ANTENNA DESIGN COURSE

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CHAPTER 2

ANTENNA DESIGN

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2.1 Introduction to Antenna Design

In this chapter the steps followed to design an antenna using CST are presented. As examples of this process, the design for different antenna types are discussed.

2.2 The Dipole

The dipole will be a reference antenna for us. Since it is a very simple antenna, we will use it as an example to explain basic antenna concepts and to begin to familiarize ourselves with the design procedure using the CST tool.

A transmitter that is connected to a dipole through a transmission line is represented in Fig. 1. Currents, electromagnetic fields and the Pointing vector are represented for the dipole. These elements are conceptually very important in the development of antennas.

A Thevenin equivalent for this system is presented in Fig. 2 [CABAL].

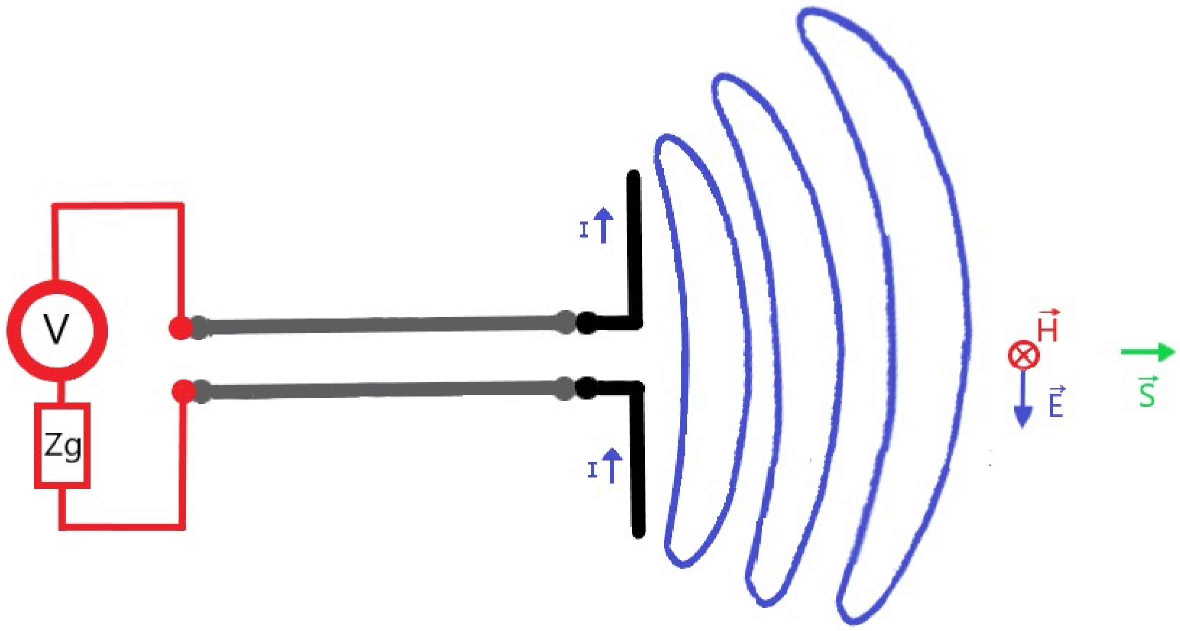

Fig. 1: Representation of a transmitter, a transmission line and a dipole.

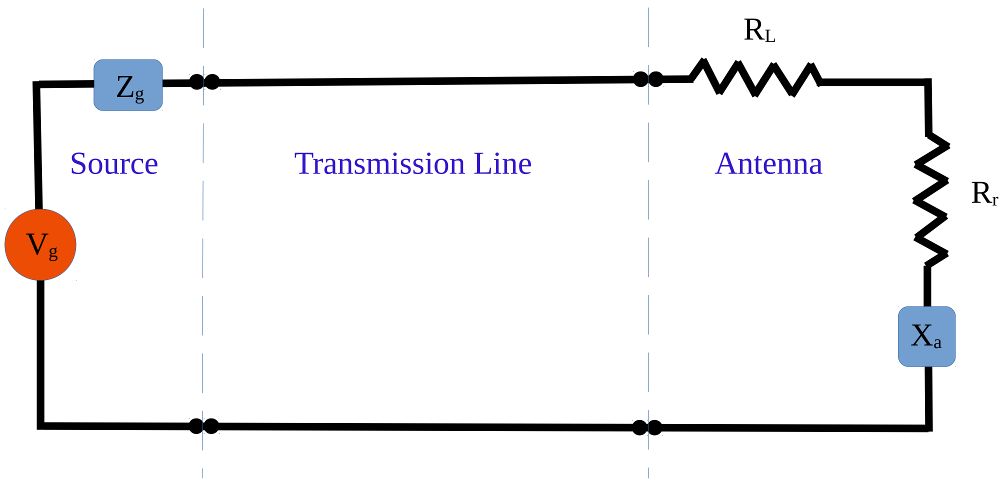

Fig. 2: Thevenin equivalent of a system consisting of transmitter + transmission line + antenna.

Regarding the dipole, we can speak of the infinitesimal dipole (an idealization), the small dipole, the ¼ wavelength dipole ($\lambda/4$), the ½ wavelength dipole ($\lambda/2$), the one wavelength dipole (λ) and the dipole of lengths greater than one wavelength. Fig. 3 conceptually shows how the radiation pattern varies according with the length of the dipole [CABAL].

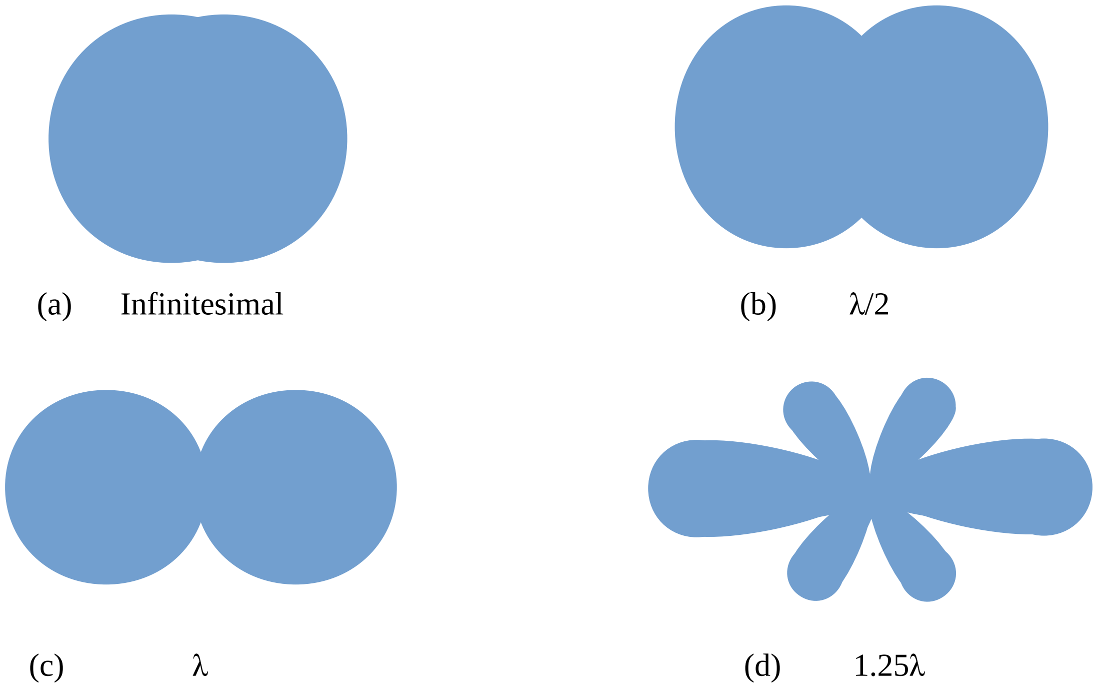

Fig. 3: Radiation pattern for dipoles with lengths: Infinitesimal, λ/2, λ and 1.25λ dipoles.

2.3 Introduction to CST

As seen in Fig. 3, by varying the length of the dipole, its radiation pattern varies very significantly, as well as other important parameters of this antenna, such as input impedance, gain, etc. Finding an optimized version of this or any other antenna, through the construction and characterization of the antenna, would be an extremely long and laborious process. That is why it is necessary to use simulation software that allows us to predict how these parameters vary when we vary the design. In this way, when the simulator tells us that we have achieved an optimal version of this antenna, we can start the process of construction and characterization of this version of the antenna in order to verify the data provided by the simulator, without having to build and characterize all previous versions that were tested.

In this course we are going to use Computer Simulation Technology (CST) software as a simulation tool. In the next section we will see the first steps to start using this tool.

2.4 Design and Simulation of the Dipole with CST

In this section the procedure to create the model of a simple antenna, and after that to simulate it, is explained step by step. This task is shown directly on the CST application.

Step by Step Description of the Introduction of a Half Wave Dipole in CST

1.- Open CST application.

2.- New Template (in Project Template).

3.- Microwaves & RF / Optical.

4.- Antennas.

5.- Wire.

6.- Time Domain *for thick wire antennas*.

7.- Create Project Template, preserve these appears and press Next.

8.- Introduce the frequency range for the simulations (Min. 0.5 GHz , Max. 1.5 GHz). We will create a half wave dipole for 1 GHz. Press Next and then Finish.

9.- Go to Modeling.

10.- Open the cylinder and draw a cylinder in the drawing environment.

11.- Double click over the cylinder to have access to its parameters. Name= Dipole1GHz. Remember that the magnitudes are in mm (as we have in point 7 setted them). Then lets to calculate the longitude.

$f*\lambda=c$ then $\lambda=c/f=3e8$ m/s / 1e9 1/s = 0.3 m then $L = \lambda/2 = 0.15$ m = 150 mm this is the longitude.
As diameter we are going to choose D =5 mm.

With this information we define the Cylinder parameters: Orientation Z, Outer radius: 2.5, Inner radius: 0, Xcenter: 0, Ycenter: 0, Zmin: -75, Zmax: 75, Segments: 0, Component: component1, Material: PEC (which means Perfect Electric Conductor).

12.- To create the feeding vaccum GAP we are going to insert a cylinder made of vacum of 20 mm of length and 5 mm of diameter.
See: <u>Model Construction Wire Dipole Antenna</u> .

For this, we are going to repeat the procedure described in step 11, but with this parameters: Name: FeedingVaccumGap, Orientation Z, Outer radius: 2.5, Inner radius: 0, Xcenter: 0, Ycenter: 0, Zmin: -10, Zmax: 10, Segments: 0, Component: component2, Material: Vacuum.

13.- Boolean combination: None at all.

14.- Go to the Components menu up at the left, choose component1, Dipole1GHz, go to the top menu, choose “Boolean”, “Insert”, it asks me to choose the element to insert, then I choose the component2 FeedingVacuumGap from the Components menu and press Enter to confirm, Then the Gap is inserted and this part of the PEC is deleted.

15.- Now we are going to put the feeding port. For this go to “Picks” in the top menu, take “Pick Edge” and make double click over the botton part of the GAP. Repeat the procedure and make double click over the top part of the GAP. Save. Then go to the left menu and, right click over Ports and select New Discrete Port. Save.

16.- Go to “Simulation” in the top menu, click over “Discrete Port”, complete the discrete port parameters, left them as these are (S- Parameter, Impedance 75 ohm, Monitor voltage and current, Type: Coordinates), press OK. Save.

Step by Step Description of the Simulation of a Half Wave Dipole in CST

1.- Simulation, (in left window, Ports, port 1, double click) Discrete port, maintain the properties as these are (S-Parameter, Name: 1, Impedance: 75 Ohm, Monitor voltage and current, Coordinates X1=2.5 Y1=0 Z1=-10, X2=2.5 Y2=0, Z2=10, Excitation at center edge), Save.

2.- Setup Solver, Mesh type: Hexahedral, Accuracy: -40 dB, Source type: All Ports, Start. See 1D Results, S-Parameters S1,1.

3. Simulation, Field Monitor, Farfield/RCS, Frequency 1, Frequency minimum: 0.5, Frequency maximum: 1.5. Setup Solver. See Farfields results in the left window, farfield (f=1), Abs. Show structure, Farfields transparent.

Step by Step Description of the Optimization of a Half Wave Dipole in CST

1.- We can see the results for 0.9 GHz and for 1.1 GHz.
* Go to Simulation, Field Monitor, Farfield/RCS, Frequency 0.9, Apply, Ok. Setup Solver, Start.
* Observe the farfield results and the S1,1 parameter.
* Go to Simulation, Field Monitor, Farfield/RCS, Frequency 1.1, Apply, Ok. Setup Solver, Start.
* Observe the farfield results and the S1,1 parameter.

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2.- To make the antenna resonate at 1 GHz we are going to change its length by a multiplicative factor MulFac.
* Define the dipole length as a parameter L=150. Go to Schematic, Parameter List, Name: L, Expression:150, Value:150, Description: Dipole length, new parameter, Name: MulFac, Expression: 0.94, Value: 0.94, Description: Multiplicative Factor.

* Go to 3D, Components, component2, Dipole1GHz, double click to edit parameters, and put first the length as L and after that the length as L*MulFac.

* Run again the simulation (Setup Solver, start) and observe the results.

* Values to test as MulFac: 0.94, 0.9, 0.898.

* After changing the value for MulFac, in the top menu press “Parametric Update”, then “Setup Solver” is enabled.

* Then the dipole is optimized for 1 GHz, Z_{in} =75 ohm, with a Gain=2.185 dBi, and an S1,1=-36dB.

* The length that optimize this dipole is Lopt=150 mm * 0.898 = 135 mm.

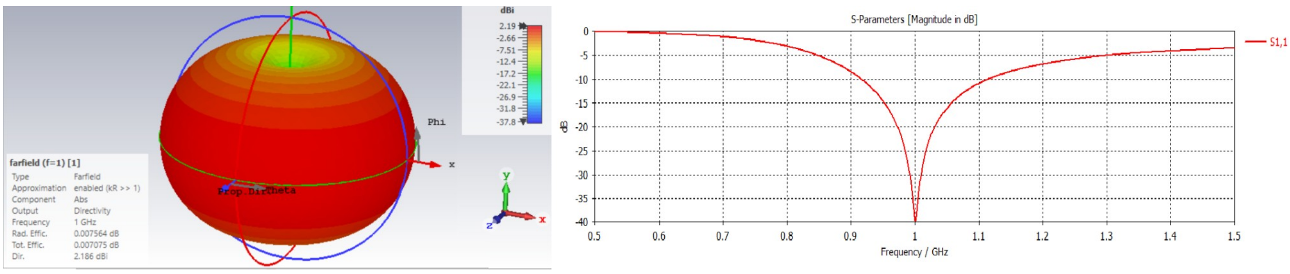

Fig. 2.4.1: $\lambda/2$ dipole at 1 GHz, Z_{in}=75 ohm, radiation pattern and $|S_{11}|$.

To understand this results is important to comment the following relations.

$$Rad.Effic.=e_{cdt} \qquad (1)$$

with “e_{cdt}” being the term efficiency in conductors and dielectrics in the Friis transmission equation (1), in Chapter 1.

$$Tot.Effic.=Rad.Effic.+P_{desImp} \qquad (2)$$

Where “P_{desImp}” is the loss due to an impedance mismatch between the antenna and the guiding device (transmission line or wave guide). This term can be calculated as follows.

$$P_{desImp}=10.\log(1-|(\Gamma_t)|^2) \qquad (3)$$

Where “Γ_t” is the reflection coefficient between guiding device (transmission line or wave guide) and the antenna.

Finally “S_{11}” is the S parameter 11 which express the reflection coefficient in logarithmic scale.

$$S_{11} = 20.\log(|\Gamma_t|) \qquad (4)$$

Then “$\mathbf{S_{11}}$”, “**Rad. Effic.**” and “**Tot. Effic.**” are three important parameters to evaluate the quality of an antenna design.

2.5 SPIDA Antenna Design

The *Swedish Institute of Computer Science* Parasitic Interference Directional Antenna (SPIDA) is a type of antenna which is useful in the field of wireless sensor networks, since it allows a very effective communication between nodes through the implementation of switched beamforming. In Fig. 5 a photo of a simple SPIDA antenna is shown, and in Fig. 6 the CST model for a simple SPIDA antenna is presented [SPI01].

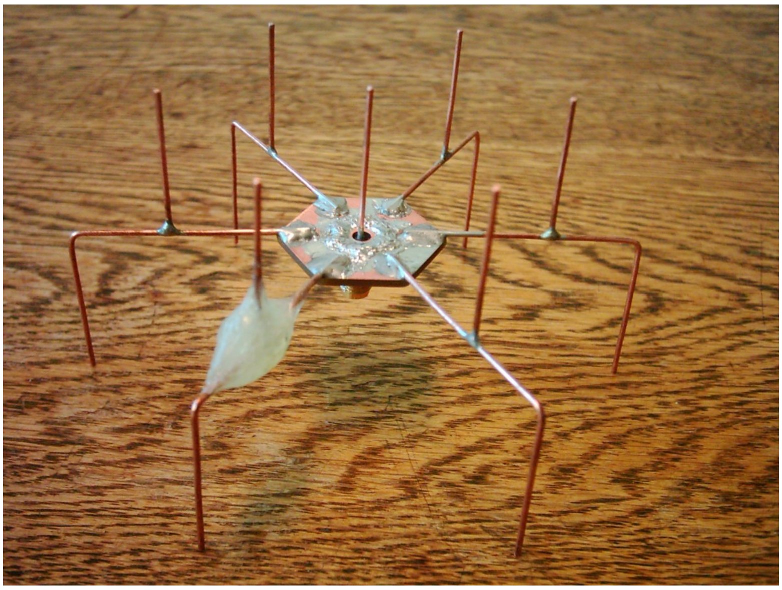

Fig. 5: Photo of a simple SPIDA antenna (source [SPI01]).

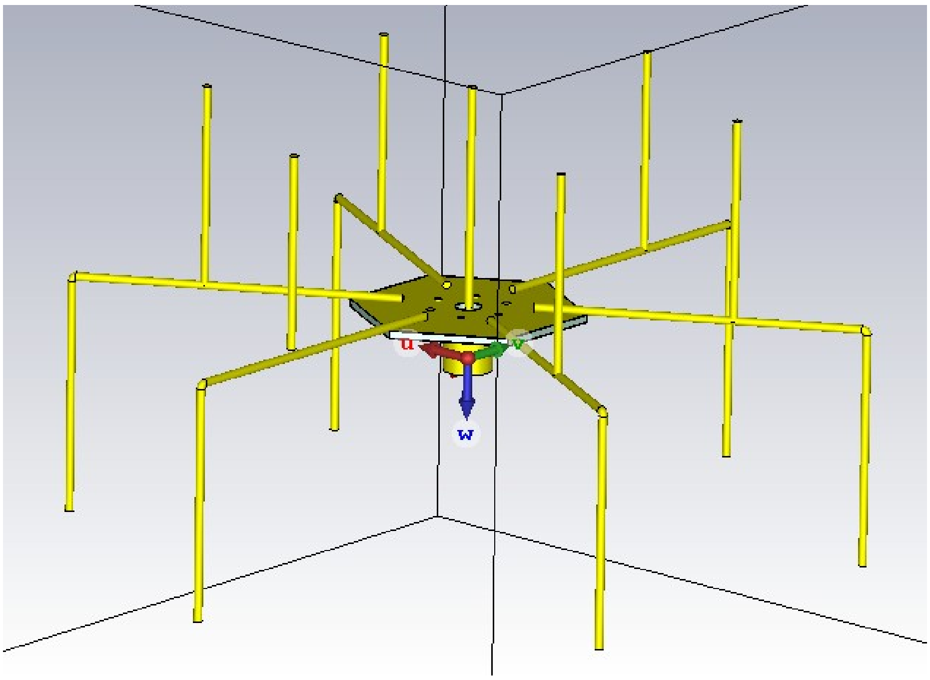

Fig. 6: Photo of the CST model of a simple SPIDA antenna (source [SPI01]).

Both in Fig. 5 and in Fig. 6, it can be observed that there is one of the parasitic elements that does not connect to the “antenna legs”, this is the director element (the main lobe will be directed towards this), the others, are the reflector elements.

Using the CST file “201120_160604_SPIDA_fr4_bias_sma_01” we are going to describe and explain the SPIDA antenna.

Simulation results for the SPIDA antenna with one director element. Later we will see how to improve the S_{11} parameter.

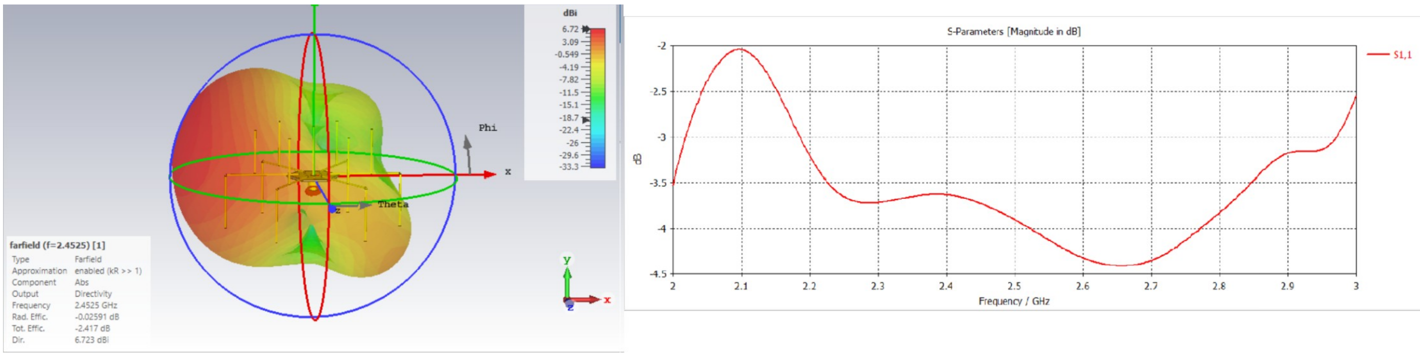

Fig. 7: SPIDA antenna with one single director element for 2.4525 GHz, Z_{in} =50 ohm, radiation pattern and $|S_{11}|$.

The results for one director SPIDA antenna are discussed in [SPI01], which can be accessed by the following link. SPI01 .

Analyzing this antenna with the CST it was found that its characteristics can be greatly improved if multiple directors are used instead of a single director. These results are discussed in [SPI02], which can be accessed by the following link. SPI02 .

In particular in Fig. 8 a SPIDA antenna with three director elements is shown, and in Fig. 9 the performance improvements obtained by using three director elements instead of one are shown.

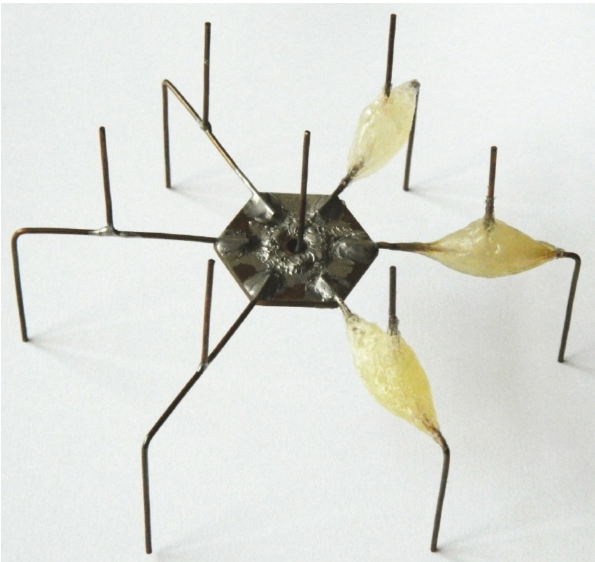

Fig. 8: SPIDA antenna with three director elements (Source [SPI02]).

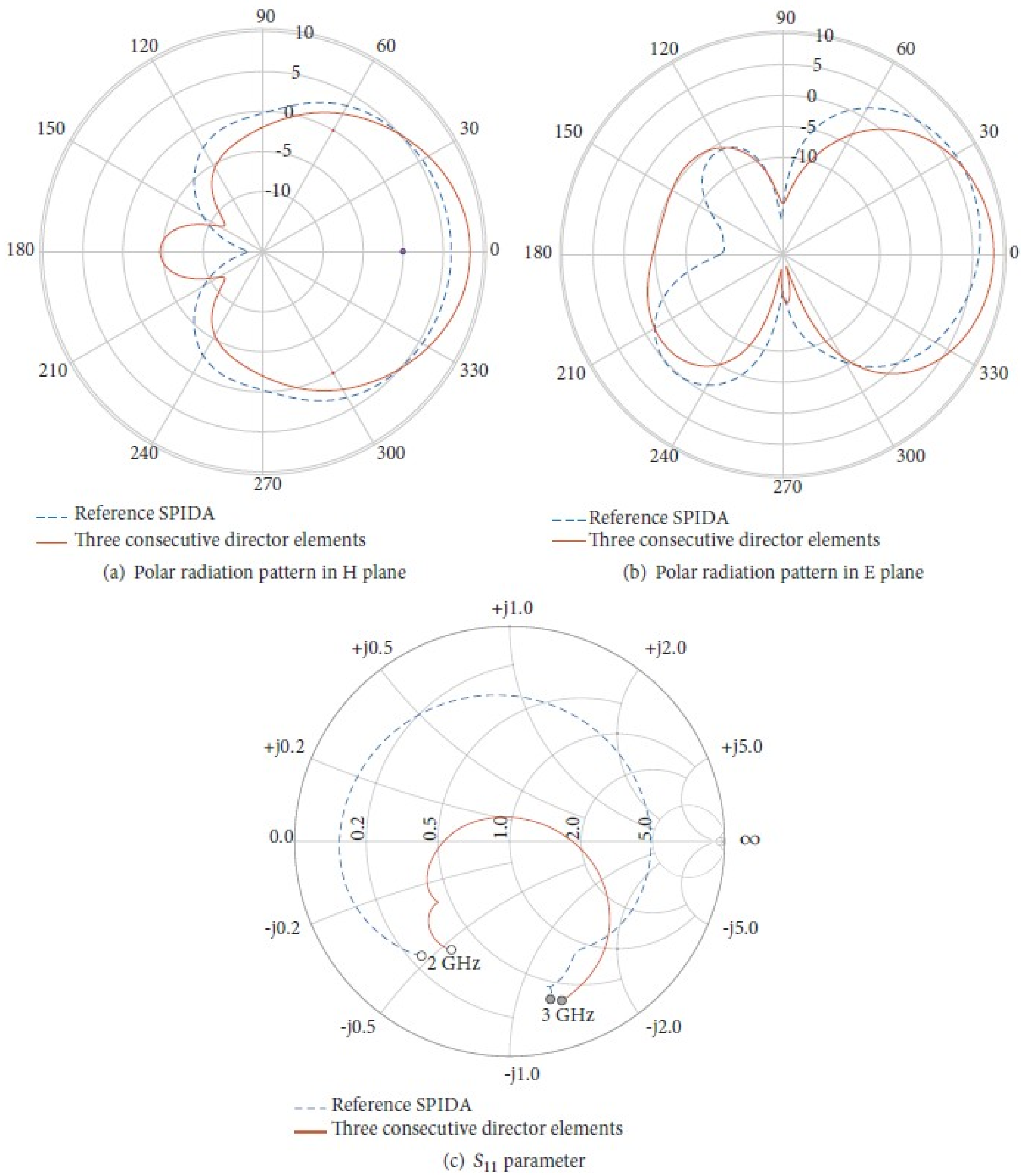

Fig. 9: Improvements obtained for a SPIDA antenna with three director elements, instead of only one (source [SPI02]).

By having the CST tool available, after thinking that some improvements could be obtained by using various director elements, we were able to verify this and obtain an approximate quantification of these improvements through simulations. In this way, we were able to evaluate the interest or not of various configurations through simulations, without having to build or characterize each configuration considered, which obviously reduces the time and cost associated with this task. Once the most convenient configuration was identified through simulations, this version was built and characterized, verifying the results that we had obtained through the simulations.

Having a suitable simulation tool allows us not to work blindly and greatly reduces the time and cost of exploring new types of antennas.

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2.6 Patch Antenna Design

Later in Chapter 4 the design of a patch antenna and a patch antenna array will be presented. In this section a patch antenna and some particular results are presented as a first contact with this kind of antennas.

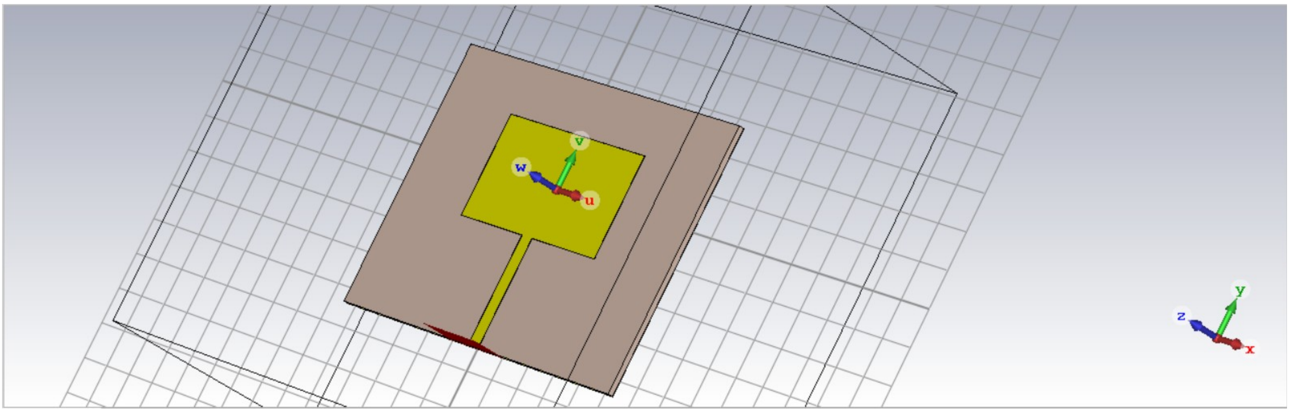

Fig. 10: Patch Antenna Model.

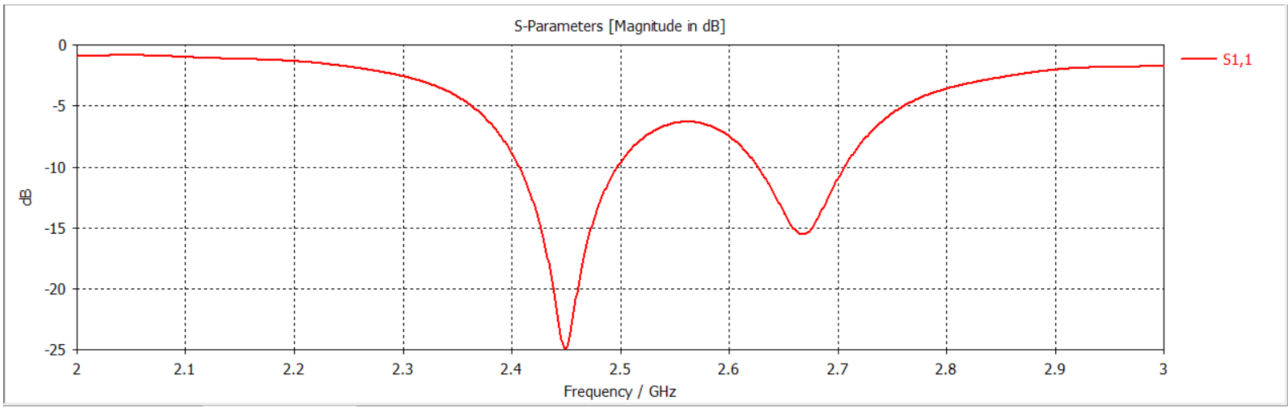

Fig. 11: S11 Parameter for this patch antenna.

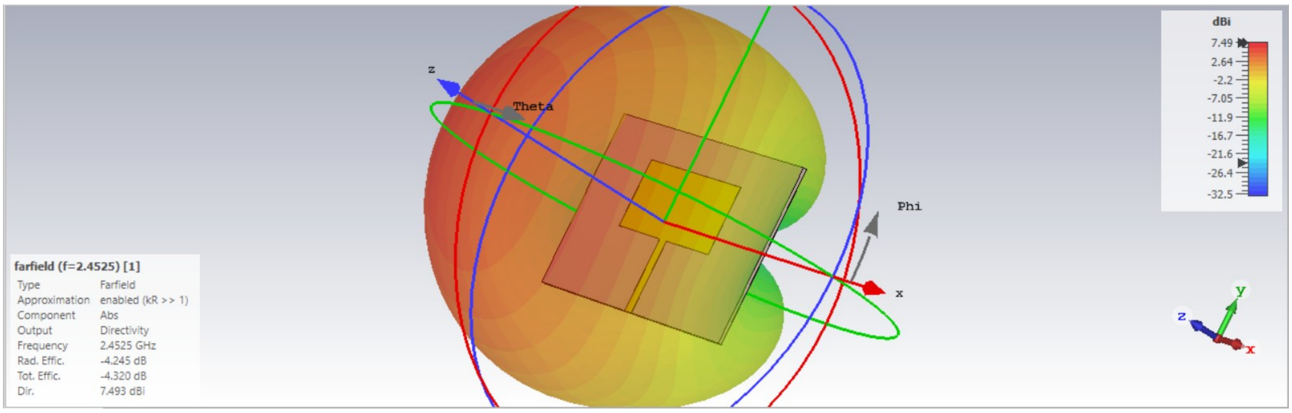

Fig. 12: Radiation Pattern of this patch antenna.

2.7 Rectenna Design

The rectennas are devices constituted by antennas and rectifiers whose function is to harvest energy (energy harvesting). A general block diagram of a rectenna is shown In Fig. 13.

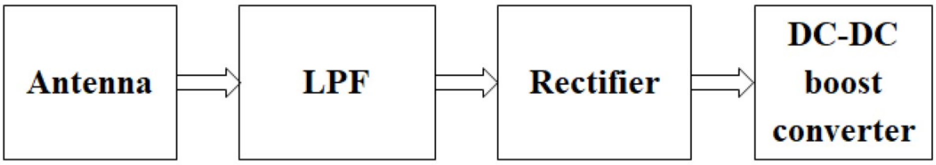

Fig. 13: General block diagram of a rectenna (source [REC01]).

Both, the antennas and the filters used for rectennas can be designed with CST.

The development of a rectenna is presented in [REC01], in this publication the CST was one of the simulation tools used. This publication can be accessed through the following link. REC01 .

The discussion about in which scenarios could be useful a rectenna as the one developed in [REC01], is presented in [REC02]. This publication can be accessed through the following link. REC02 .

REFERENCES

CHAPTER 2 REFERENCES

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[REC01] Andry Contreras, Benigno Rodríguez, Leonardo Steinfeld, Javier Schandy, Mariana Siniscalchy, Design of a Rectenna for Energy Harvesting on Wi-Fi at 2.45 GHz, In Proc. of Congreso Argentino de Electrónica (CAE 2020), 2020.

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