Dual-band antennas in CST Studio Suite

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(Dated: June 19, 2020)

The aim of this report is to learn about dual-band antennas, and carry out electromagnetic simulations of pre-designed antennas using CST Studio Suite, a commercial software. We will replicate the structural models of three representative dual-band antenna designs extracted from the scientific literature, and we will try to obtain the same results after the simulation. For this, we will first search information about the antennas we are going to work with, then we will learn how to use CST from a tutorial article provided by our instructors, and finally we will discuss the results obtained.

I. INTRODUCTION

The traffic demand for wireless communications is increasing at a breathtaking pace. Central to wireless communication systems is the radiating element and research into efficient and compact design of antennas is attracting a lot of interest. Dual-band antennas allow for a bidirectional wireless communication with a dedicated spectral band for each communication direction.

In this work we will analyze three alternatives for the design of dual band bidirectional antennas working in a spectral band centered at GHz frequencies for wireless applications such as Wi-Fi devices working in different frequency bands. The electromagnetic properties of the antennas will be simulated by a commercial tool, the CST Studio Suite.

We also include a brief analysis of the capabilities offered by the software, the assessment of the parameter options available, and explanation of the choices taken for the correct simulation of each case. We have taken into consideration the three pre-designed dual-band antennas suggested in [1], [2] and [3] and studied for each case the best method for block-designing letting its geometry as a function of certain parameters that we have later on optimized using CST tools in order to obtain the expected *S-parameters* and *radiation patterns.*

A. Patch antennas and dual-band antennas

Patch antennas are a type of antenna –i.e. printed on a PCB– consisting of dielectric substrate placed in between of a flat sheet of metal called "patch" and a larger metal sheet named "ground plane". Their low profile geometry makes them suitable for common cell-phones transceivers but they are also used in GPS devices and telemedicine, among others [4].

One of the key phenomena involved in its performance is *resonance*, which stands for the formation of standing waves due to the interception of radiation with a certain frequency by a sharp edge of the patch. If the antenna is excited at a resonant frequency, a strong field is set up inside the dielectric and an higher current flows on the patch surface, which leads to power being well radiated by it. In a patch antenna, ground plate and patch metal sheets act as a resonant transmission line where the length of the patch sheet is approximately $\lambda/2$, one-half of the operation wavelength. Hence, the length of these plates must be of several *mm* in order to obtain a bandwidth centered in the GHz, which is the most common operating frequency range for Wi-Fi or Bluetooth, for instance.

Another objective in telecommunications is to obtain an antenna that works for several frequency bands. These are the so-called *multi-band* antennas and this phenomenon is achieved by adding slots –small discontinuities in the patch or ground plate– that allow other standing modes without the loss of the lower frequency ones. Because of the complex calculations needed to obtain certain operating frequencies, EM simulation softwares are commonly used to simulate different situations of these slots in order to obtain the desired results.

The bandwith at a certain operating frequency of an antenna is determined by the *coupling* [5], which estimates the (usually) undesired energy transferred by an antenna to another adjacent one. This is an important phenomenon to consider when, for example, a measuring antenna is placed near a reflective surface or another radiating track on the same PCB. Due to the reciprocity –reception and transmission properties of an antenna are identical– mutual coupling decreases the efficiency of an antenna in both modes and alters its radiation pattern.

B. Characterization parameters

We usually take into consideration two parameters when characterizing an antenna.

The *radiation pattern* is the power radiated by the antenna for each direction of space. To characterize this parameter we represent the far-field region radiation pattern –that is, the power of the field like very far away from the radiation element–.

In a general input/output-ports network, the *S(cattering)-parameter* is a relation between incident and reflected power at each port, a_i and b_i respectively, given by:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{1,1} & S_{1,2} \\ S_{2,1} & S_{2,2} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{1}$$

$S_{1,1}$ is usually called "input port voltage reflection coefficient" since it determines the ratio of reflected power to the input port, b_1, per incident power in the same port, a_1, while $S_{2,2}$ is usually called "output port voltage reflection coefficient", otherwise. These parameters are usually represented in a logarithmic scale in order to obtain values close to 0 when these coefficients are close to 1 –and therefore power reflected is of the order of the incident power– while we obtain a negative downward peak when this value is smaller than 1 –i.e. reflections are negligible–.

When we use an EM simulation software such as CST to obtain these two parameters we can obtain directionality and intensity with the *radiation pattern* and bandwith and resonance frequencies with the *S-parameter* diagram.

II. CST DESIGN

The first structure [1] is made with a single-layer substrate, a ground plane and the patch antenna, based on two cavity resonators, and it is excited by two ports. The model that we have done with CST is shown in Figure 1.

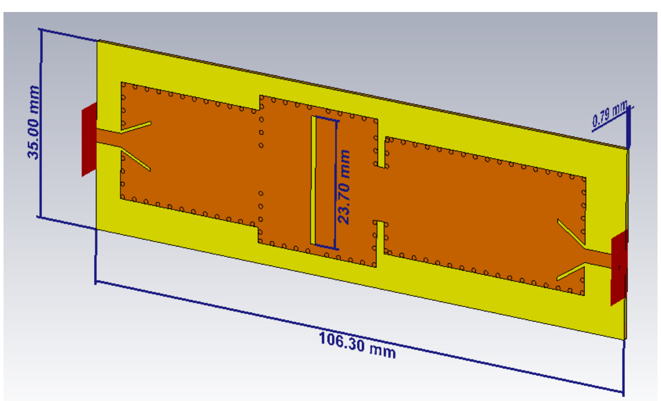

FIG. 1. Model from the first article [1] replicated with CST.

The second structure [2] is also made with a single-layer substrate, a ground plane and a patch antenna, but in this case it is based on a T-shaped resonator and two orthogonally placed patches and it is excited by a single port. One can see how it looks in CST software in Figure 2.

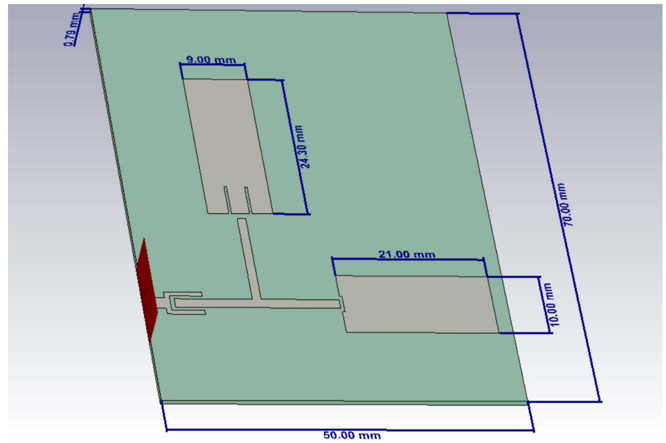

FIG. 2. Model from the second article [2] replicated with CST.

The last one [3] is composed by two substrates with a layer of foam between them, a circular patch on the top layer of the upper substrate, a ground plane, which has a U-shaped slot and two straight slots, placed on the top layer of the lower substrate and at the bottom layer of the lower substrate there are printed the miscrostrip feed, consisting of two ports, and hairpin resonators. The antenna is shown in Figure 3.

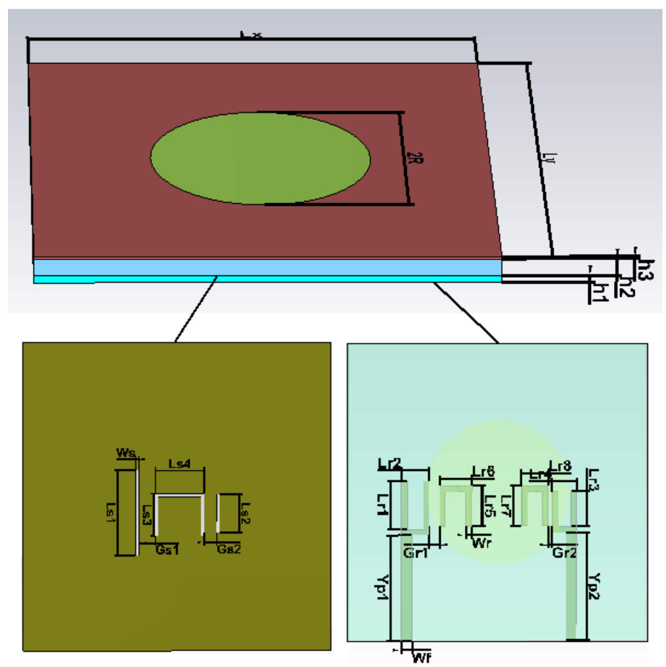

FIG. 3. Model from the third article [3] replicated with CST.

The antennas have been replicated using the drawing tools provided by the CST software, which include tools such as *Bricks*, *Cylinders* or *Extrudes* (tetrahedrons in which we have to indicate the position of the four vertices). Before starting to draw, it is important to set the

axes and have clear in which direction and position we are building the structures, as well as the units we will work with, which in our case will be in millimeters.
It is a good strategy to set the parameters of the structures as variables, so that we can change easily their value and update a new version of the model if needed. The list of parameters is shown as a list at the bottom of the screen. That makes it very easy to keep track of all the dimensions, and to change the figure settings.
It is also important to remark that CST has a very visual environment that makes very easy to rotate, zoom and move around the structure. We can now explain our experience drawing our models.
The *Mirror* tool was successfully exploited for the cases with several instances of the same shape, like for example the vias of the first structure, whereas the extrude was useful for the more complex shapes such as the polygons that we see near the ports of this same antenna, or most of the structures in the second one. Finally, to open slots over a metallic plane, we defined a vacuum brick and applied the *Substract* tool.

A. Excitation ports, frequencies and monitors

Once the structure is completed, we need to specify the excitation conditions and the ports through which the electromagnetic energy can get in and out of the structure. For this, we can use the *Waveguide Ports* tool. We have found a useful macro of the software that calculates the proper dimensions of the port and the port extension coefficient. It is important to verify that the input impedance of ports approaches 50 ohms, which can be checked by selecting 'reference impedance' in the directory tree after the simulations. This was particularly important in the case of the second structure, where the input impedance calculated by the software was around 61 instead of 50 ohms. By means of a post-processing tool we renormalized all the calculations to the desired value of reference impedance.
Then, we need to select the range of frequencies in which we want to get our results, which can be done in the *Frequency* tool. We have also to verify that a proper choice of boundary conditions is set for our design and results in *Boundaries*, which are set in "open space" by default. Then it is important to set symmetries in order to help save time in the simulations. Finally, before starting the simulation, we need to set the monitors in the results we would like to see. In our case, the monitors have been set to give the S-parameters and the far-field distributions at the resonance frequencies.

B. Simulation and optimization

The next step is to perform the simulations. CST includes many different solver types, but the best suited to our problem is the time domain transient solver. Apart from this basic simulation, we can use other simulations tools. One of them is the *Parameter Sweep*, in which we can program a set of consecutive simulations changing the value of one or more parameters in an interval. This will be useful to see how the results change if we vary the dimensions of certain structures of the model. Another tool that we will use is the *Optimizer*, in which we can set a series of goals, and the parameters we want to modify. This will allow us to get the best parameter values to the results that we want to get.
The papers used as reference do not always provide all the information required to replicate the results. It is also possible that they have used another simulation tool with different models and approximations. In order to get similar results we had to tune the structure using the optimization tools provided by CST. We have made extensive use of parameter sweeps and the optimization tool, implementing hundreds and hundreds of simulations until getting the best result. Regarding the optimization tool care should be taken in the selection of the starting point, the parameters to be optimized, and the goals to be achieved, because we can obtain different results.

C. Results

Finally, the last step is to check the results after the simulations. As our goal is to achieve the same results as the ones given in the papers of reference, we will only need to see two results. The first one is the S-Parameter, which will indicate visually where the resonances are produced, giving us peaks at the frequencies in which our model works. The second one will be the far-field radiation patterns, in which we will see a 3D picture of how the antenna radiates.
Once the antennas from the articles are replicated in CST, we proceeded to perform several simulations to obtain the best parameter values, so we could recover the results from each article. We carry out the simulations with the transient solver and, in order to achieve similar results to the ones provided by the articles, some optimizations will be necessary. However, the results we obtained are not exactly the same as the ones provided by the articles, and the antenna that best resembles the reference result is the first one, which is shown in Figure 1, and will be the one we will talk in detail in the next sections.

III. FINAL RESULTS

In this section we will present the final results and the comparison to the ones given in the papers. First we will talk a little more about the antenna we have chosen.

The antenna [1] is based on two cavity resonators that are capable of giving two different resonant frequencies, theoretically centered in 5.25 GHz and 5.8 GHz. One problem that we realized at the beginning is that the length specified in the article of the total structure in the horizontal direction is not the sum of all the dimensions in such direction; this sum gives 106.3 mm instead of the 107.5 mm that is considered in the article. We also see that some dimensions are not given, such as the slot height or the angle that forms the small slots near the ports. We will parametrize them with reasonable initial values, and we will play with them in order to get better results.

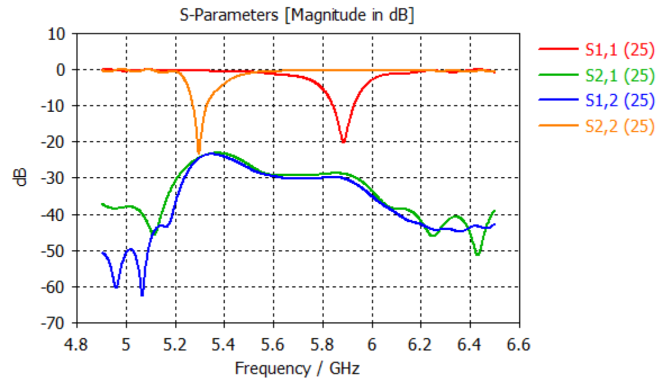

FIG. 5. Results of the S-parameter with the best values: Height of the slot = 23.7 mm, Angle port 1 = 25°, Angle port 2 = 34.37° and B2 = 27.4 mm

A. Results and discussion

First of all, we present the results in the next two figures, and then we will discuss them.

1. *Results on the port impedance and radiation patterns*

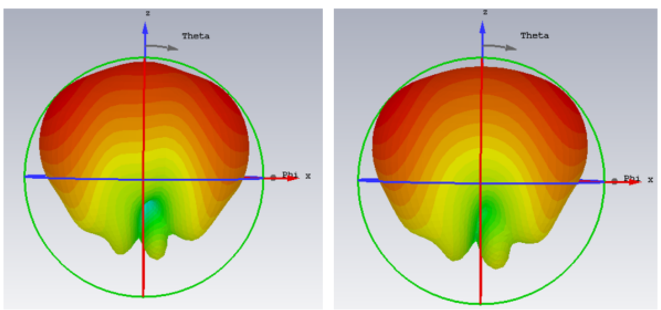

FIG. 4. On the left, the radiation pattern of port 1 (5.8 GHz). On the right, the radiation pattern of port 2 (5.25 GHz)

The first thing that we need to assure is that the port impedance in each port is the expected. In this case we want them to be of 50 Ohms, and the results give us an impedance of approximately 49 Ohms, which is a close result.

Then, we can see if the radiation patterns at each port are the ones expected (it will be at each resonance frequency, as port 1 gives peaks at 5.8 GHz and port 2 at 5.25 GHz). As we can see in Figure 4, the radiations patterns are close to the ones that are exposed in the article of reference [1].

2. *Results on the S-Parameter*

We first saw that the results were not the same, and in order to get better results, what we have done is to change some key parameters in order to modify the resonant frequencies and the bandwidths. After hundreds of simulations we conclude in the following.

a. Height of the slot. This parameter modifies the position of the resonant frequencies, and we concluded that for higher values we get better results.

b. Angles of the port slots. These parameters change the coupling properties in a way that we change the bandwidth of the peaks. For high angles, we lose the broad bandwidth (actually we do not see the two peaks expected in each port), but we get a more intense peak in dB and clearly centered at one frequency.

c. B2. Another parameter that modifies the position of the resonant frequencies is the height of the structure that has the slot in the middle. With this, combined with the height of the slot, we achieved to center the resonant frequencies near 5.25 GHz and 5.8 GHz.

In conclusion, Figure 5 shows the obtained S parameters for this antenna. It is worth noting that our results mostly agree with the ones in the paper, as they are close to the resonant frequencies expected, and with a decent intensity in dB. The only thing that we can not make better without losing the resonances that we want, is the bandwidth of the peaks, as they should be larger around -10dB.

IV. CONCLUSIONS

We have analyzed three different designs of dual-band antennas by using the CST electromagnetic fields software. The process for setting up the simulations has been shown, highlighting the key parameter choices. In spite of the incomplete information, optimization tools such as parameter sweeps and optimizers have been exploited to obtain results that agree with the ones showed in the papers. This work constitutes a useful guide for the successful design and simulation of multi-band antennas.

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