of development. We have seen that this problem can be very costly. This is why manufacturers try to pass the characteristics on the first time. But the challenge is to find rules that will apply to different modules and that would ensure that when different modules are put together hey will not interfere with each other in unforeseen ways.

In order to define some rules, we first need to understand the interaction between the different modules. Therefore, it is imperative to be able to calculate the electromagnetic fields created by an electronic module.

2.2 Project goals

Our goal was to code a program, using the simulation software Matlab, that would help to calculate the far-fields from the near-fields that are measured and therefore have a better understanding of those far-fields.

We will attach ourselves to understand the different EMC problematics, the EMC environment and the different methods that already exist in order to be able to investigate correctly our own results. We will create a code using Matlab that will help us analysing and validating some measurements done at Bang & Olufsen.

Chapter 3

EMC Overview

3.1 Terminology

3.1.1 Susceptibility and immunity

Susceptibility is defined as *"the inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance"*. This and the immunity of a device are complementary, because the latter is the ability to perform in such conditions. When we want to talk about the immunity of a certain equipment, it is only possible to insure it under concrete conditions and signals. There will always be some electromagnetic environment in which that system or device will be susceptible to suffer harmful interferences. Therefore, a desired level of immunity can be achieved under certain requirements which must be detailed.

When talking about Electromagnetic Compatibility, immunity and susceptibility are usually defined as *"the ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment"* [11]. Hence two aspects can be differentiated in this definition:

1. The fact that the device should *function satisfactorily*. It means that it can share an environment with other electromagnetic devices without suffering any unacceptable disturbance.

2. On the other hand, the device must *not introduce intolerable electromagnetic disturbances*. That means that it should not create electromagnetic interferences to any other equipments present in the environment.

3.1.2 Emissions

The signals emitted could be wanted or unwanted, creating therefore intentional and unintentional coupling paths. A wanted signal can be, for example, the one which is sent from a computer along a wire (intended coupling) to an automaton in order to perform some concrete action. Somehow, inside the computer, some crosstalk between the modules can occur. This fact plus the wiring acts like a transmitting antenna, disturbing the electromagnetic environment and hence, creating an unintended path and an unwanted signal for other equipments.

There are two types of emissions that will be extensively discussed later in this report. First comes the radiated emissions. These radiated emissions are the ones we will be focusing on as they are the emissions we are trying to quantify. However, the other type, conducted emissions, will also be studied in this report.

3.1.3 Differential and common modes of currents

The currents that run through the wires of an electronic device can be divided into two modes: the differential mode of currents and the common one. These currents are the main factors that create the emissions that concern us in the EMC field.

The differential mode of currents sees the two equal currents in the wires run in opposite directions whereas the common mode describes two equal currents running in the same direction. Any current can be described by a combination of those two modes.

3.1.4 Current probe and LISN

They are devices used to measure the differential and common modes of current inside a device. Indeed as these currents can be unexpected it is necessary to be able to measure them as models cannot predict them.

3.2 Standardisation

3.2.1 Overview

The goal of EMC is to help designing products that will not interfere with each other thus creating an environment where each electronic device is able to complete its task without being disturbed by the emissions of other electronic devices. Most products are of course designed to withstand common emissions. This property is called their immunity. However, standards and regulations have been created to reduce those emissions. There is no real international regulation existing on the matter. Each country has the responsibility of enforcing their own regulations. Two important groups of regulations exist and are the more commonly followed. In the United States the Federal Communications Commission (FCC) [3] has set some standards. Europe follows the standards of the International Electrotechnical Commission (IEC) [4], standards that are put together in the CISPR 22 (French acronym for International Special Committee on Radio Interference) [1]. Countries have the possibility of checking any kind of product in order to verify that the regulations are followed. They have the power of recalling a whole product if it does not follow the standards. However companies usually use their own regulations that are even more stringent than the national ones. The cost of recalling a whole product and of the bad publicity being too high. The automotive industry is especially drastic on regulating radiated and conducted emissions. The military also have their own standards that are even higher and cover a much larger band. Finally, medical devices are treated with special care.

3.2.2 Standards

First of all it is important to start by defining what devices fall under the jurisdiction of the FCC and the CISPR. It has been agreed that any device emitting radio frequencies whether it is intentional or not has to follow the following standards. Basically this means that any kind of electronic device is subjected to these regulations seeing that any kind of current running through a conductor is susceptible to create some sort of emissions. However a few exceptions can be noted such as telecommunications terminal equipment or aeronautical products. Also medical devices in the US are under the supervision of the FDA (Food and Drugs Administration) instead of the FCC for all other electronic devices.

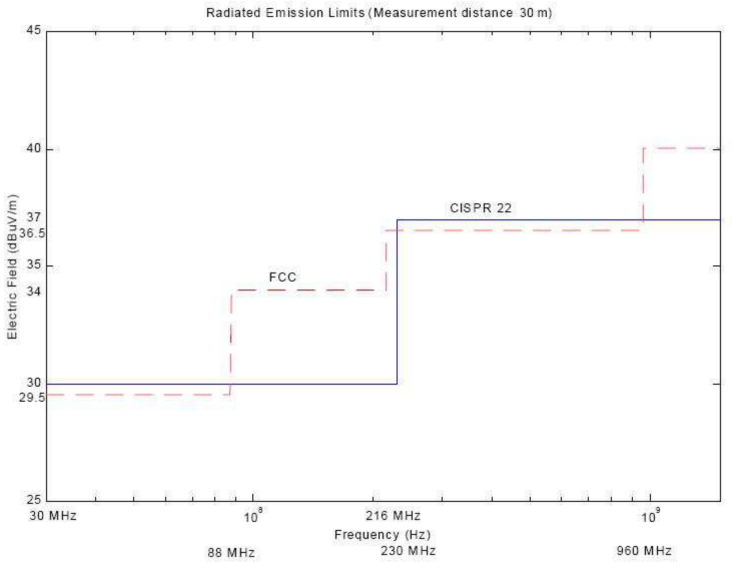

Figure 3.1: Radiated emissions for class A devices [2]

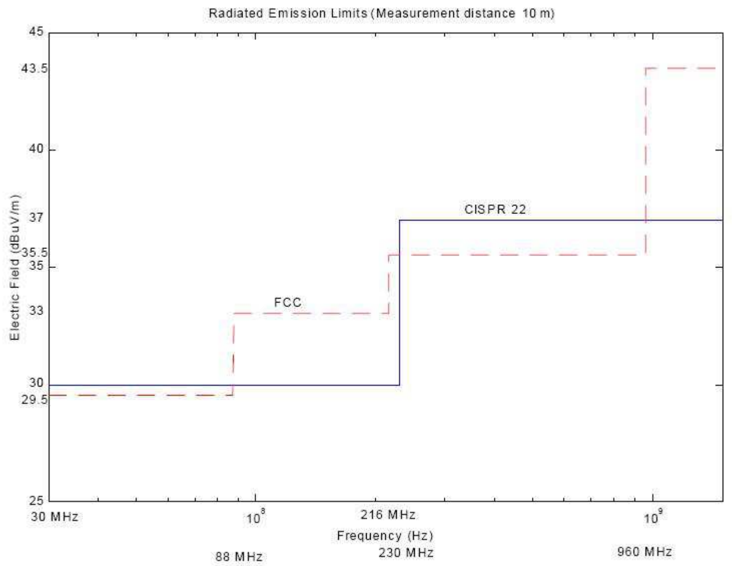

Figure 3.2: Radiated emissions for class B devices [2]

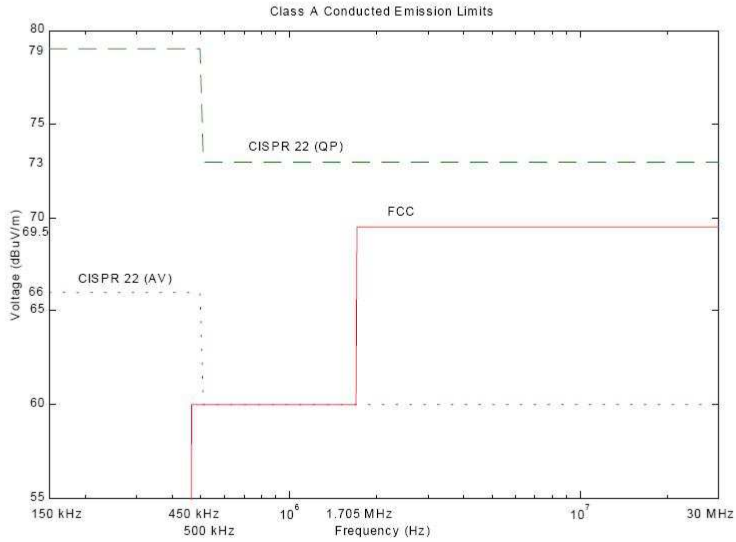

Figure 3.3: Conducted emissions for class A devices [2]

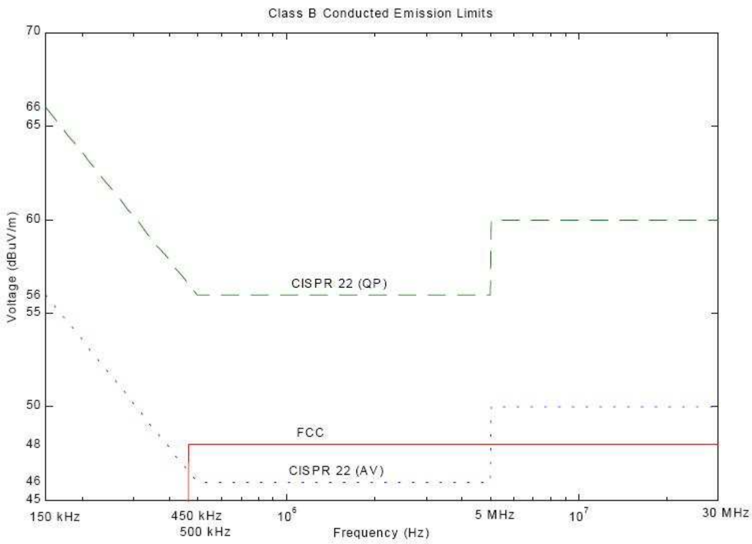

Figure 3.4: Conducted emissions for class B devices [2]

CISPR and FCC have a lot in common. First of all they separate all electronic devices into two categories. Class A for products used in business, commercial and industrial environments. Class B is for the rest, meaning electronic devices for personal use. As normal, class B products have more stringent standards to follow as they are used in more confined environment and the users do not have the knowledge to fix the problems that come with electromagnetic interferences. Regulated frequencies range from 9 kHz to 400 GHz.

In CISPR standards, measurements for radiated emissions must be made at 30m for class A and 10m for class B. In FCC regulation it is 10m and 3m for respectively class A and class B. By using the inverse distance method [14], we can still compare the two standards at the CISPR distances.

We can see in 3.1 and 3.2 that radiated emissions are mostly covered the same way by both standards. However, differences become much more visible when looking at the conducted emissions regulations as shown in 3.3 and 3.4. We notice that they do not have the same frequency range. While both standards start from the 30 MHz maximum, FCC regulates down to 450 kHz while CISPR goes all the way down to 150 kHz. CISPR rises the limit of emissions below 500 kHz. This extension was put in place in order to take into account the new switched mode power supplies that are growing in importance as they are lighter and more efficient than the usual linear power supplies. Another difference is that CISPR has different standards for when the receiver uses a quasi peak detector (QP) or an average detector (AV).

3.2.3 Measurements

In order to ensure that the tests are accurate, the FCC and CISPR have measurements standards. The tests have to be performed in normal conditions of use. Meaning that all connections are made as in real life conditions of usage. But the configuration of the system must be made to deliver maximum radiation to ensure that even in the worst case scenario, the emissions will not go over the standard limit.

Tests for radiated emissions are usually performed in an anechoic chamber to simulate the open field space required by the standards. The tests are performed with a broadband antenna so as to sweep the whole frequency range without having to change the length of the antenna for each frequency. Finally the receiver must have a minimum of a 100 kHz range so as to pick up unintentional emissions. The conducted emissions tests require an LISN.

3.2.4 IEC (International Electrotechnical Commission)

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts [4].

The IEC works on standards and norms related mainly with the electromagnetic environments, testing, measurement techniques and compatibilities in all the different range of frequencies. These standards could be eventually adopted as European Norms for example.

As seen on their website [4], the Commission's objectives are:

- meet the requirements of the global market efficiently
- ensure primacy and maximum world-wide use of its standards and conformity assessment systems
- assess and improve the quality of products and services covered by its standards
- establish the conditions for the interoperability of complex systems
- increase the efficiency of industrial processes
- contribute to the improvement of human health and safety
- contribute to the protection of the environment.

3.2.5 EMC in the law

We have seen what international standards have been created. These standards are translated into requirements by the laws of the countries. In the US the FCC standards are the law. However the testing of the devices are to follow the ANSI C63.4-1992. The European EMC directive, 89/336/EEC, translates the CISPR in the European law.

Also, the World Trade Organization (WTO) specifies that all countries should follow certain standards. Therefore, all WTO members are obliged to follow the international EMC standards. These standards are mainly developped by the IEC based on the work by the CISPR. The new series of standards are as follow:

- IEC 61000-1-Introduction, terms, and conditions.
- IEC 61000-2-Classification of electromagnetic environments.
- IEC 61000-3-Limits and disturbance levels.
- IEC 61000-4-Testing and measurement techniques.
- IEC 61000-5-Installation and mitigation guidelines.
- IEC 61000-6-Generic standards.

Medical devices have their own special clauses. Clause 36 of IEC 60601-1 is the European standard and is also used in the United States. However, in the US medical devices are under the supervision of the FDA (Food and Drugs Administration) and not the FCC.

A very thorough investigation of international standards can be found in [5] and [6].

3.2.6 Other information

European Standardisation Organisations:

- European Committee for Electro technical Standardization (CENELEC) www.cenelec.org
- European Telecommunications Standards Institute (ETSI) www.etsi.org
- European Committee for Standardization (CEN) www.cen.eu

Detailed information on the standards and harmonization in Europe can be read in [7] and [**?**].

The CE marking shown in Figure 3.5 serves as an attestation that the device follows the European standards.

Figure 3.5: CE marking

3.3 Electromagnetic environments

The design of an electromagnetic device should be done thinking which immunity levels has to be achieved by such device. In order to do this it is really important to take into account the environment in which this design is going to work and what kind of disturbances it is going to deal with. Such an environment has a great importance on the choice of the correct immunity levels that can insure a proper performance. This is a really difficult task as the electromagnetic environment and the phenomenons which take place in it are, in general, time-dependant and need a statistical approach to be studied.

According to [12] there are three basic kinds of environmental phenomena which include all type of disturbances:

- Low-frequency phenomena (conducted and radiated).
- High-frequency phenomena (conducted and radiated).
- Electrostatic discharge (ESD).

Due to the amount of different disturbances that could be present in a certain environment, it is almost impossible to describe it perfectly. In the list shown below, obtained from the IEC (International Electrotechnical Commission) and shown in [12] , it is possible to see some phenomena that could create electromagnetic disturbances:

Conducted low-frequency phenomena

- harmonics, interharmonics
- signalling voltages

- voltage fluctuations
- voltage dips and interruptions
- voltage unbalance
- power-frequency variations
- induced low-frequency voltages
- DC in AC networks
- broadband signals
- common mode voltages

Radiated low-frequency phenomena

- magnetic fields
- electric fields

Conducted high-frequency phenomena

- induced CW voltages or current
- broad band signals (PLC, power drive systems, etc)
- unidirectional transients
- oscillatory transients

Radiated high-frequency phenomena

- magnetic fields
- electric fields
- electromagnetic fields
  - continuous waves

- transients
- modulations (FM, AM, FSK, CDMA, CMA, TDMA, etc)

Electrostatic discharge phenomena (ESD)

The problem is that the electromagnetic environment is highly variable. New devices, new technologies and new tendencies make it necessary to be constantly analysing and to adapt everything to the new status. Moreover, a distinction between the location of the electromagnetic disturbances has been made in [12], so we can differentiate between:

1	Residential-rural location
2	Residential-urban location
3	Commercial location (may include densely populated public areas)
4	Light industrial location
5	Heavy industrial location
6	Traffic area
7	Telecommunication centre
8	Hospital

But nowadays these locations tend to overlap their characteristics into each other and hence are less specific. Maybe more sub-classes will be included in the future. It is because of this overlaping that a working group (WG 13) from the IEC technical committee TC 77 is studying a new classification, specially above the 1 GHz range.

When characterizing an electromagnetic environment, it is necessary to deal with probabilistic variables, both in occurrence of the phenomena or with respect to its parameters. Sometimes it is impossible to take into account every statistical and probabilistic value, so some assumptions can be made in order to achieve a heuristic approach.

3.4 EMC design

We have seen that the law has created standards. These standards enforce some limits on the radiated and conducted emissions. However there are no laws for the amount of emissions an electronic device has to be able to withstand. Unfortunately there are so many sources of external disturbance: radars, radio, TV, WiFi. All electronic devices need a certain capacity to resist to all those interferences. This capacity is called immunity. In this part we will discuss some of the existing immunity methods.

3.4.1 Shielding

The easiest method consists in shielding the cables. This way we are preventing any induced currents in the wires. This is done by surrounding the conducting wire by a cylindrical conducting shield. For the shield to be perfect there should be no breaks or discontinuities in it. Even though the actual shields are never perfect, especially at the ends of the wire, the induced currents are small enough to be ignored. It is also possible to use braided shields. Instead of completely surrounding the conducting wire with a conductive element, having a thin wire make circles around the conductive wire is often enough and even more flexible. The immunity coming from braided shields is, of course, less efficient than the immunity coming from full shields. But the braided shields are easier and cost less than the full shields.

3.4.2 Power supply filter

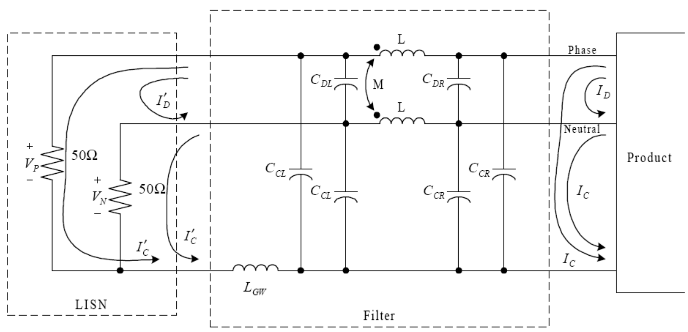

Figure 3.6: Layout of a basic power supply filter [2]

We will see in 4.2.2 a couple of very simple methods to reduce the conducted emissions. We can act directly on the ground wire or try to choose the appropriate type of power supply. Still the most efficient method is the power supply filter. We have seen that most conducted emissions come from current coupling back from the power cord. Thus it stands to reason that acting on the power supply is the easiest way to deal with these emissions. Power supply filters are a little bit different from the usual electric filter. Indeed, traditional electric filters are not enough to reduce conducted emissions as they will often not be able to filter the common modes of current. On the other hand, power supply filters are designed to reduce both differential and common modes of current.

The basic layout of a power supply filter is shown in 3.6. The goal of this filter is to reduce the differential and common modes of current from their original values I_d and I_c to the new values I'_d and I'_c. The new values are set to follow the regulations.

Chapter 4

Theory

4.1 Radiated Emissions

4.1.1 Overview

Radiated emissions are the unintentional emission of electromagnetic energy that comes out of an electronic device. As we have seen earlier, any electronic device generates an electromagnetic field. This field will always propagate away from the device thus creating the radiated emissions. Usually we associate radiated emissions with unintentional radiators. However, intentional radiators create emissions outside of their intended frequency band. These emissions are also unwanted and qualify as radiated emissions also.

We have seen that there are EMC standards created to regulate the radiated emissions from an electronic device. Because these emissions may interfere with the normal behaviour of other electronic devices at proximity. However, in order to create those standards and understand them, we need to understand the radiated emissions. In this chapter we will investigate their origin, the different ways to measure, or at least predict them and finally the methods that can be used to eliminate, or at least minimize them.

4.1.2 Fields created by the currents

The creation of the electromagnetic field that is the origin of the radiated emissions is the consequence of the currents that are carried by the conductors in an electronic device. In this part we will explain the theory that lies behind those currents.

A general current that runs on parallel conductors can be decomposed into two types: a differential mode of currents and a common mode.

- The differential mode of currents applies when the currents are equal in amplitude but run in opposite directions on the parallel conductors.
- The common mode of currents occurs when the amplitude and the direction are the same. This type of current is not taken care of in circuit theory. This is why they are the largest problems in EMC issues [13].

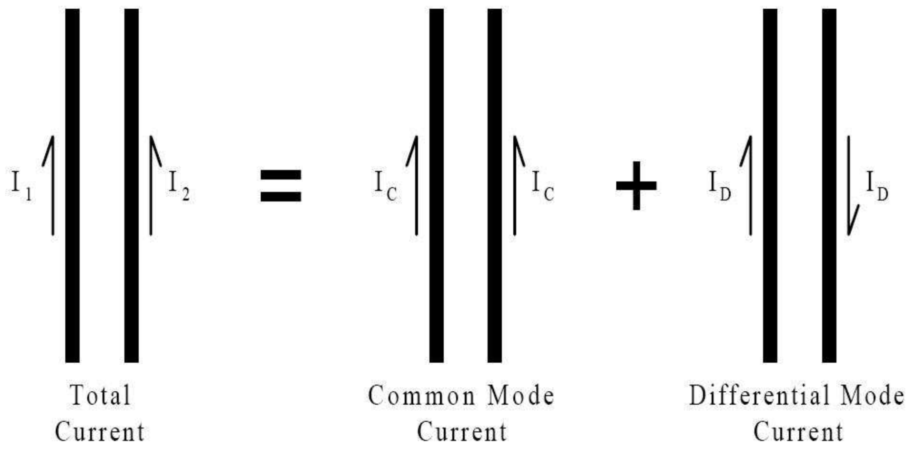

Figure 4.1: Differential and common modes of current

As shown in Figure 4.1 the differential and common modes of currents can easily be found:

$$I_d = \frac{I_1 - I_2}{2} \quad \text{and} \quad I_c = \frac{I_1 - I_2}{2} \tag{4.1}$$

Why is it important to make this distinction? Because of the electric fields created by the currents. In the case of differential mode of currents, the electric fields E1 and E2 created by the currents I1 and I2 are in opposite directions. Therefore if we get too close to the conductors there will be a small residue of those fields but they cancel each other at a distance. On the other hand, the fields created by common mode of currents are in the same direction. Therefore instead of canceling each other they sum up to become a bigger field.

In general, it is very complicated and very long to compute the exact radiating fields of an electronic device. This is why we use simple models to approximate them. These simple models are, of course, based on simple geometries.

Assuming a Hertzian dipole current distribution and the separation between the two wires on which the currents run to be small compared to the wavelength. In [13] it has been demonstrated that the radiation from a differential mode of currents depends on three factors. This is if we assume a fixed value for the distance of measurement r. Based on the following formula:

$$|\vec{E}_{max}(r)| = 1.317 * 10^{-14} \frac{f^2 Ls|I_d|}{r} \tag{4.2}$$

The factors are:

- Current magnitude: $|I_d|$
- Frequency of the current: f
- Size or area of the wires (meaning their length multiplied by the distance between them): Ls

As far as a common mode of currents goes, in the case where the same assumptions are made, we have the following formula:

$$|\vec{E}_{max}(r)| = 1.257 * 10^{6} \frac{f L|I_c|}{r} \tag{4.3}$$

The factors inducing radiated emissions are the same. However the distance between the wires is not as influential, even if the length of the wires is still important.

4.1.3 Current Probe

We now have a way of approximating the radiating fields from a device at a certain distance r based on the currents present in the system. However we still need to be able to differentiate the common mode from the differential one. Especially since common modes are mostly dependant on the geometry of the device and are usually not intended at all and are therefore very hard to predict. An EMC engineer will need to be able to measure those currents in order to predict the final radiated fields. In the following section we will describe the current probe which is a device that measures currents.

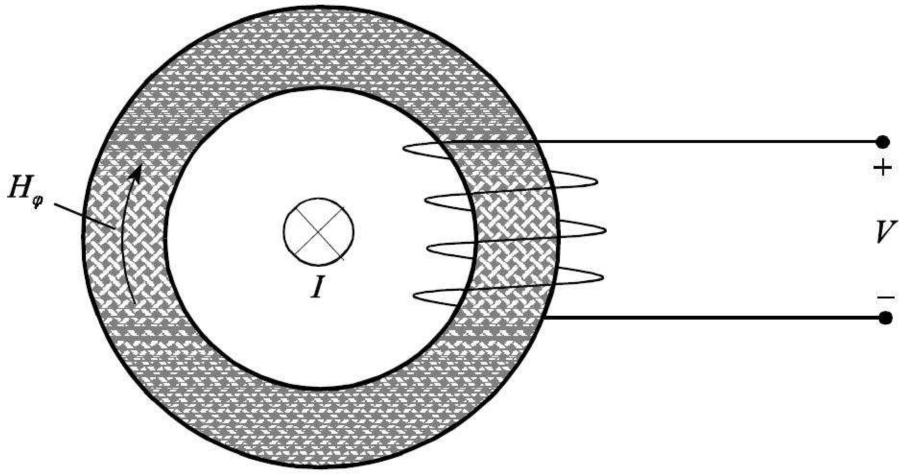

Figure 4.2: Diagram of a current probe

A current probe is a circle of ferrite with some thin wire making loops around it. The number of loops being important for the calculations. The ferrite must have a high permeability relatively to the frequency band that the probe will be measuring. The circle of ferrite constituting the probe is placed around the current we wish to measure. This current will create a directly proportional magnetic field in the ferrite (Ampere's law). This magnetic field will create an electric field inside the wire. The voltage resulting from this electric field is directly dependant on the magnetic field, thus the current we are measuring, and the number of turns made by the wire.

Current probes are a very effective way of measuring the maximum radiated field from a wire without having to use calibrated tools and complex procedures. But it is still just an approximation.

4.2 Conducted Emissions

4.2.1 Overview

Conducted emissions come from the electromagnetic field created inside the electronic device when it is coupled to the AC power cord. These emissions can find their way to the entire power distribution system and use this larger network to radiate more efficiently. This is why they are problematic.

As for radiated emissions, regulations exist. Typically, the range of frequencies where the conducted emissions are regulated is lower than that of the radiated emissions. Indeed, the longer wavelengths of conducted emissions need a much larger antenna than the ones usually present in the devices we are used to. As in the previous chapter, we will here investigate the origins of conducted emissions, a way to measure them and finally some methods to reduce conducted emissions will be presented.

4.2.2 Fields created by the currents

They are the same as the fields created for radiated emissions. They also come from either the differential or the current modes of current. As in the previous chapter, the common mode is the trickiest because it is usually unintended and therefore difficult to predict. However, we know that the current returning on the ground wire (usually the green or brown wire) is almost always present and therefore can be controlled.

The ground wire exists as a safety. It provides an alternative path for the current in the event of a ground fault. It gives the possibility to blow the circuit breaker or the fuse. But it is not intended to carry any current in normal use. However, at higher frequencies the ground wire does carry a current that can cause the device to fail the regulatory standards.

Two simple methods exist to help suppressing this conducted current in the ground wire. The first one consists in creating an inductance just after the ground wire has entered the device case. For this method, we make the ground wire circle around a ferrite core that has a high permeability. The inductance created by this method helps reducing the current in the ground wire. The second method consists in replacing the ground wire with a more complex two wire device that has the same use. We use a transformer right at the power input of the product that isolates it from the other two wires (neutral and phase) to reduce the risk of a hazard.

4.2.3 Power supplies

Even though the currents inside the electronic device do create conducted emissions, the biggest problem is the power supply. Indeed, most electronic devices rely on DC sources for power. The problem is that the conversion AC to DC creates a lot of high frequency noise. These frequencies may not interfere directly with the normal use of the product but they may create some conducted emissions on the power cord.

There are two types of power supplies that are usually used. The first one is the linear power supply. This power supply is the cleanest as far as conducted emissions are concerned for it does not create too many high frequency emissions. However this type of power supply is becoming obsolete because of its size and lack of efficiency in regard of the newest forms of power supplies. The second type is the switched mode power supply. It is more efficient (60 to 90 % whereas the linear one goes from 20 to 40 %) and much lighter than the linear power supplies. The switched mode power supply uses a MOSFET to transform the AC power to DC. Unfortunately, the MOSFET creates a lot of undesired conducted emissions as its frequency of operation is exactly in the range of emissions we want to reduce due to regulations.

4.2.4 LISN

The Line Impedance Stabilization Network (or LISN) is a method used to measure the conducted emissions of an electronic device. The reason we use the LISN instead of the current probe is because the regulations specify that the measurements must be independent from the environment they are made in. Unfortunately, the currents exiting the electronic device under investigation are subjected to the load on the power input. This load is not fixed and can change from an environment to another (different rooms or different buildings do not necessarily have the same load). Thus the current probe cannot be used in these cases as it does not take this load into account. The LISN on the other hand stabilizes the impedance seen by the electronic device. Also the LISN has the advantage of blocking any conducted currents coming from the power network into the electronic device.

The LISN is plugged between the electronic device we are investigating and its power input. Below is a diagram showing the layout of a specific LISN.

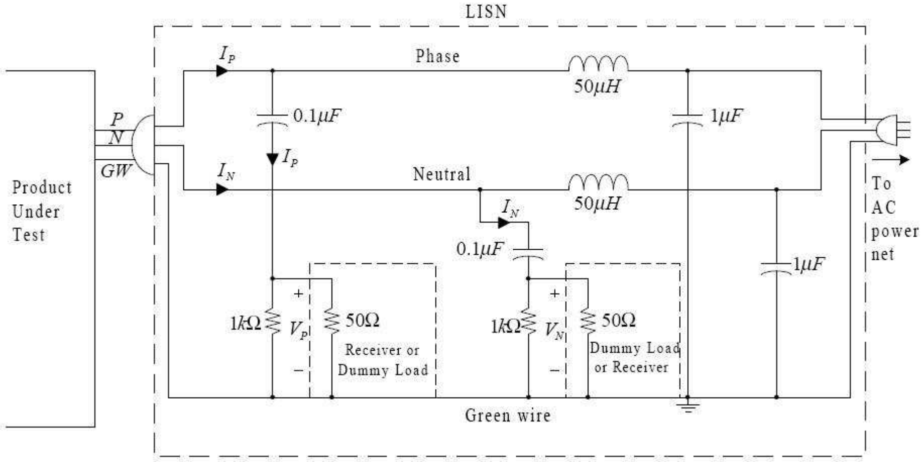

Figure 4.3: LISN [2]

4.3 Numerical methods for EMC

In order to measure and analyse the effects of the EMI (Electromagnetic Interferences) in the EMC studies, it is needed to compute the near fields produced by different devices and the far fields associated to them. Through several decades computer equipment have suffered a great evolution, however it was also needed to develop, use and improve new and different numerical methods for this purpose.

Typical EMC problems that these methods must face are: computation of shielding effectiveness, coupling into lines or cables, analysis of printed circuit boards (PCB's), resonance effects, radiation from antennas and the investigation of low-frequency magnetic fields [9]. These problems could involve great ranges of frequencies, sizes, shapes and unknowns.

There is no "global" method which could be used in every situation. It will depend on the situation and the specific circumstances, although in the latter years FDTD has revealed itself as the most popular way to deal with these problems. This is because FDTD is applicable to open-space problems using the perfectly matched layer (PML) technique. Another well known technique is the method of moments (MoM) which is able to cover a very wide frequency range.

However, it is only recommended to use it when the structures are small in comparison to their wavelength. This is due to the exponential increase of computational time [9]. There are also some useful methods like the transmission-line matrix (TLM) and the finite-element method (FEM).

4.3.1 Basics of numerical methods

All the numerical methods have the same principle: trying to approximate the solution to the Maxwell's equations satisfying the initial and boundary conditions respectively. To do that, numerical methods approximate the solution function into a sum of known functions, called *expansion or basis functions* like it is shown in [9]. One example of this could be the Fourier series expansion.

$$f(x) \simeq \sum_{n} \alpha_n \cdot f_n(x) \tag{4.4}$$

Basically, the solution is made by a approach consisting in a sum of known functions with unknown coefficients which mus be estimated. The differences between the numerical methods are mainly [10]:

- Which electromagnetic property is being approximated: fields, potentials, currents ...
- Which expansion functions are being used: in the field space, defined on boundaries ...
- How are computed the coefficients: different algorithms.

Numerical methods are also classified in time domain or frequency domain techniques, as well as 1D, 2D, 2.5D or 3D methods in function of the space variables.

4.3.2 Method of moments (MoM)

It has been demonstrated that methods using integral equations are really useful and powerful for computing electromagnetic fields. The MoM is based on solving problems in the form of electric field integral equation (EFIE) or a magnetic field integral equation (MFIE):

$$\text{EFIE} \quad L_e^{-1} J = E \tag{4.5}$$

$$\text{MFIE} \quad L_m^{-1} J = H \tag{4.6}$$

where J is the current density, E and H are the field functions and L is the inverse operator involving Green's functions which depend on the boundaries and material distribution of the specific problem. Usually this method is applied in the frequency domain but few time-domain applications exist.

Depending on the basis and weighting functions chosen and the discretization procedures, there are several different versions of MoM. However, it is frequently used with the surface-current formulation which means that the surface must be discretized properly. It is desired that in the future MoM will be able to deal with more complex and larger structures [9]. Also, mixed techniques have been used to reduce the computation time, like MoM with physical optics (PO) and geometric theory of diffraction (GTD/UTD). This mixing of techniques helps dealing with larger and more complex structures.

4.3.3 Finite element method

This is another popular method used in electromagnetics which consists in solving partial derivative equations (PDE). Normally the unknown functions to calculate are either a field or a potential. The expansion functions are always subsectional because the field domain must be discretized instead of the boundary domain (like in MoM), hence it provides great flexibility to solve the problem. These subdomains are the so-called finite elements. This algorithm is based on looking for the optimum solution which minimizes the electromagnetic energy of a system. Usually most implementations are done in the time harmonic or frequency domain.

In contrast with the method of moments, exterior or open problems do not suit really well with FEM. The solution must be truncated since it is impossible to cover the whole free space with subdomains. Although some advances, such as the Perfectly Matched Layer (PML) have been made.

4.3.4 Finite difference time domain method

This method is based in the Maxwell's differential equations, the whole domain under study is discretized and it is applied in the time domain. The roots of this technique for these purposes are dated in the 1966 Yee paper [18] where the Yee cell has its origin. The Yee algorithm solves both, electrical and magnetic field. As can be seen in Fig. 4.4, the fields are centered in time and space and both are calculated from Maxwell's curl equations.

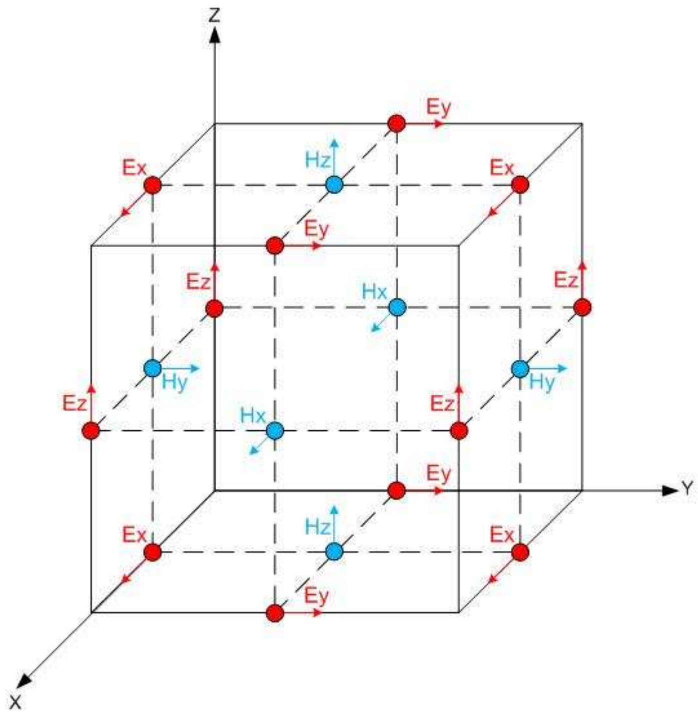

Figure 4.4: The Yee cell.

Some reasons why this method is so popular nowadays are exposed in [9]:

- Complete understanding of the numerical properties like stability, accuracy, dispersion and gridding effects.
- Developed absorbing boundary conditions.
- Adaptation to radiation and scattering problems with the total field/scattered field formalism, plane-wave sources and near-to-far-field transformations.

- Adaptation to microwave engineering problems with appropriate waveguide sources, lumped elements and extraction of network parameters.
- Coupling with thermal solvers, circuit simulators and semiconductor device solvers.
- Modelling of dispersive material.
- Efficient treatment of oblique, very thin, or very small features.
- Generalization of the Yee grid to non-orthogonal unstructured grids and adaptation to periodic or axial symmetric bodies.

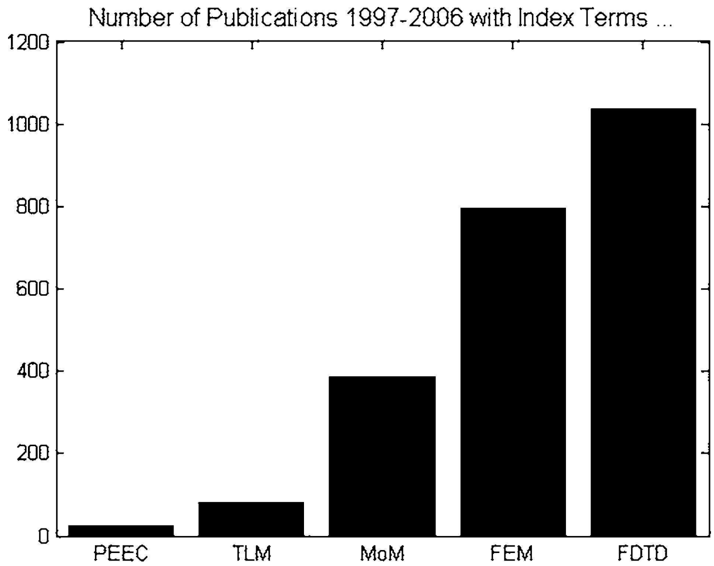

Figure 4.5: FDTD popularity [9].

Such advantages have made the FDTD a method which has been used in almost every problem.

But there are some situations where FDTD still seem to have some difficulties. When the treatment of the problem includes unbounded spaces, frequency dependence or when the time is too small. FDTD is not the best option.

4.3.5 Transmission line matrix method

This technique has been widely used to compute the 3-D electromagnetic fields numerically. It is based on the analogy of electromagnetic wave and the propagation of impulses in transmission line networks [9], where these transmission lines are shunt-connected and the nodes are acting as scattering points for voltages impulses, involving incident and reflected waves. This method has a considerable computational effort and it is formulated in the time domain mainly. It is able to represent electric and magnetic fields through voltages and currents. The basic structure for this is the symmetrical condensed node (SCN), shown in Fig. 4.6.

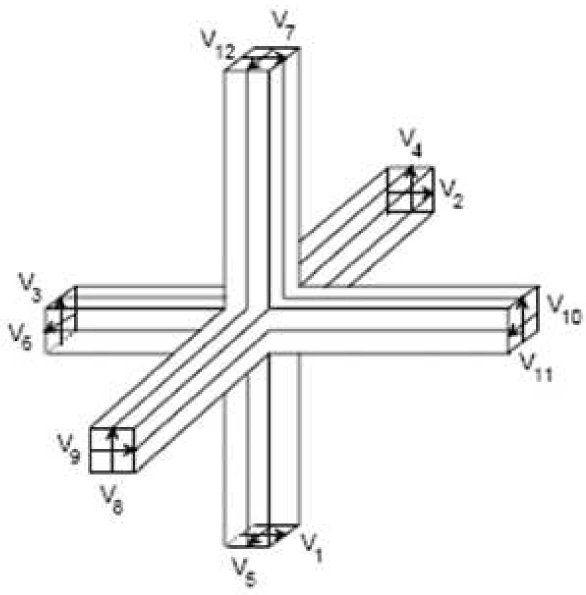

Figure 4.6: 3-D condensed TLM node proposed by P. B. Johns in 1986

Thus, TLM is based on the incident and scattered impulses in these nodes in each time step. In one time step, according to Fig. 4.6, 12 voltages pulses, one for each port (2 per transmission line) achieves the SCN and in the next time step, they are reflected and became incident pulse in the neighbouring nodes. The repetition of these steps provides the desired information about the system.

4.4 Near to far field transformation

We know how the use of the FDTD method will help us calculating the electromagnetic fields in the near field region. We could also use this method to calculate the far field region. But we have seen that the computation time of the FDTD method is very long. Thus, the larger the space we want to calculate the longer it will take. This is why we prefer using a near to far field transformation.

In this chapter we will show how using the free space Green's function in two dimensions we are able to calculate the far field response of an antenna. For this calculation, we need to know the electromagnetic near fields computed by FDTD and the tangential to a surface completely surrounding the original source of the radiation [16]. This surface is usually rectangular to fit the original FDTD Cartesian grid. Then we will use the Surface Equivalent Theorem [8] to expand this two dimensional demonstration into three dimensions in order to find the complete far field response [17]. Finally we will present some equations to calculate the field in any point of space from the surface currents.

4.4.1 Green's theorem

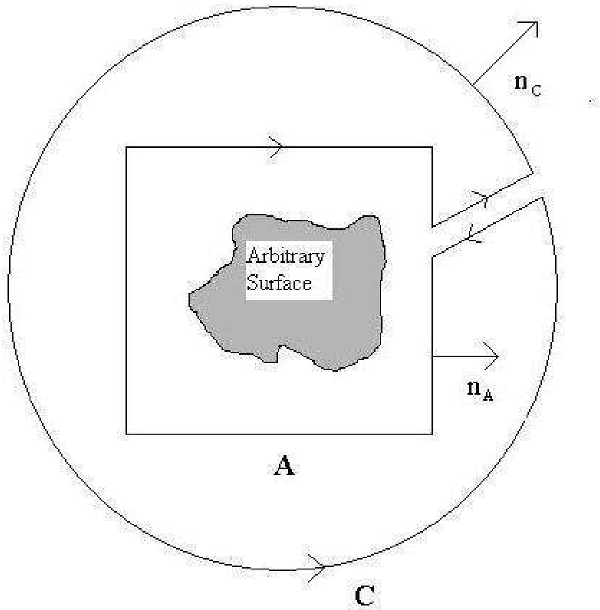

Figure 4.7: Integration contours used for Green's Theorem in two dimensional radiation

Let us consider, in 4.7, that the rectangle A and the circle C are centered on the origin of the coordinate system and that C has an infinite radius. They are connected by an infinitely long and thin path to create a closed surface around the Arbitrary Structure S. The direction given on the figure is to create a positive unit normal dS. The fields involved are E_z, H_x and H_y.

With those hypothesis made, we can now apply the Green's theorem to the scalar functions $E_z(\bar{r})$ and $G(\bar{r}|\bar{r}')$:

$$\begin{aligned}\textstyle\int_S[E_z(\bar{r}')(\nabla^2)'G(\bar{r}|\bar{r}') - G(\bar{r}|\bar{r}')(\nabla^2)'E_z(\bar{r}')]dS' \\ = \textstyle\oint_C[E_z(\bar{r}')\frac{\partial G(\bar{r}|\bar{r}')}{\partial r'} - G(\bar{r}|\bar{r}')\frac{\partial E_z(\bar{r}')}{\partial r'}]dC \\ - \textstyle\oint_A[E_z(\bar{r}')\frac{\partial G(\bar{r}|\bar{r}')}{\partial n'} - G(\bar{r}|\bar{r}')\frac{\partial E_z(\bar{r}')}{\partial n'}]dA\end{aligned} \tag{4.7}$$

In this equation, $\bar{r}$ represents an observation point anywhere in space and $\bar{r}'$ is a source point.

In the integral around C, both scalar functions decay as $\frac{1}{\sqrt{r'}}(r \to \infty)$, so the contribution of this integral is null. The same calculations cannot be applied to the integral around A.

Now let us consider the first term of the equation. Green's theorem gives us:

$$(\nabla^2)'G(\bar{r}|\bar{r}') = \delta(\bar{r} - \bar{r}') - k^2G(\bar{r}|\bar{r}') \tag{4.8}$$

And the Helmholtz equation gives us:

$$(\nabla^2)E_z(\bar{r}') = -k^2E_z(\bar{r}') \tag{4.9}$$

If we substitute those two results in the first term of 4.8:

$$\begin{aligned}\textstyle\int_S[E_z(\bar{r}') * [\delta(\bar{r} - \bar{r}') - k^2G(\bar{r}|\bar{r}')] - G(\bar{r}|\bar{r}') * [-k^2E_z(\bar{r}')]]dS' \\ = \textstyle\int_S E_z(\bar{r}')\delta(\bar{r} - \bar{r}')dS' \\ = E_z(\bar{r})\end{aligned} \tag{4.10}$$

Therefore 4.8 becomes:

$$E_z(\bar{r}) = \oint_A[G(\bar{r}|\bar{r}')\frac{\partial E_z(\bar{r}')}{\partial n'} - E_z(\bar{r}')\frac{\partial G(\bar{r}|\bar{r}')}{\partial n'}]dA \tag{4.11}$$

4.4.2 Surface Equivalence Theorem (SET)

When dealing with EMC, near fields effects must be taken into account between the different modules placed in the same device. But there is also the possibility of this device interfering another equipments in the surrounding scenario. These cases occur when we move away several wavelengths from the source and it is necessary to compute the so-called far fields. Since FDTD method deals with tiny sizes, it would be an extremely large problem to model it in that way. The solution and most common way to deal with this problem, is to use the *surface equivalent method* to calculate far fields from near fields obtained through and FDTD implementation.

This principle establishes that only knowing the tangential magnetic and electric currents in the contour of our interest, we can obtain the far fields through an integration. In our case we can enclose our source inside an imaginary surface and assume that the fields $\bar{E}_1$ and $\bar{H}_1$ are generated due to the surface currents $\bar{M}_1$ and $\bar{J}_1$ respectively like it is showed in Figure 4.8.

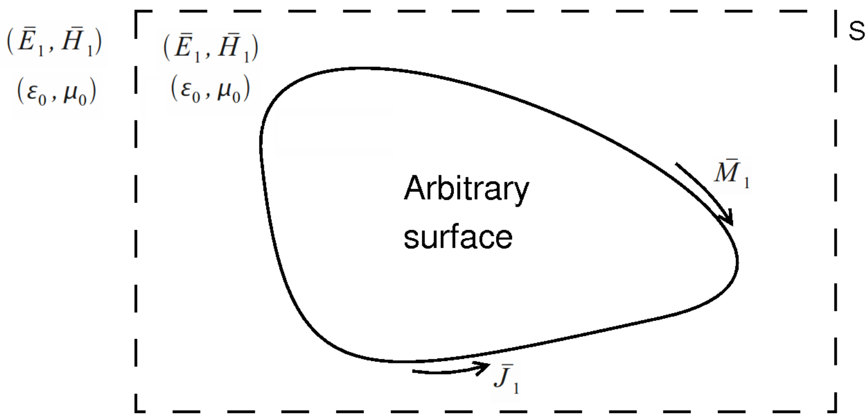

Figure 4.8: Start problem for the surface equivalent method

If we continue developing the problem, we can now assume that we remove $\bar{M}_1$ and $\bar{J}_1$ and then we have new fields $\bar{E}$ and $\bar{H}$ inside the surface S which enclosed our source. However, the fields we wish to calculate are $\bar{E}_1$ and $\bar{H}_1$, outside S.

Hence, as it is shown in Figure 4.9, to satisfy electromagnetic boundary conditions regarding the tangential component of the fields it must occurs:

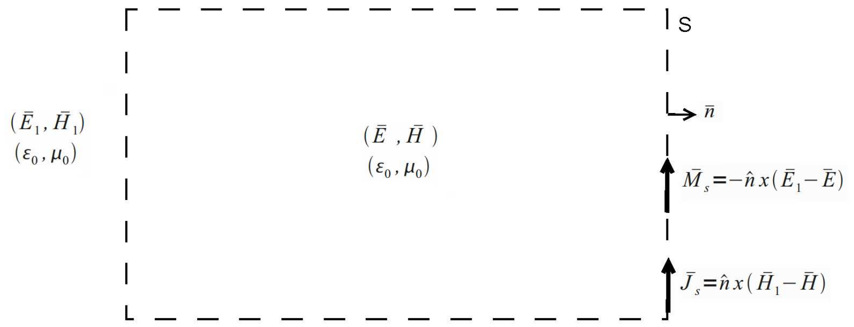

Figure 4.9: Intermediate problem.

$$\bar{M}_s = -\hat{n} \times (\bar{E}_1 - \bar{E}) \tag{4.12}$$

$$\bar{J}_s = \hat{n} \times (\bar{H}_1 - \bar{H}) \tag{4.13}$$

where $\hat{n}$ is the normal vector to surface S. Since these currents produces the fields $\bar{E}_1$ and $\bar{H}_1$ outside the surface S and the information inside S has no importance in order to compute the far fields, we are able to assume that $\bar{E}$ and $\bar{H}$ are 0 inside S. This useful assumption simplifies our problem like it is showed in Figure 4.10. From equations 4.12 and 4.13:

$$\bar{M} = -\hat{n} \times (\bar{E}_1 - \bar{E}) = -\hat{n} \times \bar{E}_1 \tag{4.14}$$

$$\bar{J}_s = \hat{n} \times (\bar{H}_1 - \bar{H}) = \hat{n} \times \bar{H}_1 \tag{4.15}$$

In our case of interest, in 3 dimensions, the source will be enclosed by a cube. On each of its six sides there will exist these currents. According to [15], it is possible to define the following vector potentials which will be used to calculate the far-fields:

$$\bar{A} = \frac{\mu_0}{4\pi} \int\int_S \bar{J}_s \frac{e^{-jkR}}{R} ds' \cong \frac{\mu_0 e^{-jkR}}{4\pi r} \bar{N} \tag{4.16}$$

$$\bar{A} = \frac{\varepsilon_0}{4\pi} \int\int_S \bar{M}_s \frac{e^{-jkR}}{R} ds' \cong \frac{\varepsilon_0 e^{-jkR}}{4\pi r} \bar{L} \tag{4.17}$$

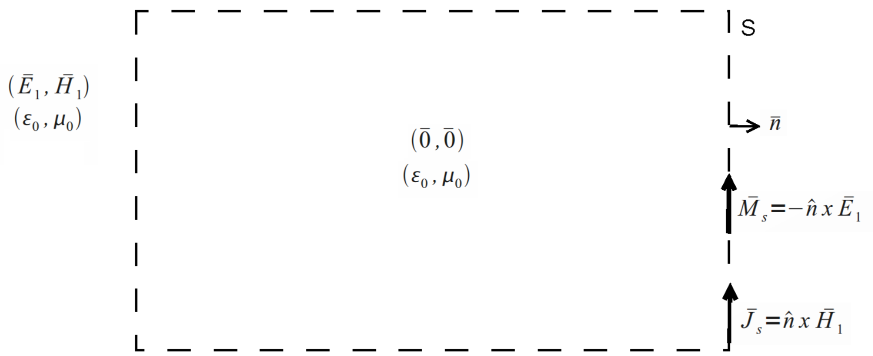

Figure 4.10: Final equivalent problem.

where:

$$\bar{N} = \int\int_S \bar{J}_s e^{-jkr' \cos\varphi} ds' \tag{4.18}$$

$$\bar{L} = \int\int_S \bar{M}_s e^{-jkr' \cos\varphi} ds' \tag{4.19}$$

$\bar{r} = r\hat{r} \equiv$ position of observation point (x,y,z)

$\bar{r'} = r'\hat{r} \equiv$ position of source point on S (x',y',z')

$\bar{R} = R\hat{R} \equiv \bar{r} - \bar{r}'$

$\varphi \equiv$ angle between $\bar{r}$ and $\bar{r}'$

and where R is given by the low of cosines in the far field:

$$R = \sqrt{r^2 + (r')^2 - 2rr' \cos\varphi} \cong \begin{cases} r - r' \cos\varphi & \text{for phase variations} \\ r & \text{for amplitude variations} \end{cases} \tag{4.20}$$

Finally, the general expressions given by the vector potentials are:

$$\bar{E} = -jw[\bar{A} + \frac{1}{k^2} \bigtriangledown (\bigtriangledown \cdot \bar{A})] - \frac{1}{\varepsilon_0} \bigtriangledown \times \bar{F} \tag{4.21}$$

$$\bar{H} = -jw[\bar{F} + \frac{1}{k^2} \bigtriangledown (\bigtriangledown \cdot \bar{F})] - \frac{1}{\mu_0} \bigtriangledown \times \bar{A} \tag{4.22}$$

If we neglect the factors depending on r in the form $\frac{1}{r^2}$ and the radial components of the fields we can write:

$$E_r \bar{\cong} 0 \tag{4.23}$$

$$\bar{E_\theta} \cong -jw(\bar{A_\theta} + \eta_0 \bar{F_\phi}) = -\frac{jke^{-jkr}}{4\pi r}(\bar{L_\phi} + \eta_0 \bar{N_\theta}) \tag{4.24}$$

$$\bar{E_\phi} \cong -jw(\bar{A_\phi} + \eta_0 \bar{F_\theta}) = \frac{jke^{-jkr}}{4\pi r}(\bar{L_\theta} + \eta_0 \bar{N_\phi}) \tag{4.25}$$

$$H_r \bar{\cong} 0 \tag{4.26}$$

$$\bar{H_\theta} \cong \frac{jw}{\eta_0}(\bar{A_\phi} - \eta_0 \bar{F_\theta}) = \frac{jke^{-jkr}}{4\pi r}(\bar{N_\phi} - \frac{\bar{L_\theta}}{\eta_0}) \tag{4.27}$$

$$\bar{H_\phi} \cong \frac{-jw}{\eta_0}(\bar{A_\theta} + \eta_0 \bar{F_\phi}) = -\frac{jke^{-jkr}}{4\pi r}(\bar{N_\theta} + \frac{\bar{L_\phi}}{\eta_0}) \tag{4.28}$$

where $\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$

Putting $\bar{N}$ and $\bar{L}$ in form of Cartesian coordinates:

$$\bar{N} = \int\int_S (\hat{x}\bar{J_x} + \hat{y}\bar{J_y} + \hat{z}\bar{J_z}) e^{jkr' \cos\varphi} ds' \tag{4.29}$$

$$\bar{L} = \int\int_S (\hat{x}\bar{M_x} + \hat{y}\bar{M_y} + \hat{z}\bar{M_z}) e^{jkr' \cos\varphi} ds' \tag{4.30}$$

And now, transforming into spherical coordinates substituting in 4.24, 4.25, 4.27 and 4.28, we obtain:

$$\bar{N_\theta} = \int\int_S (\bar{J_x}\cos\theta\cos\phi + \bar{J_y}\cos\theta\sin\phi - \bar{J_z}\sin\theta) e^{jkr' \cos\varphi} ds' \tag{4.31}$$

$$\bar{N_\phi} = \int\int_S (-\bar{J_x}\sin\phi + \bar{J_y}\cos\phi)e^{jkr'\cos\varphi}ds' \tag{4.32}$$

$$\bar{L_\theta} = \int\int_S (\bar{M_x}\cos\theta\cos\phi + \bar{M_y}\cos\theta\sin\phi - \bar{M_z}\sin\theta)e^{jkr'\cos\varphi}ds' \tag{4.33}$$

$$\bar{L_\phi} = \int\int_S (-\bar{M_x}\sin\phi + \bar{M_y}\cos\phi)e^{jkr'\cos\varphi}ds' \tag{4.34}$$

The surface of integration S will be a box centred symmetrically in the coordinate origin and with side dimensions x_0,y_0,z_0.

4.4.3 Calculate field

The previous sections explained how we could obtain the far fields. In this section we will present equations to calculate the fields in any point of space. This procedure **??** is done in two steps. First we calculate the vector potentials A and F using the surface currents J and M. Then the electric, E and magnetic, H fields can be determined.

The vector potentials A and F

Lets consider the magnetic flux density $B = \mu H$. In a source free region $\nabla B = 0$. Therefore, we can define the magnetic flux density as $B = \nabla \times A$ where A is an arbitrary vector. By combining this we have:

$$\boxed{H_A = \frac{1}{\mu}\nabla \times A} \tag{4.35}$$

Maxwell's curl equation $\nabla \times E_A = -j\omega\mu H_A$ and **??** gives:

$$\nabla \times E_A = -j\omega\nabla \times A \tag{4.36}$$

also written:

$$\nabla \times [E_A + j\omega A] = 0 \tag{4.37}$$

Then we can combine 4.37 with the vector identity formula $\nabla \times (-\nabla\phi_E) = 0$, where ϕ_E is an arbitrary electric scalar. We have:

$$E_A = -\nabla\phi_E - j\omega A \tag{4.38}$$

Then we take $\nabla \times \nabla \times A = \nabla(\nabla A) - \nabla^2 A$ and by using **??**:

$$\mu\nabla \times H_A = \nabla(\nabla A) - \nabla^2 A \tag{4.39}$$

Maxwell's equation $\nabla \times H_A = J + j\omega\epsilon E_A$ combined with equation 4.39 leads to:

$$\mu J + j\omega\mu\epsilon E_A = \nabla(\nabla A) - \nabla^2 A \tag{4.40}$$

Finally, substituting 4.38 into 4.40 gives us:

$$\boxed{\nabla^2 A + \beta^2 A = -\mu J} \tag{4.41}$$

Where $\beta^2 = \omega^2\mu\epsilon$. In addition:

$$\boxed{E_A = -j\omega A - j\tfrac{1}{\omega\mu\epsilon}\nabla(\nabla A)} \tag{4.42}$$

By using the electric flux density defined as: $D_F = -\nabla \times F$, we obtain the following equations for the second vector potential F:

$$\boxed{E_F = -\tfrac{1}{\epsilon}\nabla \times F} \tag{4.43}$$

$$\boxed{\nabla^2 F + \beta^2 F = -\epsilon M} \tag{4.44}$$

Where $\beta^2 = \omega^2\mu\epsilon$.

$$\boxed{H_F = -j\omega F - \tfrac{j}{\omega\mu\epsilon}\nabla(\nabla F)} \tag{4.45}$$

The electric and magnetic fields E and H

It is now very easy for us to find the electric and magnetic fields at any point in space. Indeed, the total fields are just the sum of the fields created by the vector potentials. Therefore:

$$\boxed{E = E_A + E_F = \frac{1}{j\omega\epsilon}\nabla \times H_A - \frac{1}{\epsilon}\nabla \times F} \tag{4.46}$$

And

$$\boxed{H = H_A + H_F = \frac{1}{\mu}\nabla \times A - \frac{1}{j\omega\mu}\nabla \times E_F} \tag{4.47}$$

Chapter 5

Solution

5.1 Creation of the code

The problem on which this report is focused is the radiated emissions. These kind of emissions could cause unexpected interferences in some devices susceptible to be influenced by them. Such devices are present in the environment in which the product under study is located.

When studying the capability of an electromagnetic device to cause some disturbance, we must measure the intensity of the disturbance to the nearby environment. A module of a PCB, for example, could create some problems or difficulties to other modules around it. Such environments are tending to be smaller and smaller every day. Due to that fact, near fields have become an important part of the study of EMC. However, while focusing on these near fields and closer parts to quantify the electromagnetic interference, the far fields which derive from these small near fields have to be taken into account too.

It is possible to design an integrated system where all the modules are perfectly working without disturbing the rest of them and, therefore, satisfying the standards. But at the same time it could be possible that this system, due to the far fields derived from this performance, which are propagated across the environment, is creating harmful interferences to other susceptible systems, preventing them from working properly.

In order to be able to add this problem to the study of an EMC design, a code to make a near to far field transformation has been made following the theory exposed in 4.4.

5.1.1 Validation of the code

A Matlab script was written to be able to compute the far fields from the near fields obtained. To be sure that the code developed is correct and applicable to every case, a dipole was the starting point to validate it. Because the radiation pattern of this antenna is well known, it is a perfect way ensure the efficiency of the computation.

The near fields which were the starting point, have been calculated using a Matlab code developed at Aalborg University known as *AAU3*. The computation makes an FDTD simulation and obtains the fields from it by using an Fourier transform. Figure 5.1 shows the scenario which was simulated, including the FDTD boundaries.

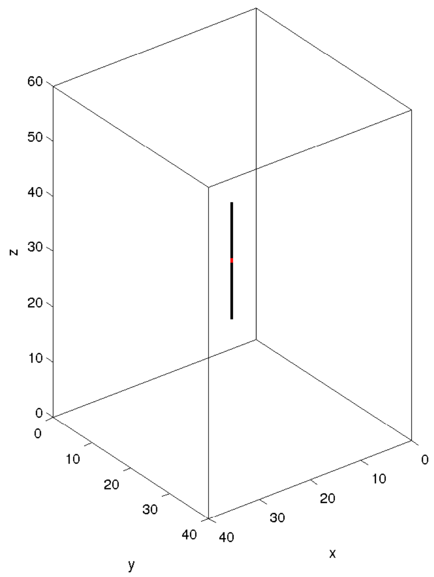

Figure 5.1: Dipole and FDTD boundaries simulated to obtain the near fields

Figure 5.2 illustrates the idea of the local importance of near field and why they are important to the closest devices.

As it is explained in 4.4.2, it is necessary to select a surface enclosing the dipole in order to be able to apply the Surface Equivalence Theorem. Due to the fact that the cell size used in this simulation was 5 milimiters it seems enough to use a 5 cell separation between the dipole and the surface. This fact is shown in Figure 5.3.

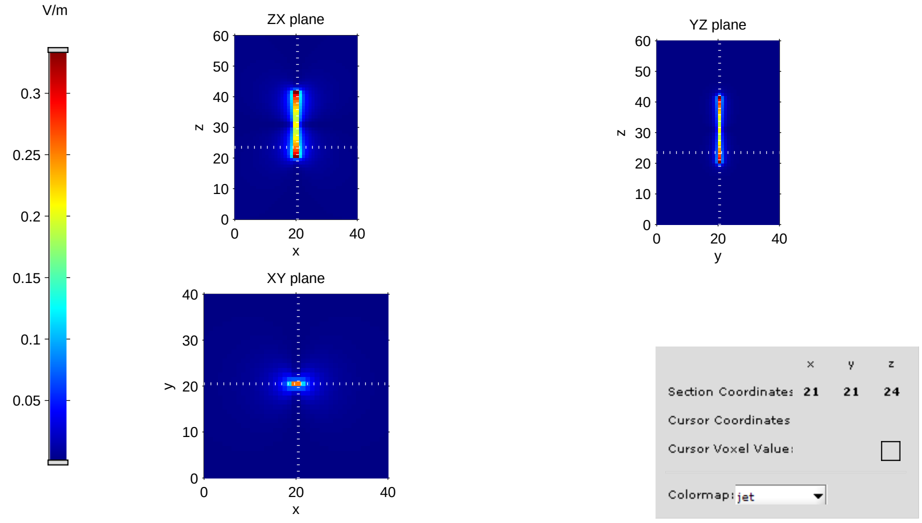

Figure 5.2: Near field E_x component computed by an FDTD simulation using the AAU3 code

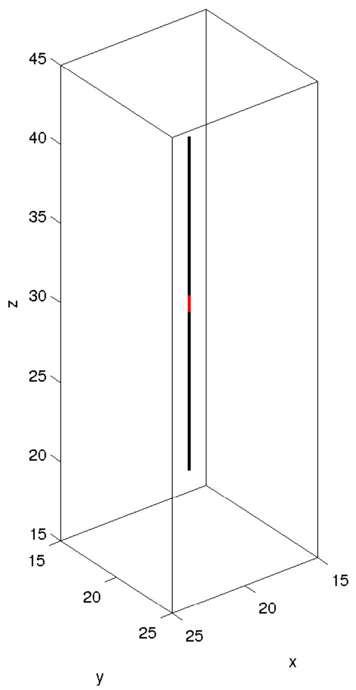

Figure 5.3: Surface enclosing the dipole to be used in the SET

Taking the near-fields obtained from the *AAU3* code simulation it is possible to apply the SET calculations explained in 4.4.2 to eventually be able to calculate the far-fields. From those far-fields we obtain the radiation pattern to, finally, assure that the code is working properly. Figures 5.4 and 5.5 show the results of this process. We can see that the radiation pattern from our calculations coincides with of the ideal dipole. Therefore, the script is correct and can be applied to any case under test.

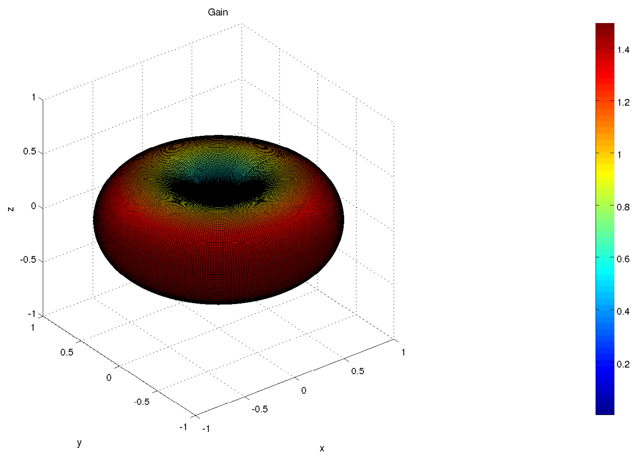

Figure 5.4: 3D radiation pattern of the far field obtained

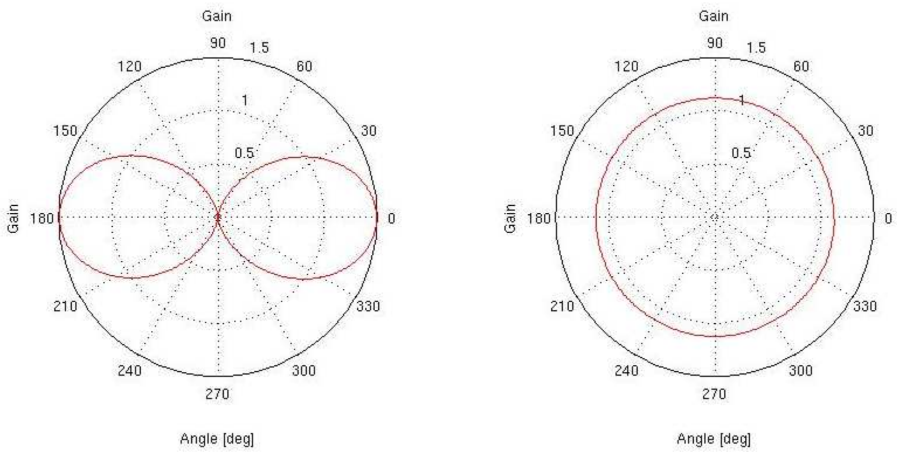

Figure 5.5: Radiation pattern in planes XY and YZ

5.2 Study of a real case

One of the problems of EMC design is that sometimes the previsions do not coincide with the real results. The aim of this section is to try to study a real case and to find which type of problems are necessary to deal with.

The device which has been studied is a small antenna (e.g. a cell phone antenna). The measures were obtained in an anechoic chamber by Bang & Olufsen employees. The antenna was placed over a module which was rotating in order to capture the measures of the near fields. The data was obtained scanning 3 planes around the antenna, as is shown in Figure 5.6.

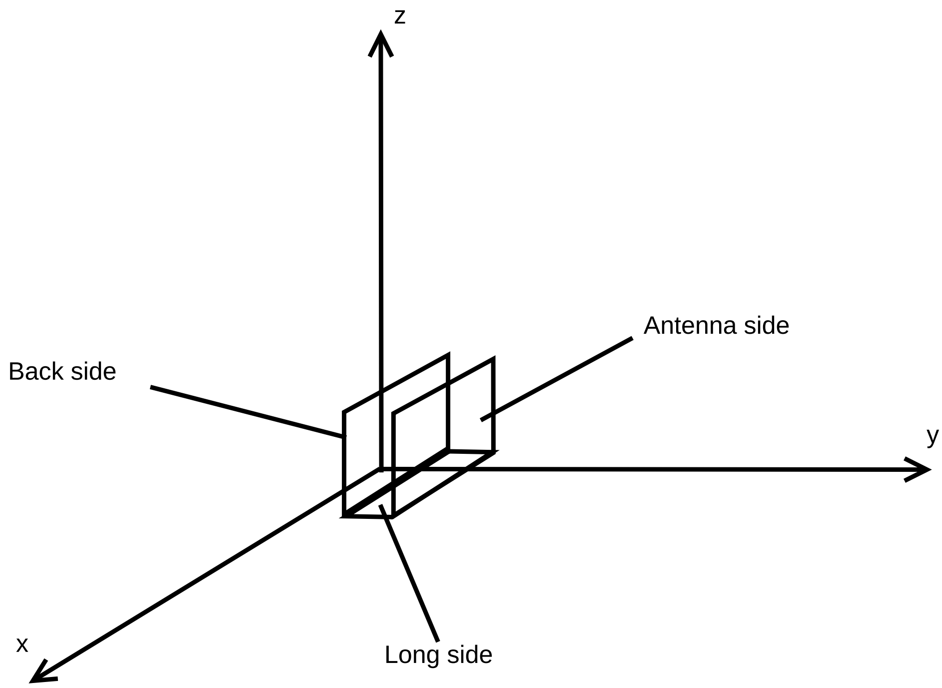

Figure 5.6: Scheme of planes where the measurements were taken

In order to calculate and study the rest of the near fields, it is possible to obtain some information from the initial data. The scanning took place over the plane surfaces indicated in Figure 5.6, therefore they include 2 field components per plane. The module rotated for every scan to place every surface over the XY plane. This was just a method to make the measurement process easier. Indeed, when applying the SET this problem is geometrically solved faithfully following the Figure 5.6, where the planes which were not scanned are supposed to have value

0 for their near fields.

When trying to quantify the influence of the near fields it is obviously important to know in which frequencies the field strength takes place. In this case the range of study was from 30 Mhz to 1 Ghz. The result of this search is shown in Figure 5.7 for the antenna side, 5.8 for the long side and 5.9 for the back side.

Both field components, x and y, are interdependent in each plane, so the peaks appear at the same frequencies. For the back and long side, peaks appeared in frequencies: 70, 150, 400, 630 MHz and in the margin between 800 and 1 GHz, these last ones being the most important. However, in the antenna side, peaks are observed around 100–200, 300, 400, 460, 550, 630 and 800–1 GHz. The reason why this plane is more susceptible to the field is because it is the one where the antenna is oriented to.

The data provided by Bang & Olufsen about the far field were measured in an anechoic chamber. The bandwidth was 120 kHz and the measure time of 1000 ms. The data is presented in Table 5.1. It is significant to see that the peaks which were observed in the near field hardly match the ones obtained from the measurement made from the far field. Only in a few cases there seems to be some obvious relation between both strength distributions (150, 799,98 and 933,33 MHz) and a small relation in others (225 MHz). Apparently the field polarization is not important on this issue.

An important fact to consider is that the high far field peaks do not match the ones in the near field. Only at frequency 799.98 is it possible to find this coincidence but it is absolutely non existent at 666.66, where the highest far field value appears. This is an important and a really revealing fact because it shows that when designing a system under the EMC standards, the far field environment is completely different from the field situated closer to the source.

5.3 Field intensity distrubution

The measures of the peaks were made in an anechoic chamber, placing a receiver at a constant distance of 3 meters away from the module which was emitting and placed 90 cm high. The high peaks for the transmitter in each frequency measured are shown in Table 5.1. Applying a simple trigonometric relation (see 5.1) we obtain the theta angles for each case just doing $\theta = 90 - \alpha$.

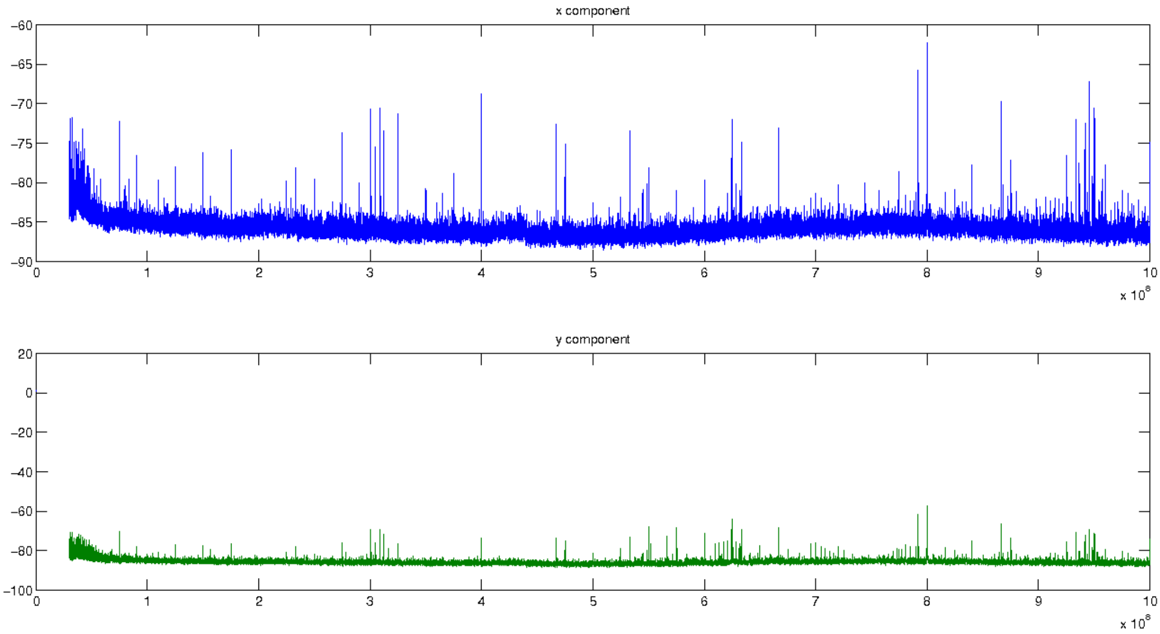

Figure 5.7: Frequency pikes for antenna side plane

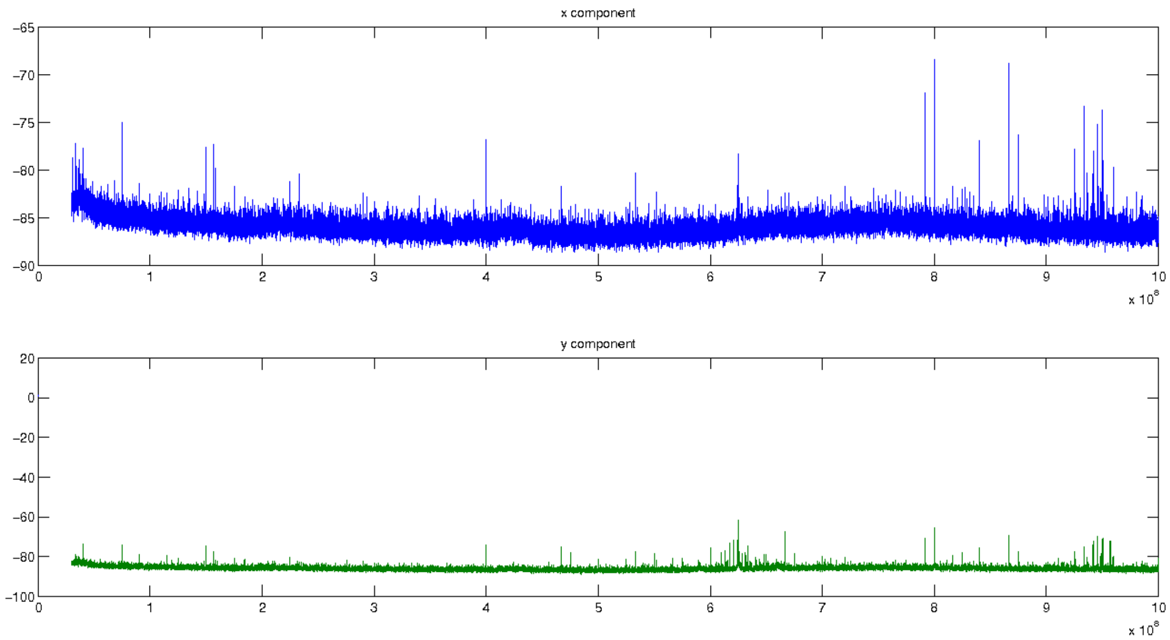

Figure 5.8: Frequency pikes for long side plane

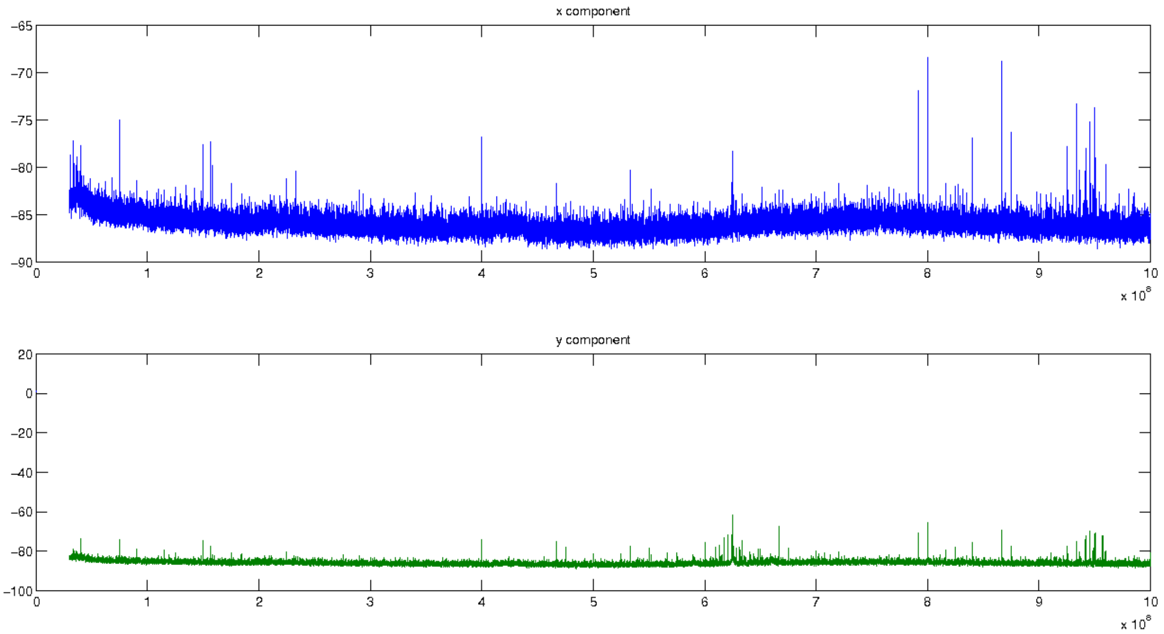

Figure 5.9: Frequency pikes for back side plane

Frequency (Mhz)	QuasiPeak (dbμV)	Heigh (cm)	Azimuth (deg)	Polarization
38.670000	25.7	90.0	167.0	V
150.000000	30.9	187.0	37.0	H
174.990000	44.4	133.0	17.0	H
187.500000	37.9	149.0	15.0	H
200.010000	41.6	123.0	22.0	H
225.000000	40.0	207.0	165.0	V
300.000000	42.0	90.0	7.0	H
349.980000	41.9	172.0	112.0	V
666.660000	56.7	110.0	187.0	H
799.980000	52.8	90.0	7.0	H
924.990000	45.2	90.0	352.0	V
933.330000	46.1	90.0	330.0	V
984.630000	43.4	90.0	341.0	V
1000.000000	42.5	90.0	37.0	V

Table 5.1: Measurements of an electromagnetic interferences in an anechoic chamber

$$\alpha = \arctan \frac{h_{rx} - h_{tx}}{300} \tag{5.1}$$

The table with both angles is shown in 5.2.

Frequency (Mhz)	Azimuth [ϕ](deg)	Θ (deg)
38.670000	167.0	71.13
150.000000	37.0	81.76
174.990000	17.0	78.66
187.500000	15.0	83.68
200.010000	22.0	67.05
225.000000	165.0	90
300.000000	47.0	74.14
349.980000	112.0	86.177
666.660000	187.0	90
799.980000	7.0	90
924.990000	352.0	90
933.330000	330.0	90
984.630000	341.0	90
1000.000000	37.0	90

Table 5.2: Angles for each frequency

The scanning of this data was incomplete and it is only a way to have an approximate idea of the results. It could be checked that only a few peaks are located around the same zone in the field intensity graphics obtained from the code and from the real measures.

The code provides a field intensity pattern where the highest field values are concentrated in a range around a non constant band. Some frequencies almost satisfy this condition as shown in 5.10,5.11 where the measured peaks are marked as a black ellipse over the theoretical results. Matching is not perfect due to the fact that the theoretical approach is the perfect case and it differs from the real case. So values are not perfectly located at the maximum level areas but nearby.

As frequency increases, the field intensity distribution becomes distorted and results mismatch in a more important way (see 5.12 and 5.13 or the radiation patterns in 5.14 and 5.15). This

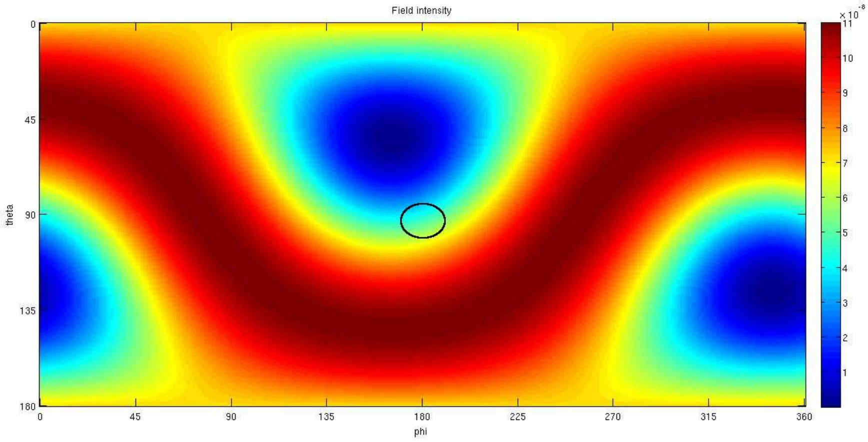

Figure 5.10: Field intensity distribution for 38.67 Mhz

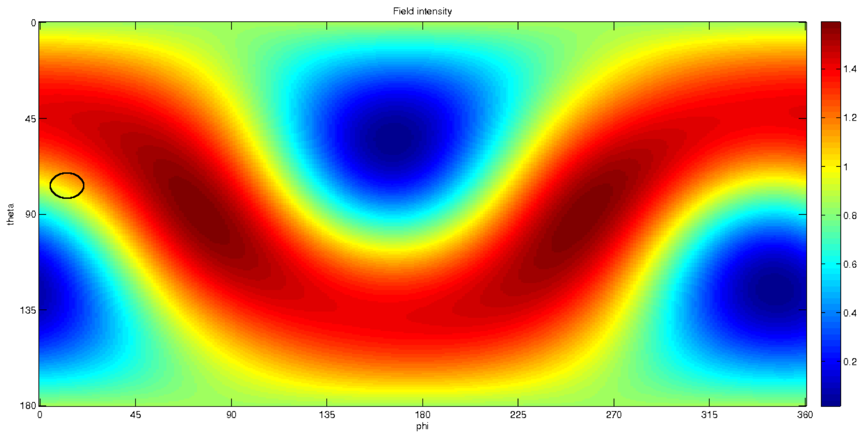

Figure 5.11: Field intensity distribution for 200.01 Mhz

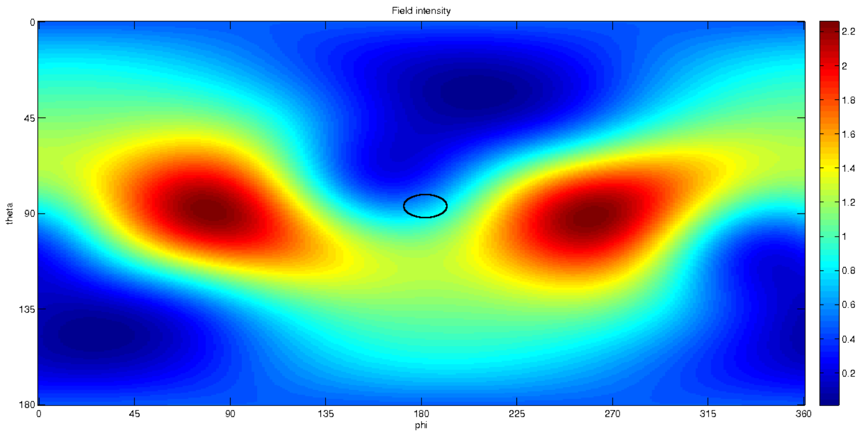

Figure 5.12: Field intensity distribution for 666.66 Mhz

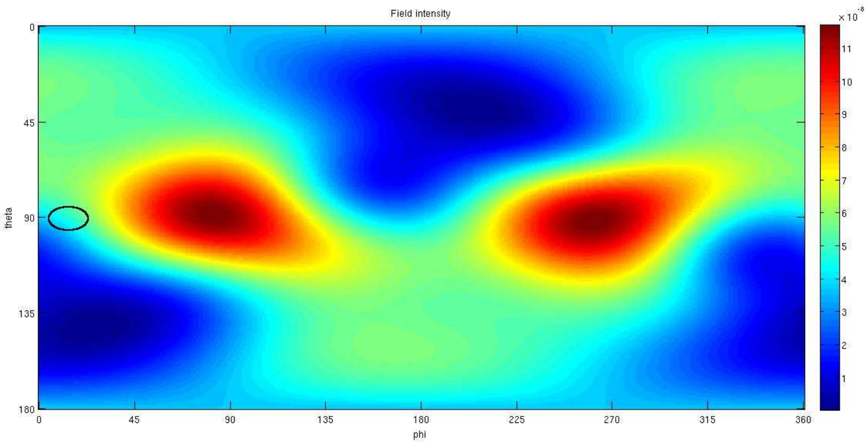

Figure 5.13: Field intensity distribution for 666.66 Mhz

is due to the fact that losses increase with the frequency of operation. Also, it could be that the frequency deviates from the optimum value or value range of operation.

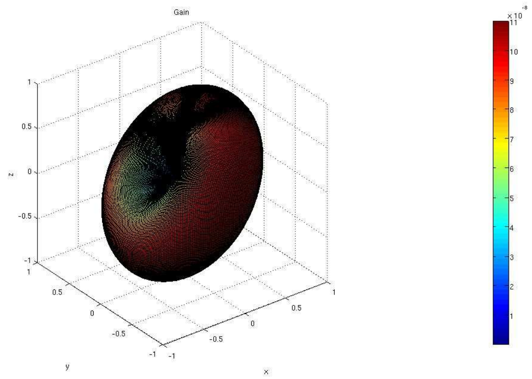

Figure 5.14: 3D radiation pattern for the 38.67 Mhz frequency

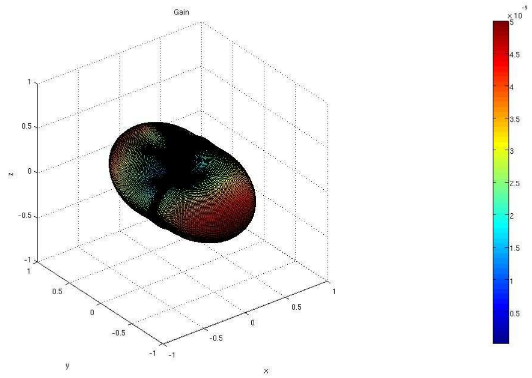

Figure 5.15: 3D radiation pattern for the 800 Mhz frequency

Incomplete surfaces to apply the SET?

Maybe the first hypothesis about these mismatches could be that the 3 surfaces given are not enough in order to use properly the Surface Equivalence Theorem. With the purpose of checking this theory, some simulations have been done. Firstly with the dipole and afterwards with the real data.

Results for the dipole are shown in Figures 5.16 and 5.17. Not only some sides are not essential but it is even possible to apply the theorem with only one of the faces of the surface enclosing

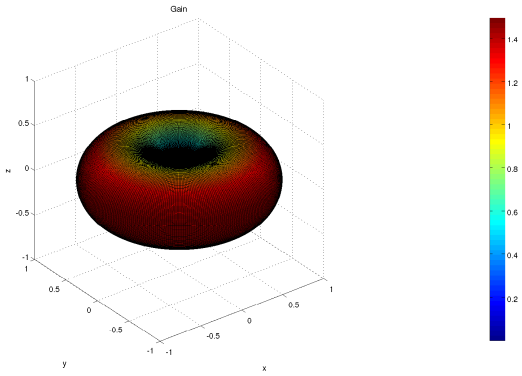

Figure 5.16: Simulatoin without XY and ZX sides. Only XZ sides has been used.

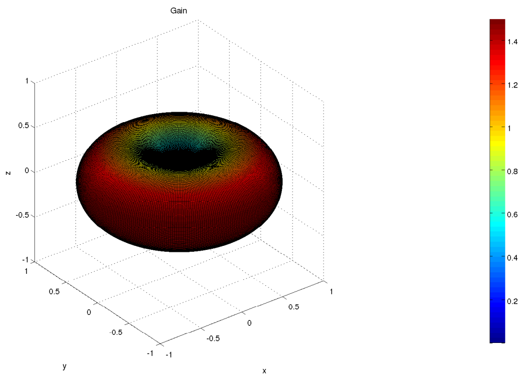

Figure 5.17: Simulation using only a ZY side.

the device (the dipole in this case) under test. As shown, results are exactly the same for the radiation pattern.

It should be exactly the same for the module where the real data has been obtained from. But since the device is not so well known, 3 simulations were made (5.18, 5.19, 5.20), one per each face, just to corroborate that the absence of faces it is not bringing false data.

It is easily checked that the absence of the rest of the sides is not the reason for the imperfect results. The code has shown to work perfectly when it has been validated with the dipole and the pattern obtained from the real data appears to have a plausible shape for an antenna. Therefore several reasons could be causing these results :

1. The scanning of the far field was incomplete, so maybe there are higher peaks in another

points in the space and these are not actually the real ones.

2. The far fields measured were the electric ones. The near fields provided were the magnetic ones. It is well known that when measuring near fields, it is highly recommended to obtain both fields, calibrating the measure devices for each one due to the complex relation between them and the special behaviour in this zone.

3. A more exhaustive and detailed scanning of the near fields could help. Meaning scanning more points, both fields and planes placed closer or further to or from the antenna...

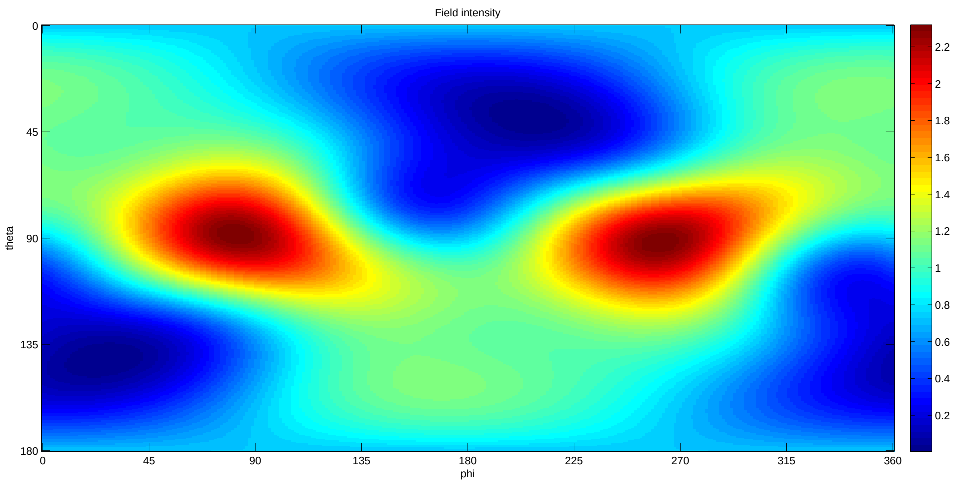

Figure 5.18: Simulation using only the antenna side.

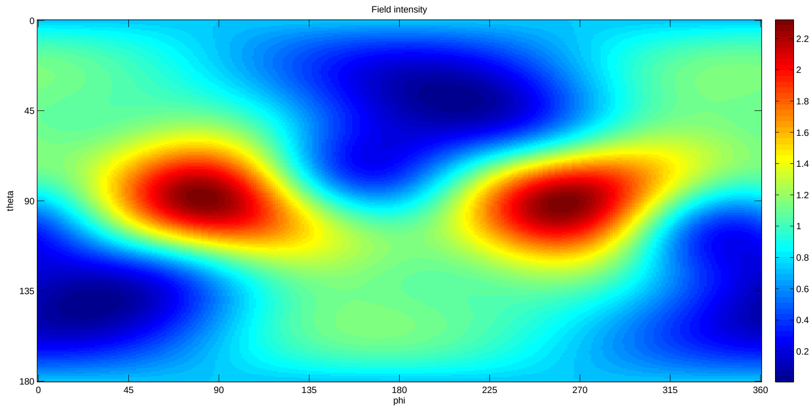

Figure 5.19: Simulation using only the back side.

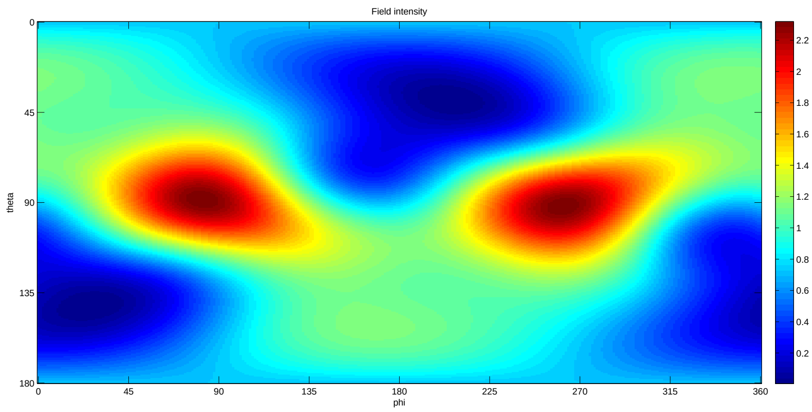

Figure 5.20: Simulation using only the long side.

Chapter 6

Conclusion

The aim of this project has been the analysis of the effect of the electromagnetic interferences caused by the near fields. It has been focused on studying one of the most important sources of interference in EMC, the radiated emissions.

Firstly an overview of EMC has been done in order to give the reader a brief idea of the topic discussed, including a presentation of the main numerical methods used in this field of study. Then the problem is raised and a theoretical study of a possible solution is presented, the Near-to-far-field transformation, a concrete case of the Surface Equivalence Theorem.

Once the solution was clear, several scripts were written in Matlab in order to implement this theory in a practical way. This code has been validated correctly using a well known example, the dipole. After this, the code has been used with real data.

It has been demonstrated that it is not strictly necessary to use a complete surface to apply properly the SET. The code has proven to be a good tool to study the near-to-far-field transformation under real conditions, while at the same time has highlighted the need for rigorous measurement campaigns to obtain a useful prediction. Also it came out that a detailed study of the effect on different frequencies is necessary when dealing with these kind of problems. Indeed, it is not the same frequencies that are affected by the near fields and by the far fields. All these concepts together will help to develop a correct design in the first attempt, saving in this way time, money and resources while satisfying the standards.

As future work it is proposed to extend the transformation code written in order to apply it to any point of space, not only in the far field zone. Also some corrections could be made in order to provide more accuracy and become a really reliable tool for professional use.

Bibliography

[1] Cispr22 standard. http://webstore.iec.ch/preview/info_cispr22{ed6.0.RL}b.pdf.

[2] Electromagnetics research group, emc course notes. http://www.egr.msu.edu/em/.

[3] Fcc offial website. 1.http://www.fcc.gov/.

[4] Iec website. http://www.iec.ch/about/mission-e.htm.

[5] Information about standards. http://www.ce-mag.com/99ARG/EMCStandards61.html.

[6] Information about standards. http://www.ce-mag.com/99ARG/EMCStandards61.html.

[7] Information about standards. http://ec.europa.eu/comm/enterprise/electr_equipment.

[8] C.A. Balanis. *Advanced Engineering Electromagnetics*. Wiley, 1989.

[9] H.-D. Bruns, C. Schuster, and H. Singer. Numerical electromagnetic field analysis for emc problems. *Electromagnetic Compatibility, IEEE Transactions on*, 49(2):253 –262, may 2007.

[10] Jr. Daniel G. Swanson and Wolfang J. R. Hoefer. *Microwave circuit modeling using electromagnetic field simulation*. Artech House, Inc, 2003.

[11] Jasper J. Goedbloed. *Electromagnetic Compatibility*. Prentice Hall, 1992.

[12] B.W. Jaekel. Electromagnetic environments - phenomena, classification, compatibility and immunity levels. In *EUROCON 2009, EUROCON '09. IEEE*, pages 1498 –1502, 18-23 2009.

[13] C. Paul. *Introduction to Electromagnetic Compatibility,*. John Wiley and Sons, 1992.

[14] Donald Shepard. A two-dimensional interpolation function for irregularly-spaced data. In *ACM '68: Proceedings of the 1968 23rd ACM national conference*, pages 517–524, New York, NY, USA, 1968. ACM.

[15] Allen Taflove. *Computational electrodynamics: the finite-difference time-domain method.* Artech House, INC., 1995.

[16] K.R. Umashankar and A. Taflove. A novel method to analyze electromagnetic scattering of complex objects. *IEEE Trans. Electromagnetic Compatibility*, 24:397–405, 1982.

[17] K.R. Umashankar and A. Taflove. Radar cross section of general three dimensional structures. *IEEE Trans. Electromagnetic Compatibility*, 25:433–440, 1983.

[18] K. S. Yee. Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media. *IEEE T. Antenn. Propag.*, 14, 1966.