BANDWIDTH OPTIMIZATION OF FLEXIBLE ANTENNAS

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Abstract

It is a well-known fact that antennas have been widely used in communication technologies and electrical studies for at least a century. Unsurprisingly, along with the global trend of miniaturization of most daily use technological devices through the years, antennas also had their share of this size reduction movement. Therefore, it is important that the antenna carries at least the same performance specifications and even has improvements such as wider bandwidth, lower mismatch in parallel to becoming smaller in size. The main goal of this project is combining metamaterials and patch antennas in order to maximize its bandwidth performance and to minimize its reflected power with the help of topology optimization and certain software programs. In this respect, Comsol Multiphysics and Matlab used in order to accomplish the desired results.

1)Introduction

An antenna is a device which transmits or receives signals in the form of electromagnetic radiation used in the telecommunication industry. There are many antenna types such as Microstrrip Patch Antenna, Dipole Antena, Planer Inverted-L/F Antenna and many more of them exist. Each of the antenna types has advantages and disadvantages compared with each other. In this project, we have focused on Patch Antenna because of ease of fabrication and also their shape and size. Patch Antennas have also subgroups depending on their geometry. The most common Patch Antenna is Rectangular as shown in the below figure. (Kishk et al., 2009)

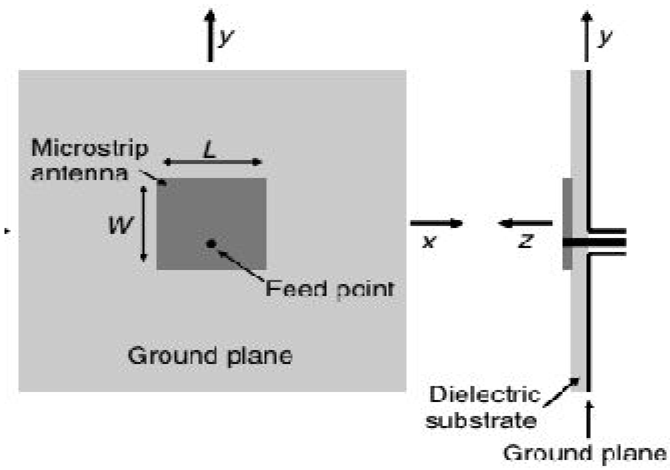

Figure 1

The dielectric substrate is between the patch and the ground plane also there is a feed point in Figure 1 where the power is delivered to the antenna. There are many loss mechanisms in antenna systems, the most important loss mechanism is impedance mismatch. Due to the mismatch, some amount of the given power can be reflected back. The ratio of reflected power divided by the incident power gives us the parameter called S11. The mismatch is frequency-dependent and the frequency value when the mismatch becomes minimum is called resonance frequency. When the frequency is close to the resonance at a certain range, the antenna still works. This “certain range” is called bandwidth and it is the operational frequency range of the antenna. Resonance frequency, bandwidth, mismatch all these parameters also depend on the geometry of the antenna, dielectric substrate, and feed location.
Metamaterials are artificially designed materials which exhibit unique interaction with the electromagnetic radiation and produce ‘unusual’ performance. We have been working artificial dielectrics such as FR-4 and Duroid as a metamaterial in this project. FR-4 and Duroid have different permittivity and loss values and the combination of these materials minimizes the loss and affects bandwidth. A combination of these materials is not arbitrary with the help of the Topology Optimization combination becomes clear. (Syagıner ,2016)

Topology Optimization

It is an advanced design method that maximizes the performance of the system by determining its topological and geometrical conformation with regards to material composition and connectedness (Sigmund, O., & Maute, K. 2013). Although there are several Topology Optimization methods, Homogenization and Level Set Approaches used in this study in order to minimize the reflected power and maximize the bandwidth performance of the antennas with given geometries. Therefore, polymer-ceramic composite substrates were used due to their spatial dielectric permittivity and multilayer configurations. In this respect, FR-4 as artificial dielectric and Duroid as metamaterial combined in this study in order to accomplish the desired results (Sayginer, 2016).

Computer modeling and Simulations

Adjusting the parameters and seeing the differences in the measurement has always been a good method of finding useful results. Although we have previous measurement results, the common use of computer modeling software has made it significantly easier to carry on different research tasks and cover a wide range of possibilities for further improvements to the solution or model. Comsol Multiphysics is a software which utilizes the Finite Element Method (FEM) to determine the change in physical properties throughout the space for the given material properties. This was the program used for modeling the patch antenna and simulating different specifications for optimal results of the S11 parameter. Another use was to observe the electric field distribution and radiation patterns of the antenna to ensure that we were getting similar results to our expectations, double-checking the simulations.
Another program used for this project was MATLAB. In engineering sciences, it is a popular tool with lots of functions, graphics which helps in optimization problems, analyzing data and statistics. Our usage of MATLAB was to create graphs which included the combination of different results of measurements, using the data from Comsol simulations and actual measurement of the antenna.

2)Patch Antenna

To begin with, the model of the patch antenna was drawn in Comsol to determine the performance of the antenna in computer simulations in various conditions. The model parts and simulation materials which were used could be explained on the Figure 2 below.

1. Feed of the antenna where we give the signal to the antenna from
2. Patch of the antenna, downward facing side. It is assumed to be a good electric conductor
3. Substrate is the part lying between the ground and the patch. It’s property called relative permittivity(ε) governs how the S11 graph will look in terms of bandwidth and resonance frequency.

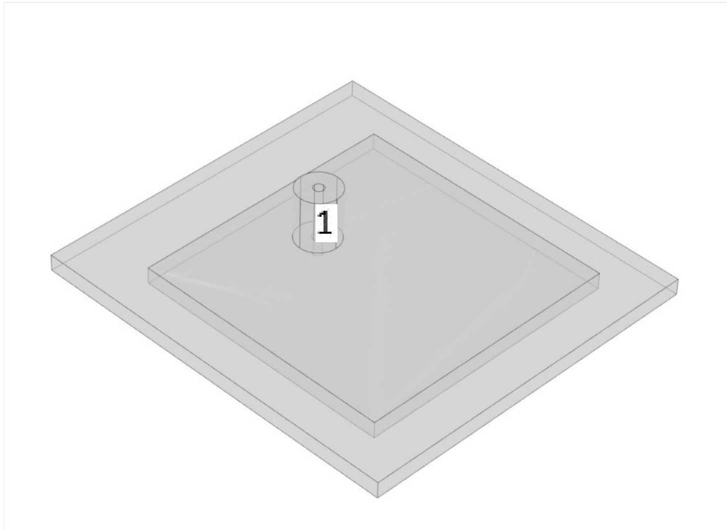

Figure 2

We have three different types of antenna in terms of material and design. As it can be seen in the figure below there are three materials with color code such as grey, white, pink. Each of them has different permittivity, loss and tangential loss value varying with frequency. All of the antenna graphs are S11 versus frequency and the blue curves indicate measurement, yellow and red curves indicate simulation graph generated in respectively HFSS and Comsol software. Simulations and the measurement graphs do not match with each other in terms of resonance frequency and S11 value. When we adjusted the material parameters in Comsol we saw that resonance frequency of the antenna 3 was close to the measurement value which is $2.1x10^{9}$ Hz. The only problem with the antenna 3 graph was mismatch inconsistency which affects the S11 value higher than we expected. We overcame the mismatch inconsistency with the help of parametric sweep.

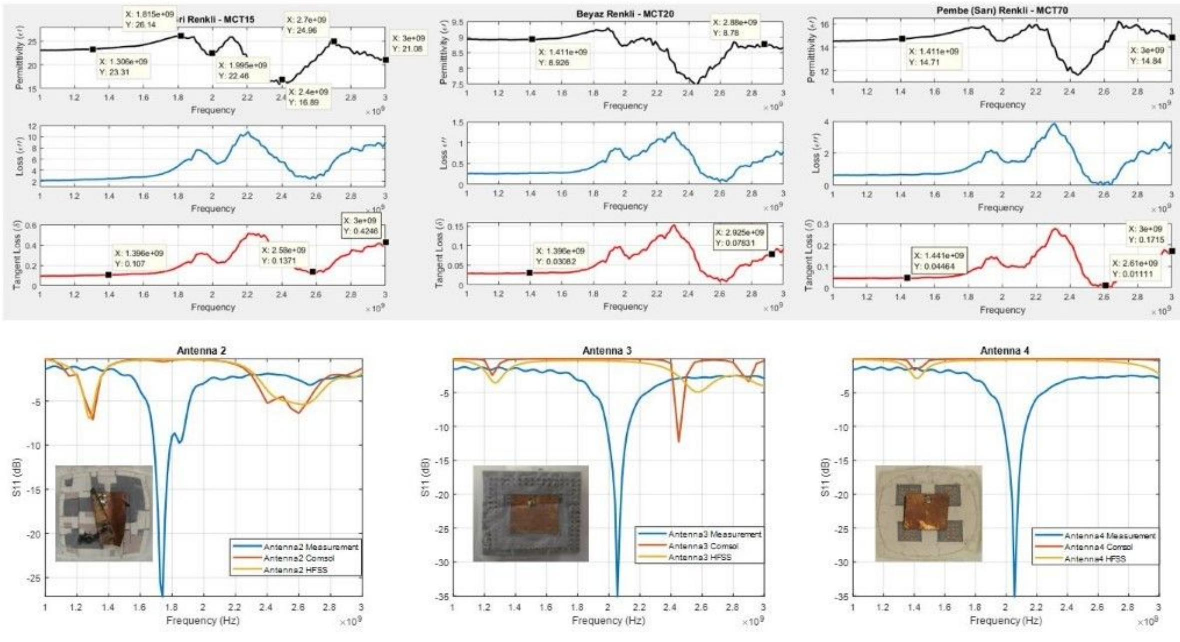

Figure 3

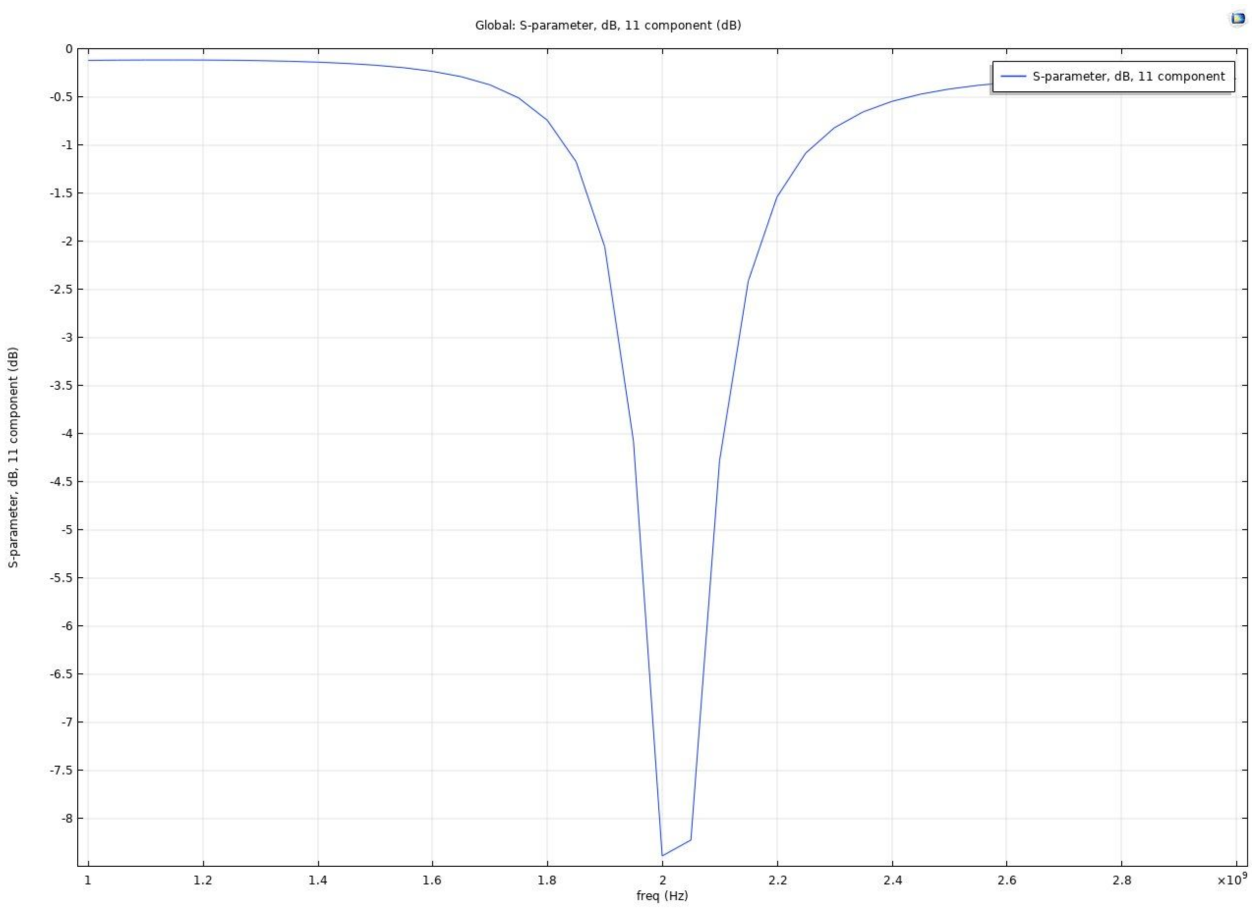

Figure 4

2.1) Computing Antenna 3 without holes

First of all, this study focused on Antenna 3 due to its correlation between measurements and Comsol Multiphysics results. We divided the computation of Antenna 3 into three parts. Normally, Antenna 3 contains holes in its configuration which designed by topology optimization. However, in the beginning, we excluded these holes in order to achieve faster results (See figure 4). Thereafter, we simulated the program and examined the results in a 1D graph. First, we wanted to find an approximate feed location coherently with the S11 value for the antenna without the hole case. After that when we found the approximate feed location we wanted to investigate the narrowed area on the antenna 3 with holes. We added the dielectric constant values both complex and imaginary parts of air, substrate and coaxial. We had an antenna draft which was created in Solidworks and we could not perform parametric sweep so we drew the antenna from the beginning in the Comsol.

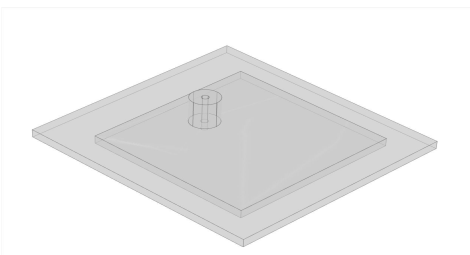

Figure 5

2.1.2) Parametric Sweep for Antenna 3 without holes

The final version of antenna 3 without holes shown above. We performed parametric sweep to feed location in order to fix mismatch problems. We adjusted the interval of parametric sweep 2 mm in the x-direction and 2 mm in the y-direction and we controlled the boundaries such that parametric sweep did not exceed the patch area.

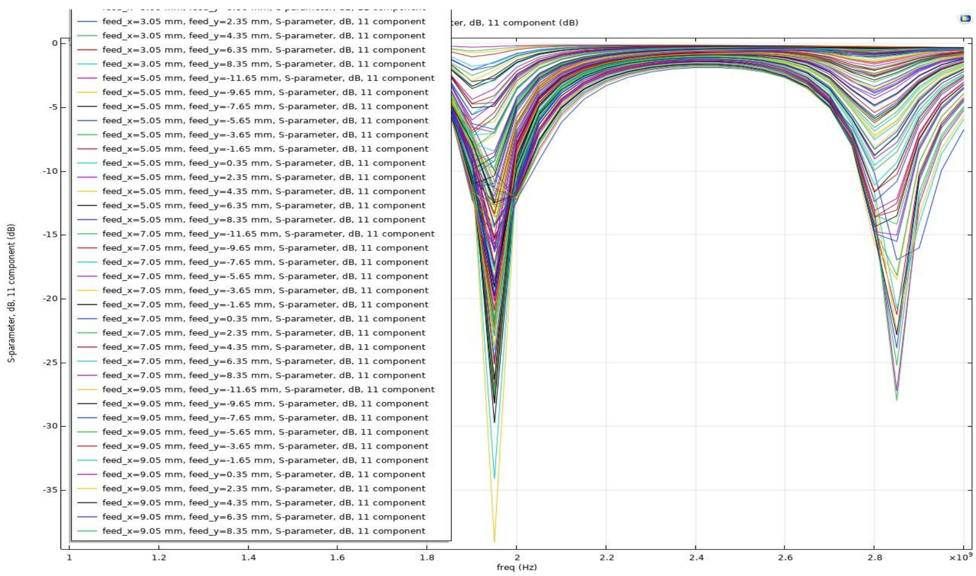

Figure 6

In the figure above, there are many curves corresponding to different coordinate values thus different S11 values. We picked the best curves which fit our measurement values manually. The resonance frequency is close to $2x10^{9}$ Hz and the S11 value close to -35 dB.

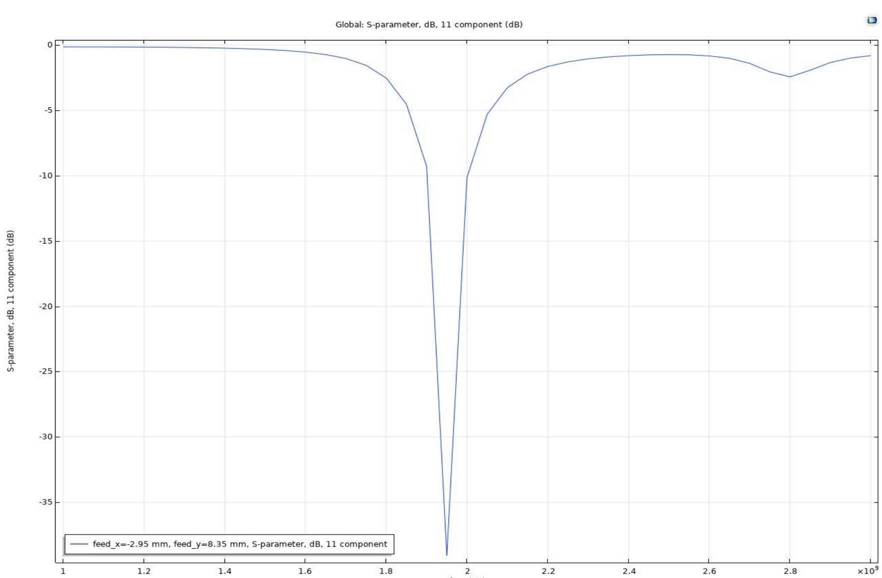

Figure 7

2.2.1) Computing Antenna 3 with holes

After determining the best feed location, we implemented our specific parameters into the simulation of Antenna 3 which contains designed holes. Although using perforated antennas in simulations takes much more time, it is essential to obtain reliable results because the main design of Antenna 3 contains these optimized holes in its configuration.

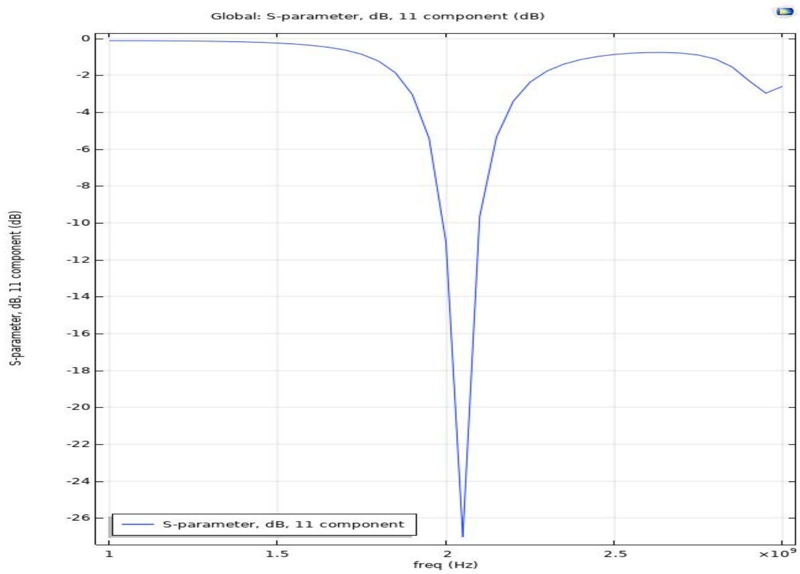

Figure 8

After we plugged the values of feed location we observed that the S11 value approximately increased from -35 dB to -27 dB. Resonance frequency almost shifted $0.1x10^{9}$ Hz towards the right because resonance frequency and the dielectric constant are inversely proportional. The dielectric constant of the antenna which contains holes is smaller than the antenna without holes because these holes filled with air.

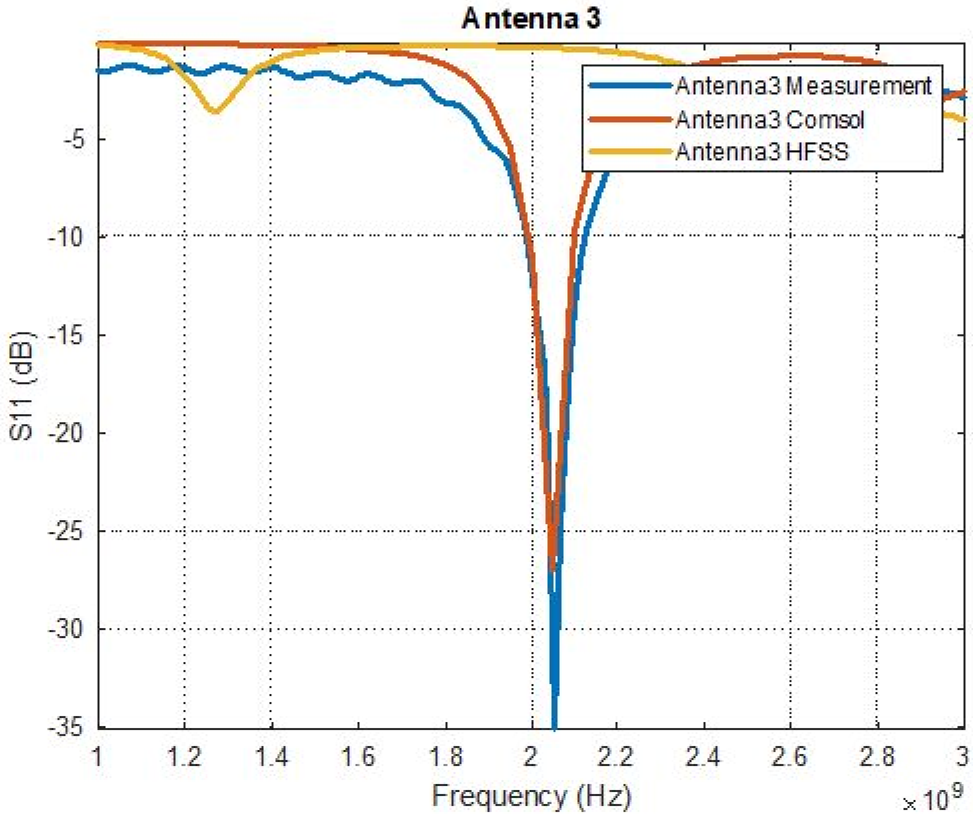

Figure 9

As it can be seen in the figure above, after designing perforated antenna in the comsol and performing the parametric sweep, S11 (dB) value decreased. In addition to this, manually made measurements matched with digital measurements while resonance frequency had negligible change.

2.2.2) Parametric Study for Antenna 3 with holes

We had a matching result before and tried that on the model with holes, the resonance frequency was strongly parallel to the holeless model's results but their S11 values were different by around 10 dB. This happens to be the case because of the introduction of holes to the substrate, changing the dielectric constant (ε) drastically. Even though this location of the feed came up with a satisfactory outcome, it may not have been the most optimal place for the feed. Because our parametric sweep in Antenna 3 without holes, was not so finely tuned to search every possible (x,y) coordinate combination on the patch (that would take a lot of time), it was a necessity to check if there was an even better match around our current solution. That's why we ran parametric sweep again with coordinates x=(0,-1,-2) and y=(5,6,7). (Center of the model is considered (0,0).)

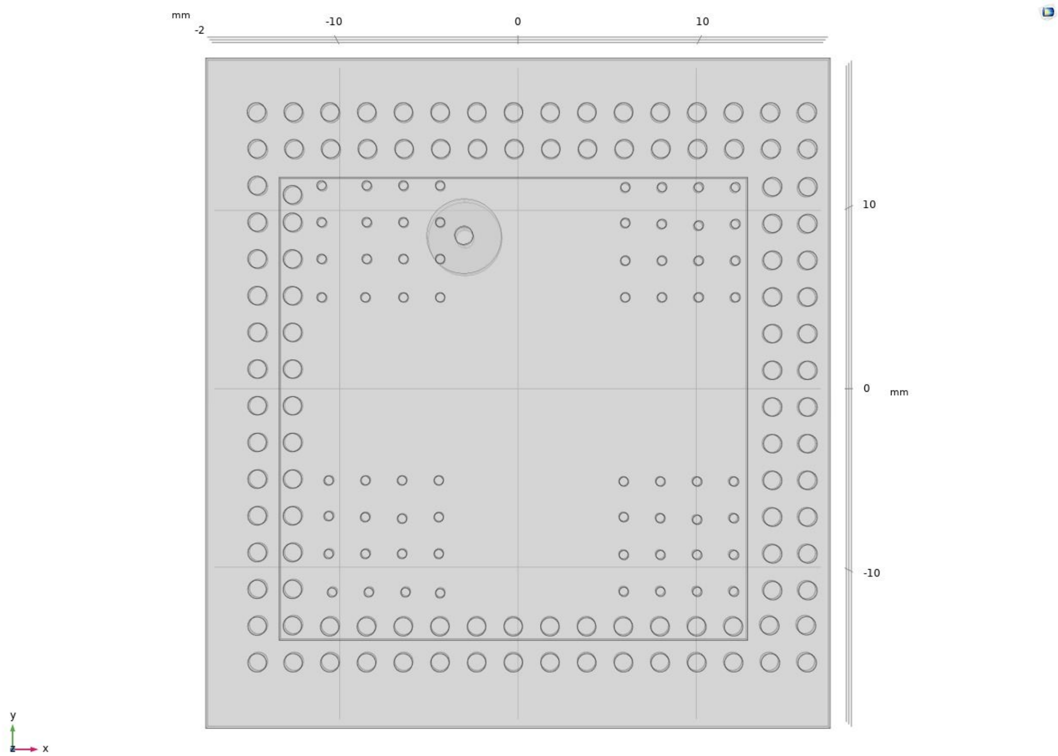

Figure 10

All of their combinations were simulated and plotted in the figure below.

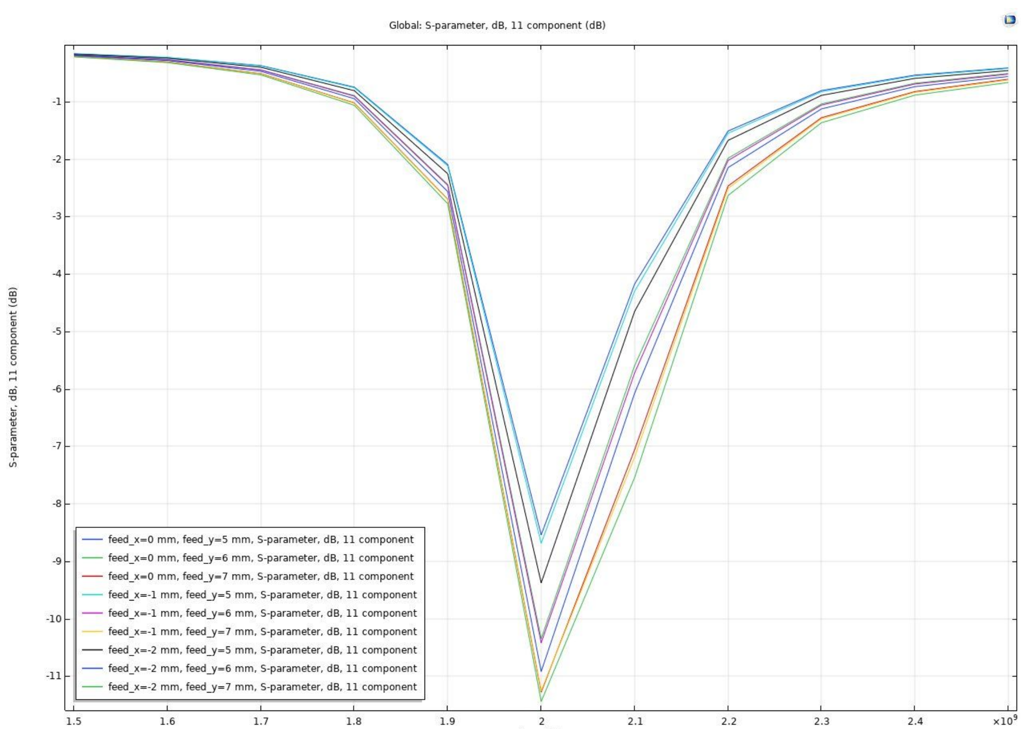

Figure 11

They all have a resonance frequency of 2 GHz but their S11 values vary according to the feed's location. The minimum S11 dB value was achieved at the coordinates (x,y)=(-2,7). To have a brief understanding of how the S11 value changes with the movement along the x and y axes. Let's consider x=-2 and determine the correlation between the S11 parameter and movement in the y-axis. It is clear that as the feed moves from y=5 to y=7, we are lowering the impedance mismatch, therefore getting improved results.

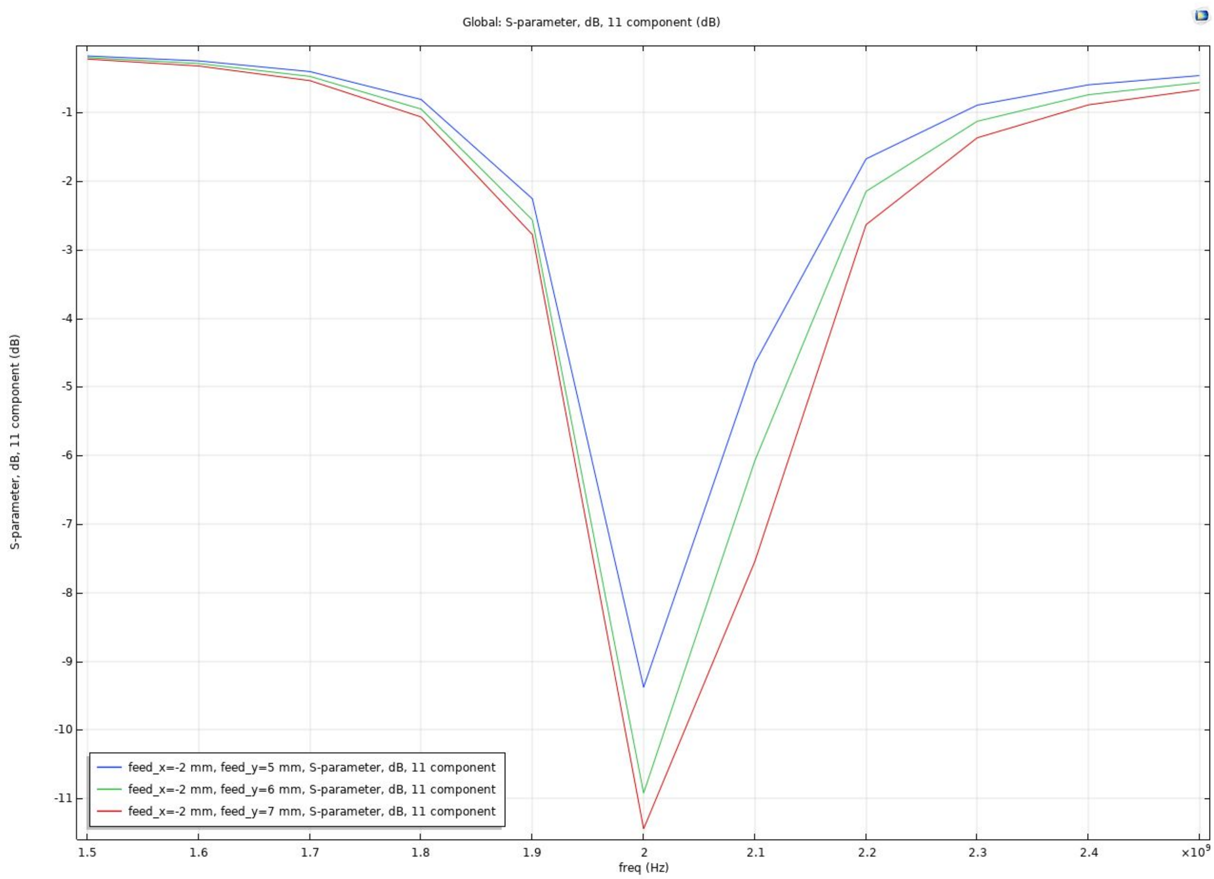

Figure 12

Secondly, analyzing for y=7 with different values of x position in the figure12, although the values don't change significantly with different x positions, it can still be noted that there is a small variation but nothing as noteworthy as the change in previous y-position case.
The result of this parametric study is that the (S11)dB tends to be lower when the feed is moving outwards to the corner of the patch. The change in the y-direction is much larger than in the x-direction, nevertheless, they both have an impact on the general picture which is observed through the plot.

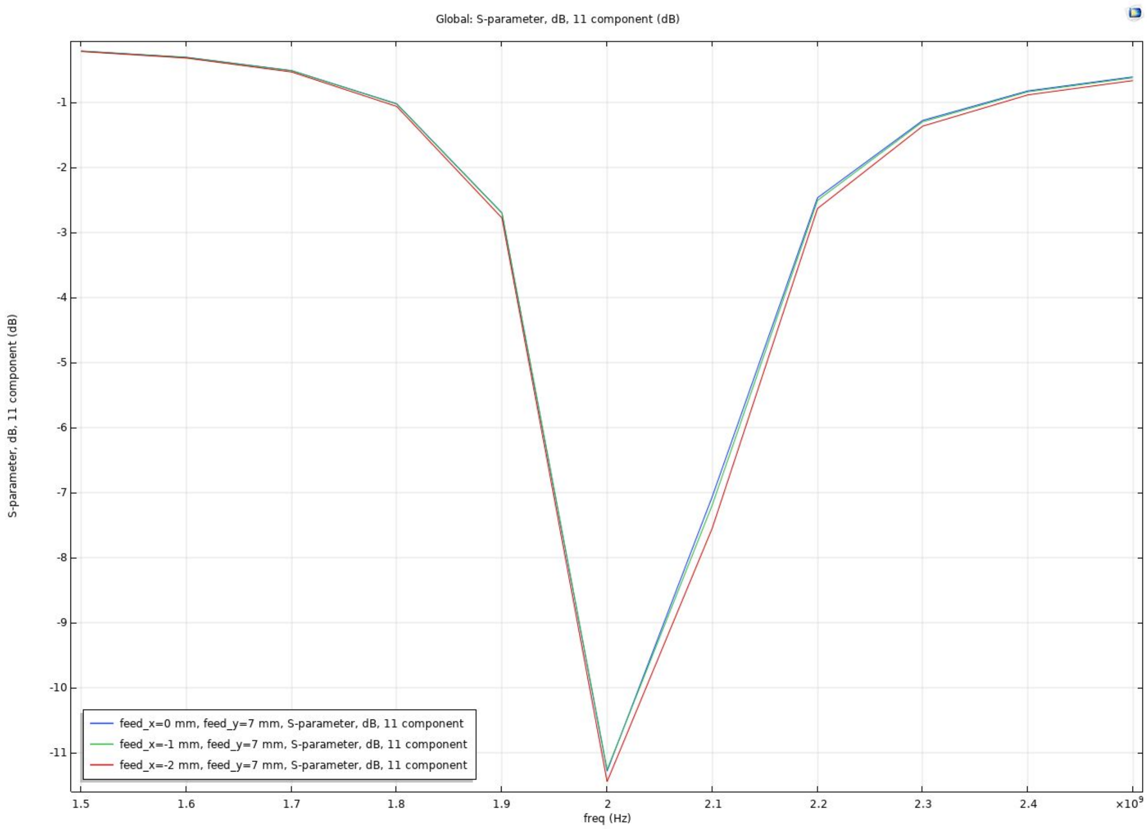

Figure 13

2.3) Study on Feed Size

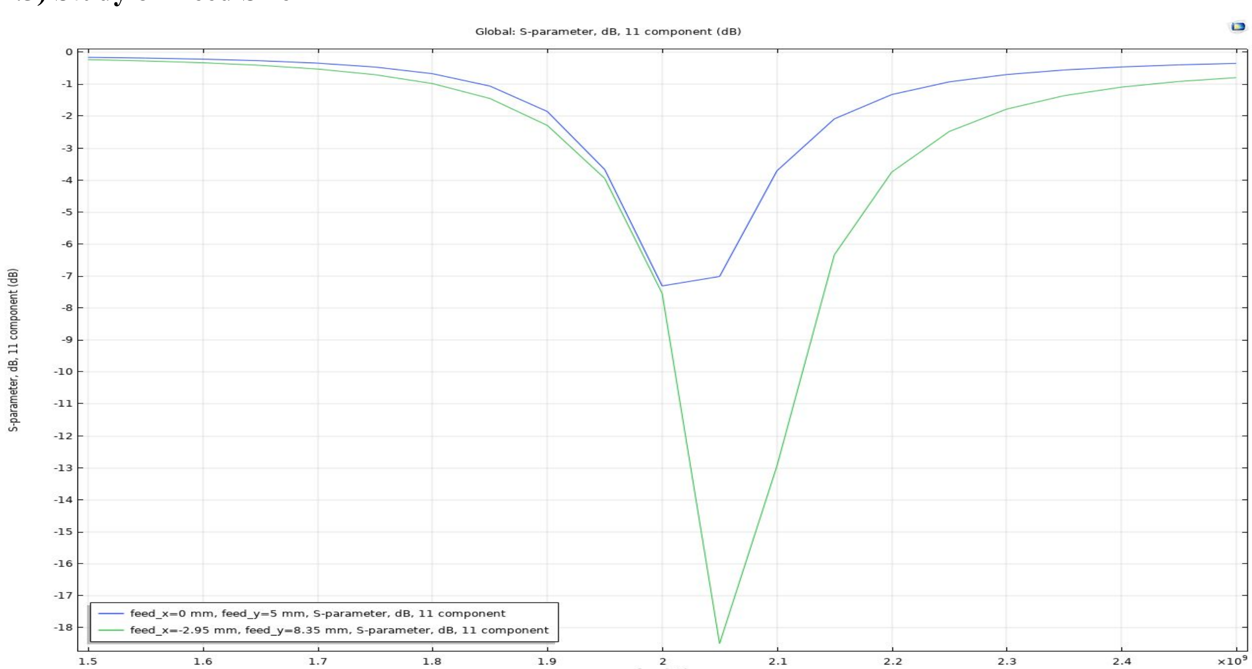

Figure 14

The coaxial feed line consists of co-centered two cylinders. We measured the coaxial feed line in the lab with a micrometer ruler. We found that the inner cylinder radius is 0.95 mm and the outer radius 2.8 mm. When we updated the simulation with new radius values, our S11 value increases as shown in figure 14 compared with the old radius values shown in Figure 12.

Conclusions

To conclude, the main goal of this project was to improve operational bandwidth performance and to decrease the antenna size while keeping the impedance mismatch as minimum as possible. Firstly, we have investigated the specific characteristics of patch antennas by running the simple holeless model with Comsol Multiphysics 5.4 since the simulation of holeless antenna takes much less time. After obtaining the accurate resonance frequency, in order to decrease the impedance mismatch, we did several parametric studies and compared the actual measurements with the results. In this respect, we did a parametric sweep and changed the feed location of the holeless model to observe how it affected the mismatch, therefore, the value of the S11 parameter which is the ratio of output power to antenna's input power. Thereafter, we reached the result that mismatch can be reduced by the correct positioning of the feed on the patch.

In the next part, we carried on our research by transferring our outcomes from the holeless model to the real life model of our patch antenna in order to analyze if their results are matching each other. The optimal location of the feed was taken into consideration for our subsequent step where we decreased the step size of the movement of feed in x and y axes. While we were doing parametric sweep we also analyzed the S11 and resonance frequency values by changing only one coordinate and keeping the other coordinate constant. In addition to this, While transferring our parameters into the perforated antenna, we also increased the radius of the coaxial feed from 2.05 mm to 2.8 mm in order to achieve more accurate results.

As future work, we are planning to follow the same steps for Antenna 2 and Antenna 4 in order to analyze the results for substrates with different kinds of composite materials and layouts. Taking a look at the bigger picture, this project needs more work to be successfully implemented as health monitoring sensors with flexibility. (Bonfiglio & Rossi, 2011)

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