UNIVERSIDAD POLITECNICA DE VALENCIA

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I.T. Telecomunicación (Sist. de Telecomunicación)

"Performance of antennas in an industrial environment"

TRABAJO FINAL DE CARRERA

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Abstract

The industry is constantly growing and thus needs new applications for the future. The problems for these technologies are the main worries for the developers because in an industrial environment there are interference factors, which make use of other kind of technologies and antennas.

Generally, the technologies currently used in an industry are not optimized for industrial environments although some standard organizations are working to develop future standards (ETSI). Special structures, which are used in industries, include different materials; these materials produce changes in the behavior of transmitters and receivers. Absorbent materials can reduce this problem and reduce propagation.

The main goal of this project is to analyze different antennas using the software Savant, to choose the best one in an industrial environment. The analysis of antennas will simulate the usage of different antennas in an industrial environment in the frequency range of (300 MHz-3 GHz). Further, different coats will be used to find out which one is the better one concerning the coat. By using the software Savant we will design the coating to analyze it.

We will use two different kinds of coat Metal (PEC) and Single layer dielectric.Once we found the result we will look in the range of frequency 2.4 GHz and we will select the best one for calculating the losses of the difference between total field of Metal PEC and Singer layer dielectric.

The study showed that the best antennas for industrial environments are the dipole and monopole ones, because both of them have low losses in this hostile environment. The sections provided during the study intend to guide the research into the important aspects that revolve around the experiment.

Acknowledgments

In the following I like to thank Dr. Jose Chilo and Mr.Sathyaveer Prasad, who guided me towards my final thesis and gave me very helpful instructions due to their knowledge. Further, I am thankful to the University of Gävle for giving me the opportunity to write my final thesis and thus being able to graduate.

Sincere thanks and a special attention is given to my father, who, besides my mother, has been the most important and inspiring person for me, as he tragically passed away five months ago. He would have loved to read my thesis and been very proud of me.

Table of contents

1 Introduction

1.1 Background

The industry is constantly growing and the new wireless technologies are in need of new applications for the future. These technologies are of great importance and affect the future. An industry provides increased flexibility and productivity for this technology. However, the demand of technologies will arise within these harsh environments, which may contain different kinds of materials.

Generally the technologies currently used in an industry are not optimized for industrial environments, although some standard organizations are working to develop future standards (ETSI).

The industry has special building structures that include a high amount of different materials. This produces changes in the behavior of the transmitting channels, whose troubles can disturb the communication. Therefore some industrial environments present opposite properties as absorbent material and can considerably reduce the propagation. [1].

Moreover the industrial environment has lower contaminants than the other like marine ambient but the corrosion is higher [6].

Some common incident in industrial environment could be materials and distance of the technologies.

1.2 Industrial Environment

The industrial environment which we are going to analyze is situated within an industrial building that has different materials and we can find different interferences from many devices that are working in the same time and we can't determinate it.

Nowadays it is really important to get good connections in this hostile ambient in a determinate range of frequency where the WLAN and Bluetooth technologies can develop applications to improve the connections in this ambient.

1.3 The Aims

The goal of the thesis, it is to analyze the different antennas in an industrial environment and suggest the best one for this ambient.

To be able to perform the analysis of the antennas, we will simulate an industrial environment using different antennas in the frequency range of (300 MHz -3 GHz). It is possible to use several kinds of antennas to analyze the environment with different coats to choose.
Using the software Savant we will design the coats to analyze it. We will use two different kinds of coat Metal (PEC) and Single layer dielectric.

Once we obtained the result we will look in a single point and we will take the best one to calculate the losses and also we will choose the best one depending on the polarization.

The range of frequency is used for WLAN and Bluetooth and this kind of technologies provides better performance.

1.4 The procedure about the thesis

The procedure Figure (1) of this thesis is realized in Savant by simulating an industrial environment. I therefore need to create an industrial environment with different materials to simulate with the antennas.

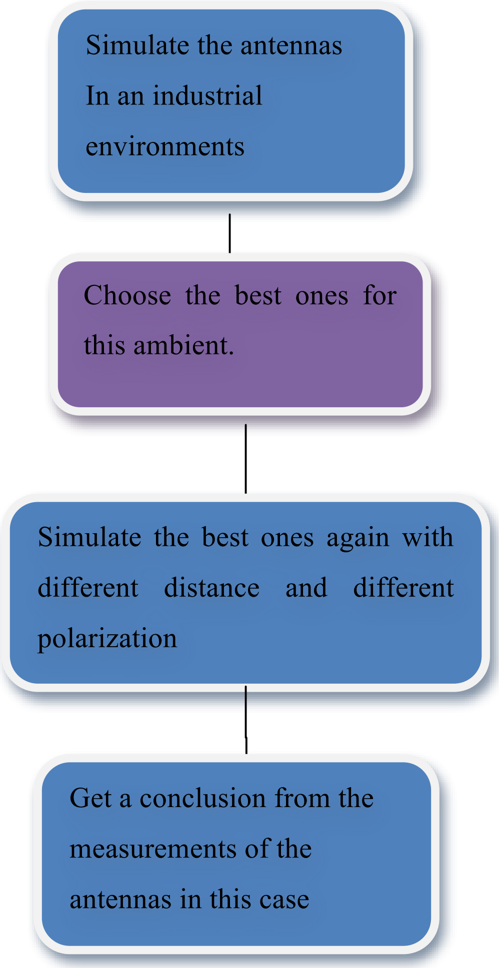


Figure (1): Procedure of the thesis

1.5 Limitations:

To be able to get an exact estimation, we will have to take the real measurements, because the simulation does not take into consideration the source of errors, which can disturb the measurements, so we can say that it can be a limitation for this thesis. Even the fact that I am focusing in a single point is a kind of limitation.

2 Theory

The theory section explains the main concepts and methodology implemented in Savant and the main reference [2] for this chapter. This section intends to provide key concepts that will be used throughout the study [3].

2.1 Main concepts:

Far-field is the region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna.

The E and H plane patterns are defined as: the plane E contains the electric-field vector (and the direction of maximum radiation) and the plane H as the plane that contains the magnetic-field (and the direction of maximum radiation.)

Incident Field is the field that arrives to the objet radiated by Tx antenna in free space (as if the scattering geometry was not there).

Scattered Field is the field, which doesn't radiate by Tx in and free space.

Total Field - field generated by Tx antenna in the presence of the scattering geometry (coherent sum of incident and scattered field)

Power of antenna: the power of the antenna is calculating by Power= 1/ $(\text{distance})^2$

Friss Antennas Equation: the Friis equation is used to know the power received from one antenna (G1) when we are transmitting from another antenna (G2) with a distance (R) given by Figure (2.1).

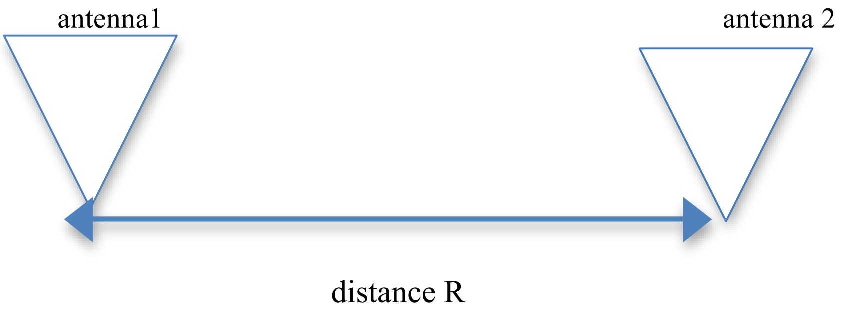


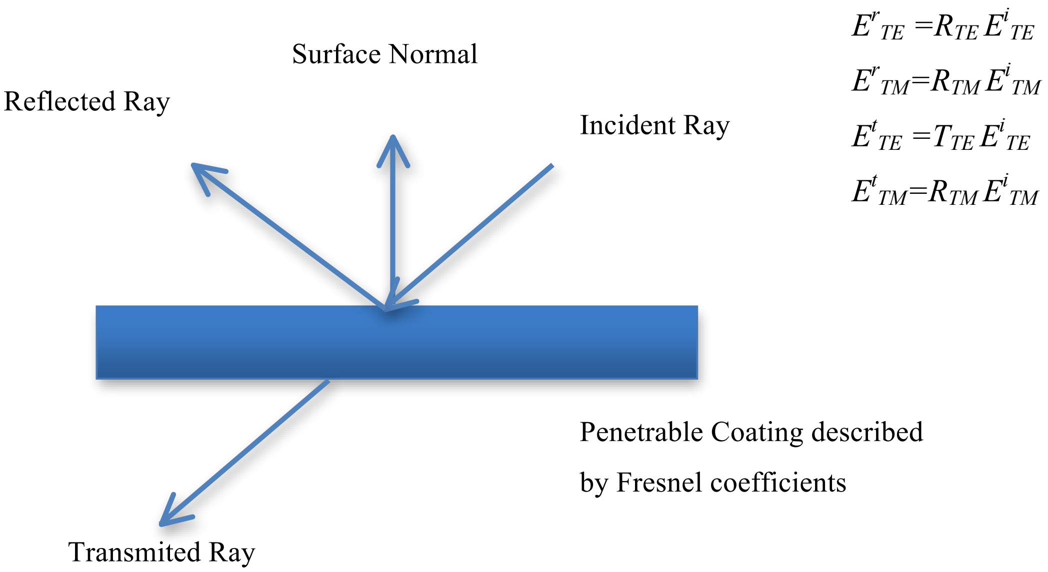
Figure (2.1)

2.2 Software Capabilities:

Savant is simulation software for predicting the performance of antennas in an environment such as industrial environments, aircraft, buildings and other platforms. Savant can predict : Far field radiation pattern, Scattered field incident field, cosite coupling/ isolation between antennas mounted on a common platform. Source antenna the Tx launch rays assigned a vector field according with the polarization. Savant can give us the result in a table (Appendix A).

2.3 Material Coatings it is based on Fresnel reflection [5].

The coatings is the materials that one choices for a cad. Savant provides one with two possibilities; Single layer dielectric, Perfect electric conductor (PEC)
The performance the analysis the ray hits the surface and discomposed into transverse-electric (TE) and transverse-magnetic (TM) polarizations depending of the material coating assigned to the surface and the incident. The coefficients are obtained from the table 2.3.1



$$E^{r}_{TE} = R_{TE} E^{i}_{TE}$$
$$E^{r}_{TM} = R_{TM} E^{i}_{TM}$$
$$E^{t}_{TE} = T_{TE} E^{i}_{TE}$$
$$E^{t}_{TM} = R_{TM} E^{i}_{TM}$$

Figure (2.3.1)

2.4 Antennas types:

Short dipole: it is the simples of all antennas. It is a open-circuited wire shown in the Figure (2.4.1) and is a kind of antenna that it is relative with the wavelength so only matter the size of the wire relative to the wavelength of the frequency of operation [4].

Figure (2 4.1): Short dipole.

Half-dipole: it is a special case of antenna means that it is the half wavelength at the frequency operation shown in the Figure (2.4.2) [4].

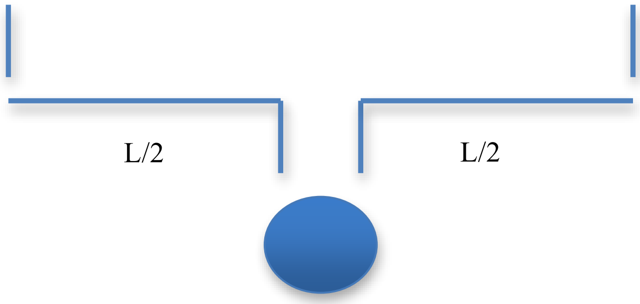


Figure (2.4.2): Half dipole.

Quarter wave-antenna: it is a single element antenna fed and one end. $\frac{\lambda}{4}$ in length and behaves as dipole. The quarter-wave conductor and its image together form a half-wave dipole that radiates only in the upper half of space [4].

Wire-Dipole: It is the antenna with a very thin radius is considered and it is similar to the short dipole but this one no required a small compared to the wavelength [4].

Wire monopole: It is one half of a dipole antenna and the length of the antenna is shown in Figure (3) and almost always mounted above some sort of ground plane [4].

Small loop: it is antenna with low radiation resistance and high reactance shown in it is a closed loop. This kind of antennas is most often used to receive antennas because for transmitter is difficult to match and as a receiver the mismatched can be tolerated [4].

Industrial Environment: In industrial environments we can observe two cases LoS (Line of Sight) or NLoS (Non Line of Sight), see Figure 2.4.3 [4].

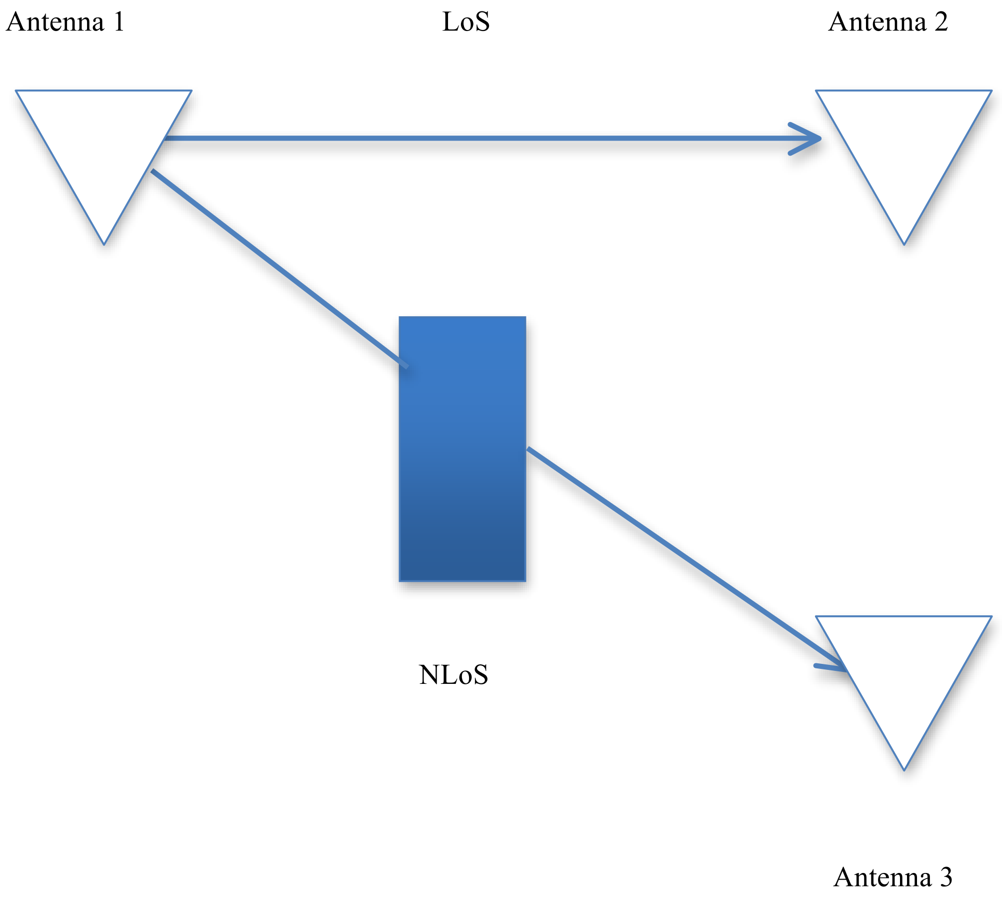


Figure (2.4.3): LoS and LNoS.

The characteristics for an industrial environment at LoS (Line of Sight) are when we haven't objects or materials that they can degrade our connection between transmitter and receiver. As we can observe in the Figure 2.4.3, NLoS (Non Line of Sight) is when we have objects or materials that they are placed between transmitter and receiver [4].

In indoor industrial environment we can considerer several kind of situations depending on the dimensions and quantity of metallic objects, high, medium and low reflective. [1]

High reflective can be found at halls with a big amount of metallic structural materials and objects composed by metal, on other hand the interferences of the machinery is another factor that degrade our connections.

Medium reflective is the typical industrial building, the structure walls and the ceiling are made with metallic materials. In this kind of environments there are metallic objects but its density is lower than the high reflective.

The environments with **Low reflective** don't have just reflective and there are absorbent objects.

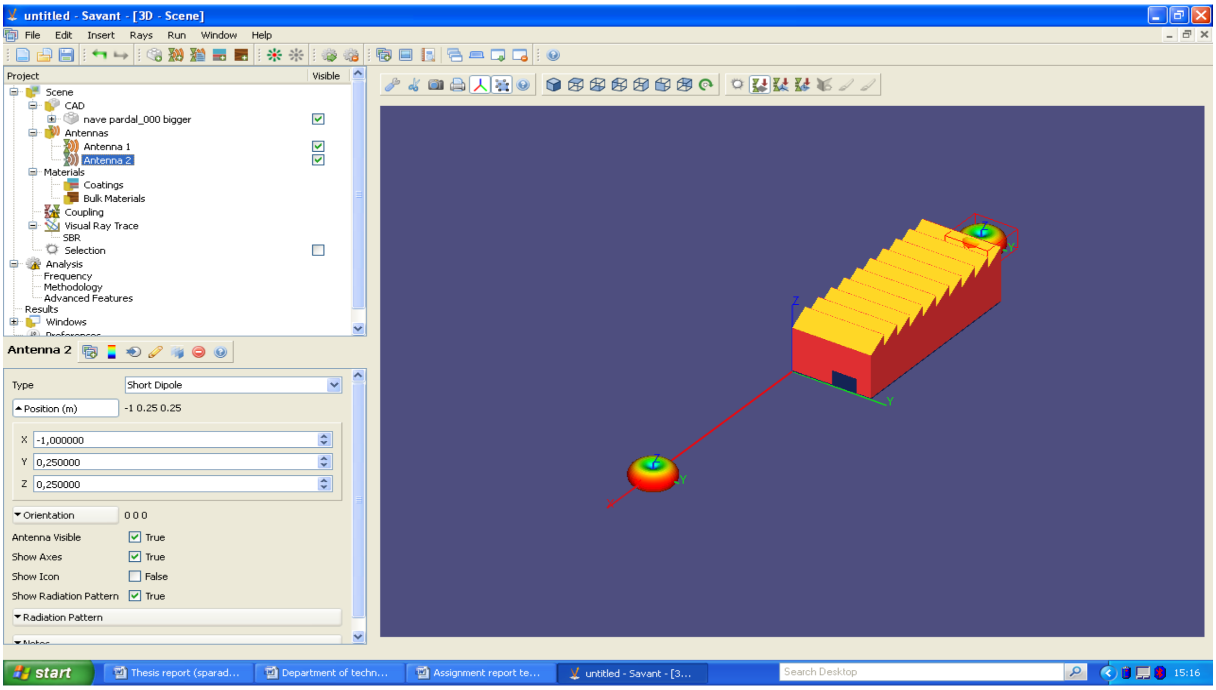
3 Process and results

In this section we are going to use a determinate range of frequency (300 MHz – 3 GHz) and the six antennas that work in the same range in an industrial environment. The industrial environment that we are going to consider is an industrial building with different materials.

The first process will be to analyze all antennas with the coat Metal (PEC) and Single layer dielectric by looking the main factor of antennas (Power dB) in an industrial environment.

First of all we have to charge the building and put the antennas in the same distance to get the best one for this ambient Figure (3.1).

The Figure is created by the software Rhino appendix B1.



Type: Short Dipole

Position (m): -1 0.25 0.25

X: -1,000000

Y: 0,250000

Z: 0,250000

Orientation: 0 0 0

Antenna Visible ☑ True

Show Axes ☑ True

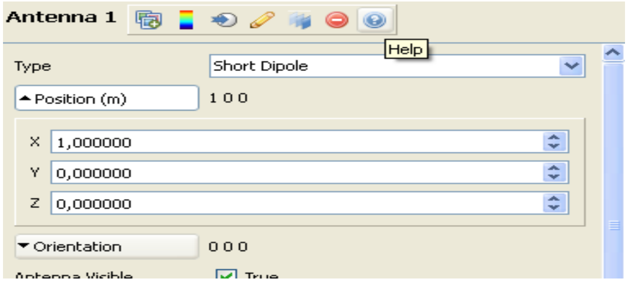
Show Icon ☐ False

Show Radiation Pattern ☑ True

Figure (3.1): It is our environment industrial created with Rhino appendix B.

After of load the cad we have to set the parameters of distance Figure (3.2) and Figure (3.3) for each antenna and the kind of the antenna for our analysis. We can use six different kinds of antennas before mentioned in theory chapter.

Set the antenna as transmitter Figure (3.4) and the other one as receiver Figure (3.5) and set the range frequency and the distance that we going to work our case (300Mhz – 3Ghz) Figure (3.6).



Antenna 1

Type: Short Dipole

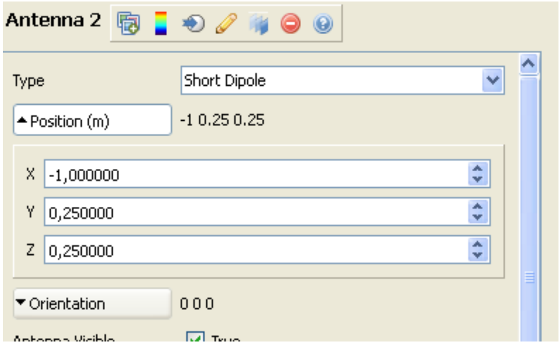
Position (m): 1 0 0

X 1,000000
Y 0,000000
Z 0,000000

Orientation: 0 0 0

Antenna Visible ☑ True

Figure (3.2): Setting the distance of the antenna 1.



Antenna 2

Type: Short Dipole

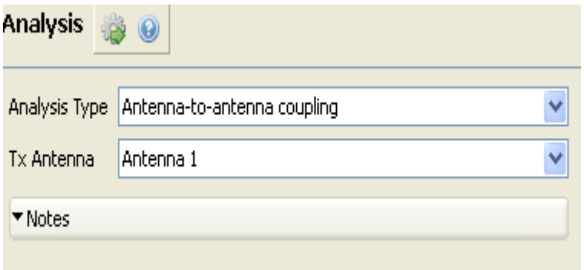
Position (m): -1 0.25 0.25

X -1,000000
Y 0,250000
Z 0,250000

Orientation: 0 0 0

Antenna Visible ☑ True

Figure (3.3): Setting the distance of the antenna 2.

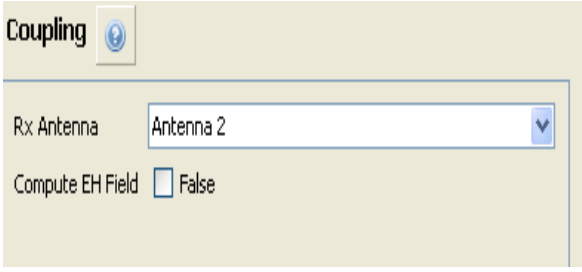


Analysis

Analysis Type: Antenna-to-antenna coupling

Tx Antenna: Antenna 1

Notes



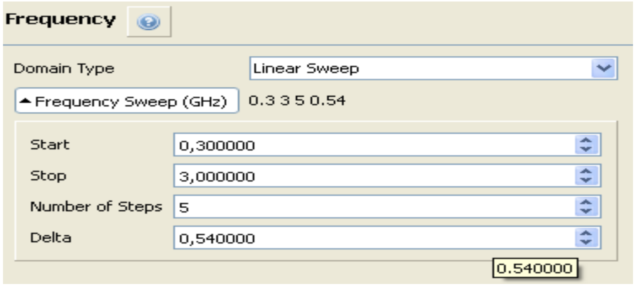
Coupling

Rx Antenna: Antenna 2

Compute EH Field: ☐ False

Figure (3.4): Set antenna Tx. *Figure (3.5): Set antenna Rx.*

We have to set the characteristics of the antennas for Metal (PEC) Figure (3.7) and Single layer dielectric Figure (3.8). For Single layer dielectric we will set the characteristic of the thickness (900mm) and permeability (Teflon 2,4).



Frequency

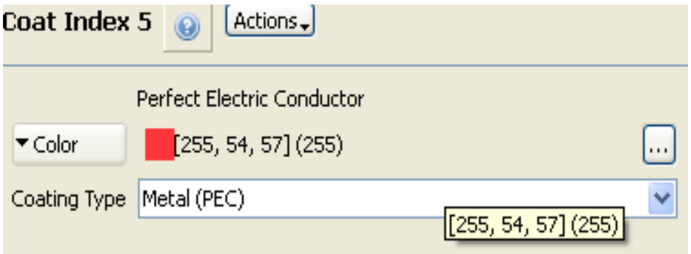
Domain Type: Linear Sweep

Frequency Sweep (GHz): 0.3 3 5 0.54

Start 0,300000
Stop 3,000000
Number of Steps 5
Delta 0,540000

0.540000

Figure (3.6): Setting the range of frequency that we are going to work.



Coat Index 5

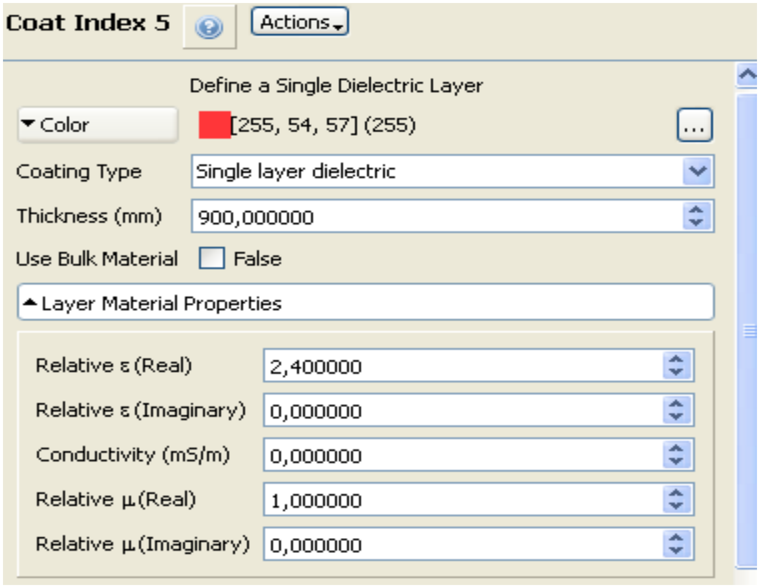
Perfect Electric Conductor

Color: 🟥 [255, 54, 57] (255)

Coating Type: Metal (PEC)

[255, 54, 57] (255)

Figure (3.7): Setting the coating.



Coat Index 5

Define a Single Dielectric Layer

Color 🟥 [255, 54, 57] (255)

Coating Type: Single layer dielectric

Thickness (mm): 900,000000

Use Bulk Material ☐ False

Layer Material Properties

Relative ε (Real): 2,400000

Relative ε (Imaginary): 0,000000

Conductivity (mS/m): 0,000000

Relative μ (Real): 1,000000

Relative μ (Imaginary): 0,000000

Figure (3.8): Single layer dielectric.

Once set the parameters we can start to simulation with each antenna, to get the best one for this environment Savant performance the Soothing Bounce Ray (SBR) to analyze the conditions of the materials, that ray is based in Fresnel reflection before mentioned in theory chapter.

In the table below we can see the result of the simulation for all antennas. The best for us are Wire-monopole and Wire-dipole because these ones have less losses in 2.4 GHz.

Comparing the result of all antennas we can decide which is the most appropriate to an industrial environment. It is the antennas with less loss.

The losses are calculating by:

Losses = Total field PEC – Total field Dielectric

Attached in appendix A an example of Savant result to calculate the losses.

Software Savant use the Shooting bounce ray to performance the results.

"Shooting bounce ray (SBR) it is an algorithmic implement in Savant and explained in following steps"[2]:

1. Launch many rays from the Tx antenna.
2. Assign each ray a vector field weight according to the Tx.
3.

   a. The ray is ignored if it is escapes to space.
   b. It is generate a reflected ray when the ray hits a surface. Compute its fields according to the incident ray fields, the material properties of the surface.
   c. Also generate a transmitted in the same direction as the incident ray and then extend and process it as one would the reflected ray if the ray hits a penetrable surface.
4. The incident and reflected field on the surface are compute by. Use these and the PO approximation to determine equivalent surface currents.
5. Radiate the equivalent currents to observation angles/points.
   a. If the obsrvation point represents an Rx antenna, compute the coupling of the radiated fields into the receiver according to the Rx antenna pattern or current distribution.
6. Continue tracing the reflected ray generated in step 3b and repeate from there. Likewise for any transmitted ray generated in step 3c. Continue until either the ray escapes (Step 3a) or the maximum bounce limit is reached.

Step 5 is implemented with the following equation: **[2]**

$$\mathbf{Es\ (\ r\ )} = \frac{\mathbf{1}}{\mathbf{4\pi}} \int s\, dS'\left[(n * E)\nabla' \frac{e^{-jkR}}{R} + (n * E) * \nabla' \frac{e^{-jkR}}{R} - jw\mu(n * H)\frac{e^{-jkR}}{R}\right]$$

Equation (3.1): The SBR is based in this equation.

Bellow is the table of losses depending of antenna and frequency for total field.

***Table (3.1)**: Represent the losses values of all antennas in the range frequency of 0.3 MHz -3 GHz.*

Frequency	300 MHz	500 MHz	1GHz	1,5GHz	2GHz	2,5GHz	3GHz
Short dipole (dB)	-0,3	0,1	0,2	-0,2	-1	2,1	-0,4
Half wave-dipole(dB)	-0,2	0,1	0,3	0	-1,5	2,3	-0,7
Quarter wire-dipole(dB)	-0,4	0	0,6	-0,6	-2,4	4,6	-1,8
Wire dipole (dB)	0	0,2	0,5	-0,1	-0,1	-0,2	0,5
Wire monopole(dB)	-0,4	-0,6	1	-0,2	-2,2	-0,5	1,2
Small sloop(dB)	0,3	-0,1	-0,6	0,9	1,7	-1,7	1,1

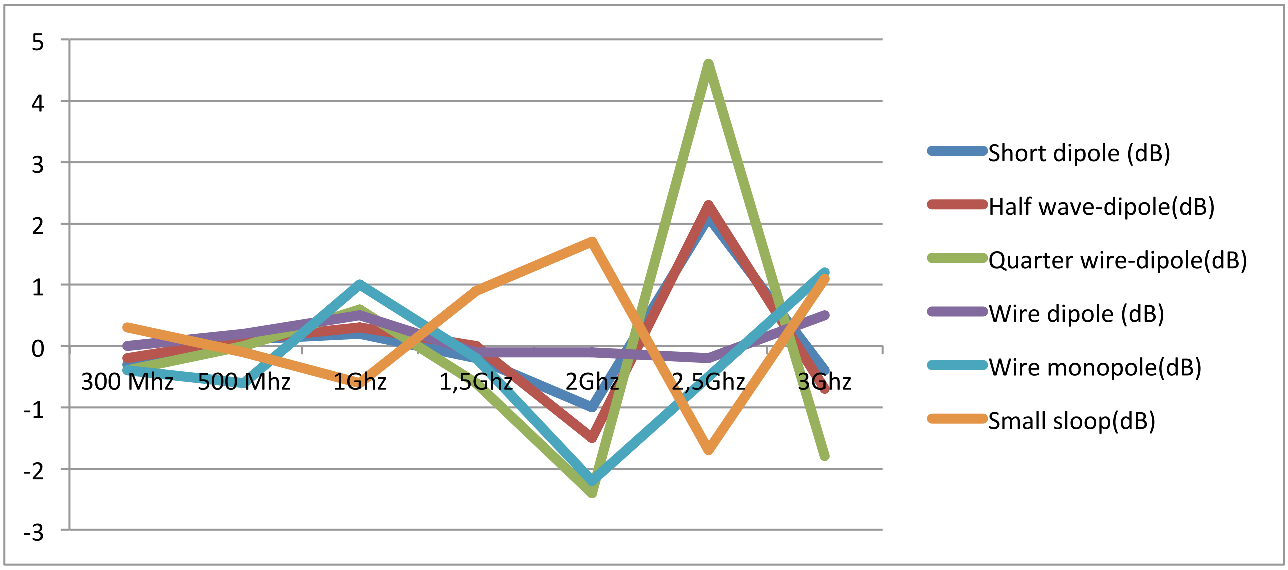


Figure (3.2): Represent the losses of the antennas in the range o frequency of 0.3 MHz -3 GHz, X-axis frequency and Y-axis (dB).

3.1 Wire-dipole and wire-monopole simulation: In the range of frequency of 2.4 GHz and with different distance the results are.

The losses of both antennas are:

Losses = Total field Metal (PEC) – Total field of Single layer dielectric

Table (3.1.1): Represent the values of both antennas with different distance.

Frequency 2,4GHz	1 m	5 m	10 m	15 m	20 m	50 m
Wire dipole (dB)	-105	-106	-115	-119	-124	-135
Wire monopole (dB)	-108	-124,5	-129,1	-138,5	-143,5	-159,3

We can observe that when we are increasing the distance the power is decreasing, depending of the polarization we have the same results table (3.1.2) and table (3.1.3) from here we are getting a conclusion.

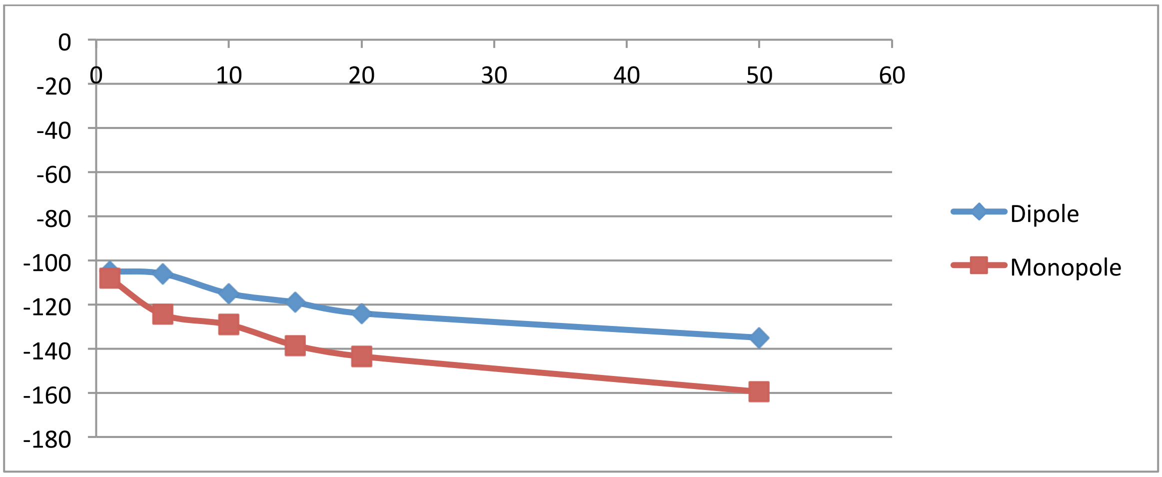


Figure (1): Losses at 2.4 GHz, X-axis distance (m) and Y-axis (dB).

Depending of the polarization:

Vertical:

Table: (3.1.2): show the losses in the vertical polarization.

Frequency 2,4GHz	0,1 m	1 m	5 m	10 m	15 m	20 m	50 m
Wire dipole (dB)	-100	-102	-104	-111	-116	-122	-137
Wire monopole (dB)	-100	-103	-106	-113	-118	-124	-138

Horizontal:

Table: (3.1.3): show the losses in the horizontal polarization.

Frequency 2,4GHz	0,1 m	1 m	5 m	10 m	15 m	20 m	50 m
Wire dipole (dB)	-101	-107	-109	-119,4	-125,5	-130	-145,8
Wire monopole (dB)	-102	-106	-109	-121	-126,5	-130	-145,8

4 Discussion and conclusion

In this thesis, we can see the different antennas and with different distances and polarizations, according to the simulations we can discuss that for an industrial environment the best antennas are dipole and monopole because these both antennas present low losses in this hostile environment. [10]

Simulating environments with high reflective and amount of metal structures and medium reflective environments and with some metals we calculate the losses and the antenna properly.

In the frequency of 2.4 GHz both meet Power= 1/ $(\text{distance})^2$ so if when the antennas are away then the power is low and when the antennas are close then the power is high. For having a good service of the antennas in industrial environment we should take the measurements depending on the materials and the losses and by taking the best distance to satisfy our requirements.[8]

To take the best antenna and the environment we can even consider the polarization view.
In the Figure (3.2) we have seen the frequency of the antenna at less numbers of points and this is due to the limitation of software to simulate only 300MHz to 3GHz with the spam of 0.5 GHz.

The frequency 2.4GHz was not included due to the limitation of the software and moreover the performance of the antennas at 2.4 GHz will be similar as at 2.5GHz.

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Appendix A

The result of the simulation with Savant are given in the next picture to calculate the losses we have to know the Wire-dipole Single layer dielectric (Figure 7) and Wire-dipole Metal (PEC) (Figure 8).

Figure7

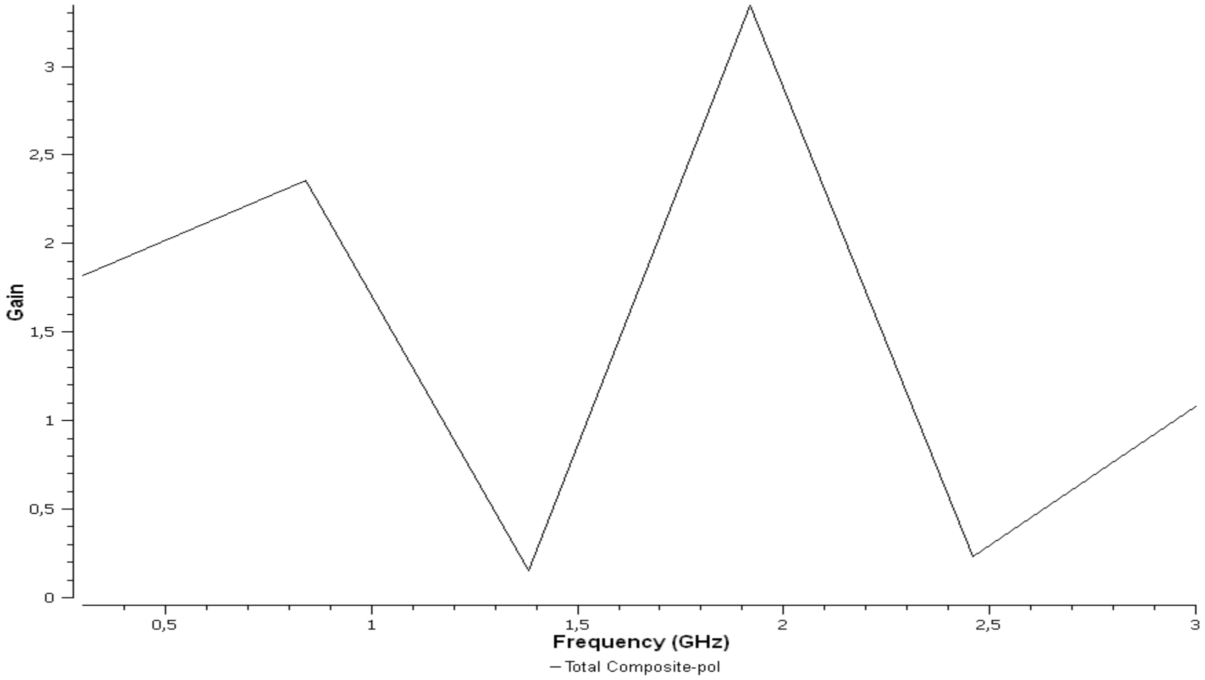
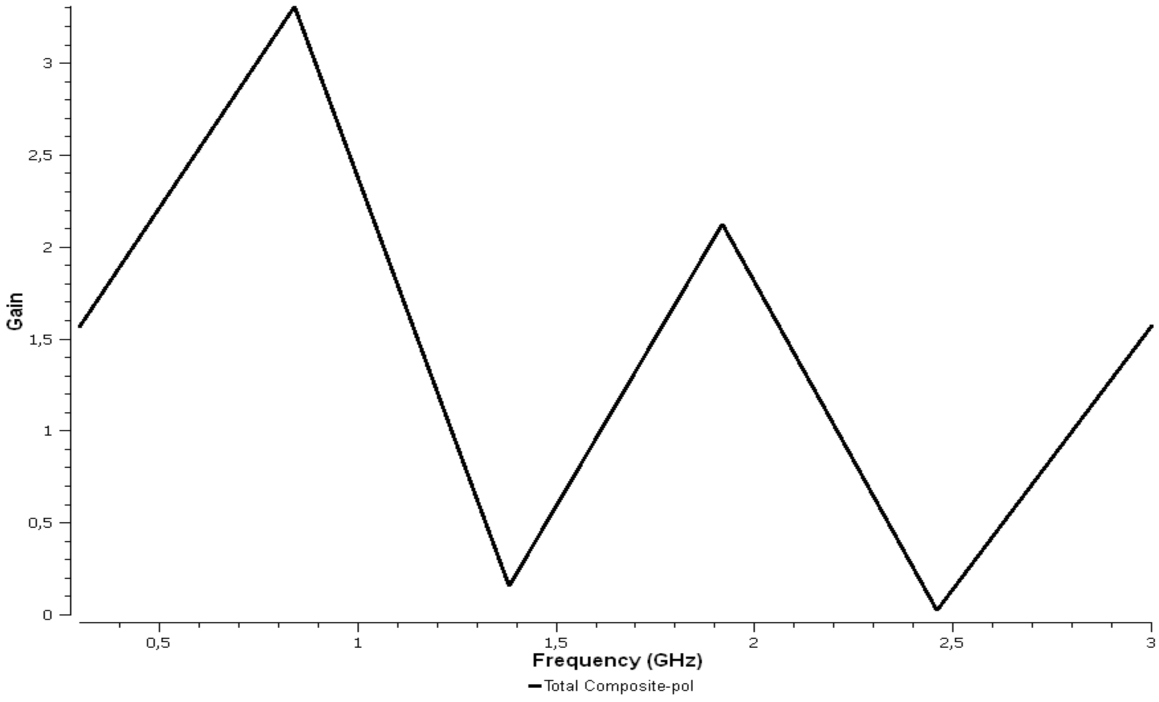
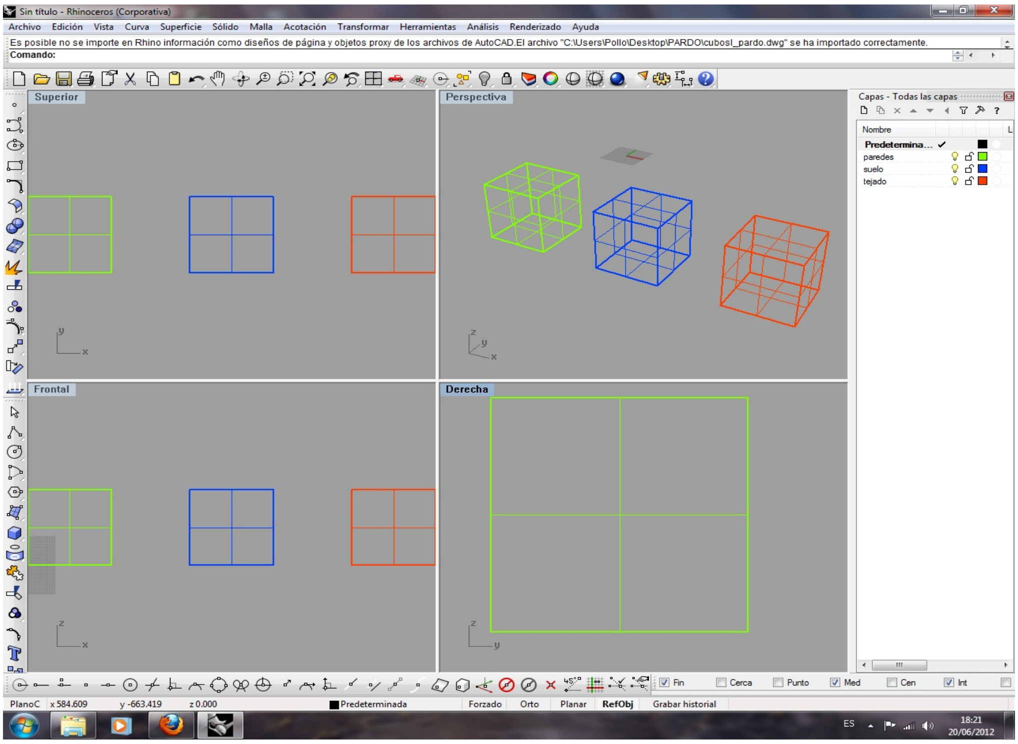


Figure 8



Appendix B

The software Rhino creates the building. It is an extension compatible with Savant and to create it just we have to set the parameters width, length and height. We can design with colours the kind of parts, and then we will set with Savant the materials.



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Es posible no se importe en Rhino información como diseños de página y objetos proxy de los archivos de AutoCAD.El archivo "C:\Users\Pollo\Desktop\PARDO\cubosl_pardo.dwg" se ha importado correctamente.
Comando:
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