Microstrip Patch Antenna Array – 2x2

In this document we will be documenting our efforts to design and create a simulation of an antenna array, more specifically, a microstrip patch antenna array.

The assignment was given to us by our communications professor – Ely Levine, as per our request to learn more about antennas.

Before we started simulating, we wanted to gain a deeper understanding of microstrip patch antennas. For that reason, we read more about the topic in Constantine A. Balanis' book, *Antenna Theory: Analysis and Design*".

After understanding the fundamentals of design, we needed a simulation tool. From scouring the internet, we learned that there are 2 major simulation applications that are used for design and simulation of antennas: CST and HFSS. We have decided to simulate the design using HFSS, so we started learning about the program from various websites and videos.

Here are links for all the information to start the design:
Antenna Theory: Analysis and Design: Balanis, Constantine A.
Ansys HFSS | 3D High Frequency Simulation Software
Forum for Electronics
EECS 430: Adding Coaxial Connectors to HFSS Simulations
2.3 GHz Probe Feed Patch Antenna - ANSYS HFSS Simulation
What is an SMA Connector? Everything You Need to Know - MetabeeAI
Microstrip Patch Antenna Calculator - everything RF
Coaxial Cable Impedance Calculator - everything RF
Antenna Near Field & Far Field Distance Calculator

Feel free to look at the .aedt file to see the full design and the measurements:
TomSimkin/Microstrip_Patch_Antenna_Array_2x2: Designed and simulated a microstrip patch antenna array 2x2

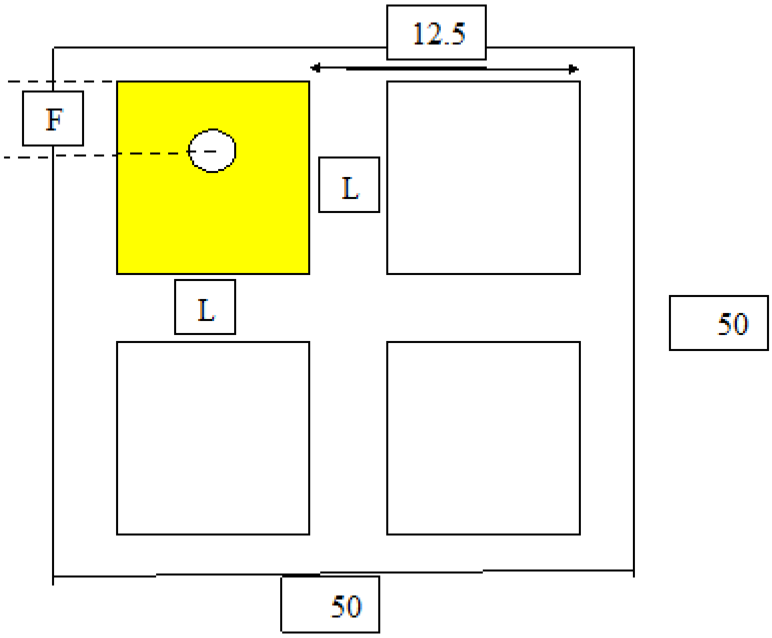
We hope you also learn something from this attempt 😊

Let's begin.

The specifications of the antenna array are as follows:

- 4 elements that are in a 2x2 order.
- Each element is connected by an individual vertical SMA connector.
- Distance between each element is 12.5mm.
- The elements lie on 2 substrates: FR4 and Rogers 4350.
  The former substrate will be positioned between the ground and Rogers 4350; each substrate is 0.8mm thick.
  The substrate dimensions are 50x50 mm.

Here is a crude sketch of the specifications:



We need to find the patch size (L) and the distance between the patch and the SMA connection (F) for a single element (In the presence of the neighboring elements).

Our antenna needs to work in the following conditions:

- Center frequency – 18 GHz.
- Bandwidth – 5%.
- 5 dBi gain in all the relevant frequencies.
- VSWR = 2.
- Linear polarization.
- Beamwidth - 70^ox70^o optimally.

For starters, we created the ground level, 50x50mm. On top of the ground plane, we placed the two substrates – Rogers 4350 (ε_r = 3.66) and above that the FR4 (ε_r = 4.4). Each substrate has a height of 0.8mm.

On the top substrate (FR4) we placed 4 identical patches. Keeping in mind of the specifications and using the Microstrip Patch Antenna Calculator - everything RF, we placed the patches symmetrical to the center.

We used this calculator for initial calculations. After some testing and fine tuning, we concluded that the optimal patch size is: 3.9x3.4mm.

Each patch is fed with an SMA connector. Using the measurements from Coaxial Cable Impedance Calculator - everything RF, we attached the connectors. At first, we placed the connectors in the middle of the patch. Testing the impedance matching, we saw that it was unsuccessful (far below 50Ω). After some more testing, we figured out that the best place to attach the connector is at the top of the patch, very close to its edge, in the middle.

After the patches, we placed an airbox. The airbox dimensions were calculated using the far field Antenna Near Field & Far Field Distance Calculator.

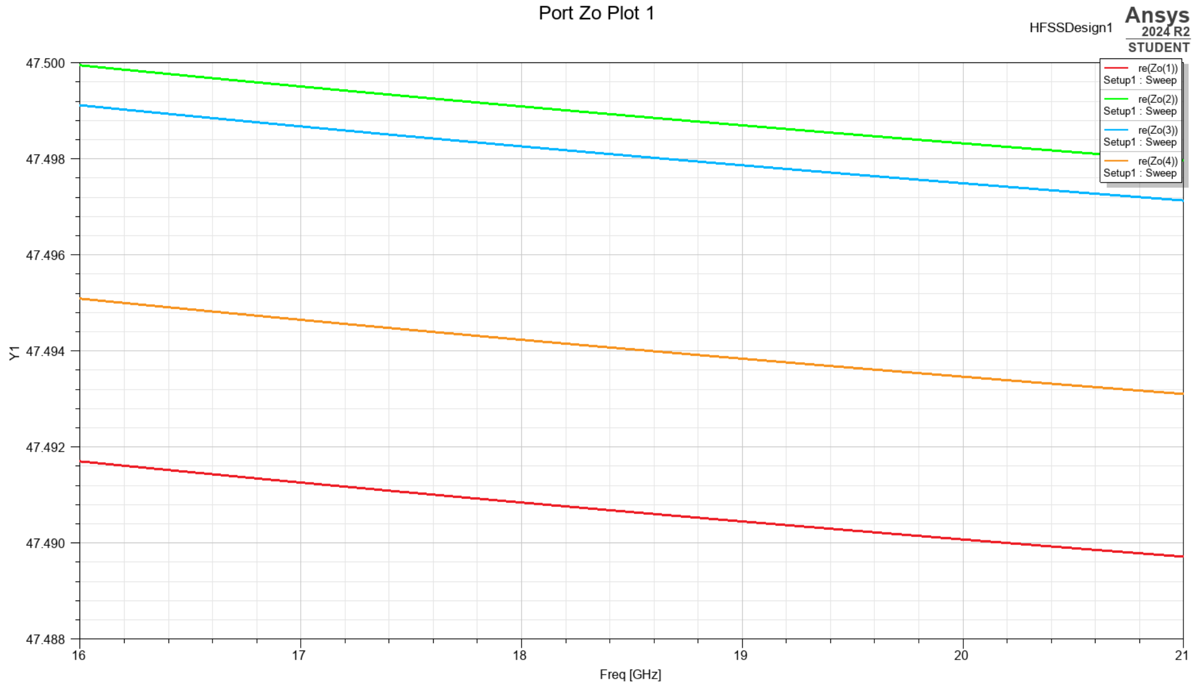
The design is almost finished. What is left is to apply excitations and boundaries to the design.

Setting up the analysis, we have 2 setups.

The first setup is for "regular" calculations, the second setup is for more precise calculations.

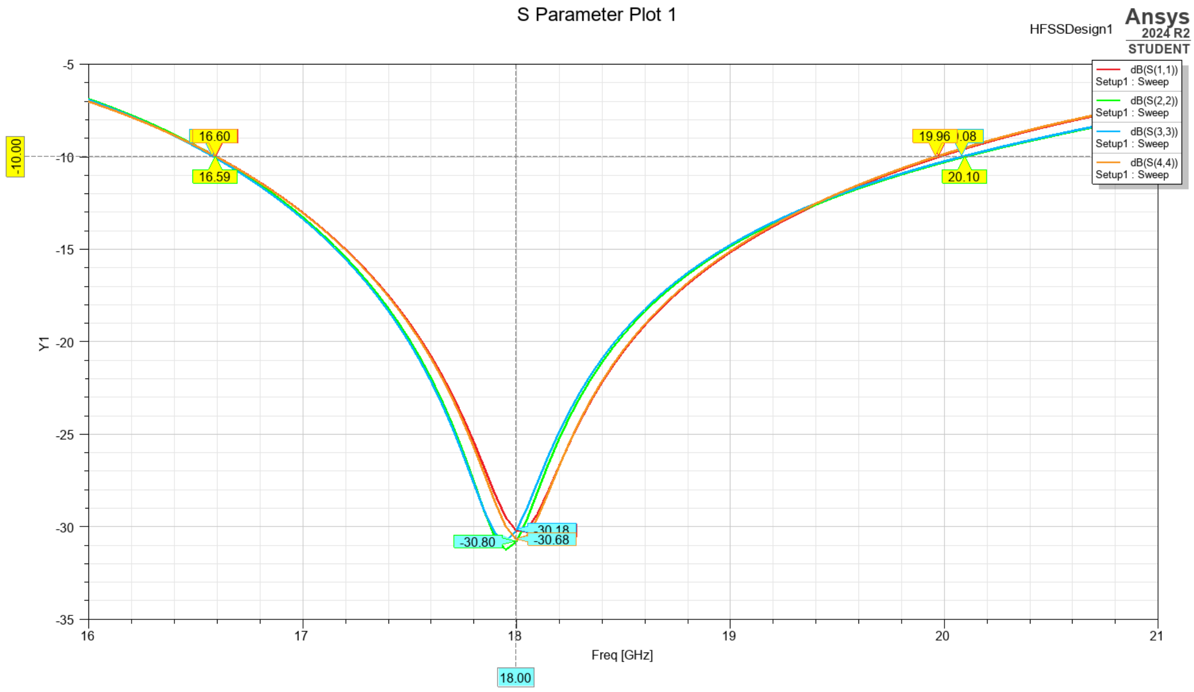
Here are the results of the design:

<u>Impedance Matching plot</u>



We got around 47.5Ω impedance, which is relatively close to 50 Ω.

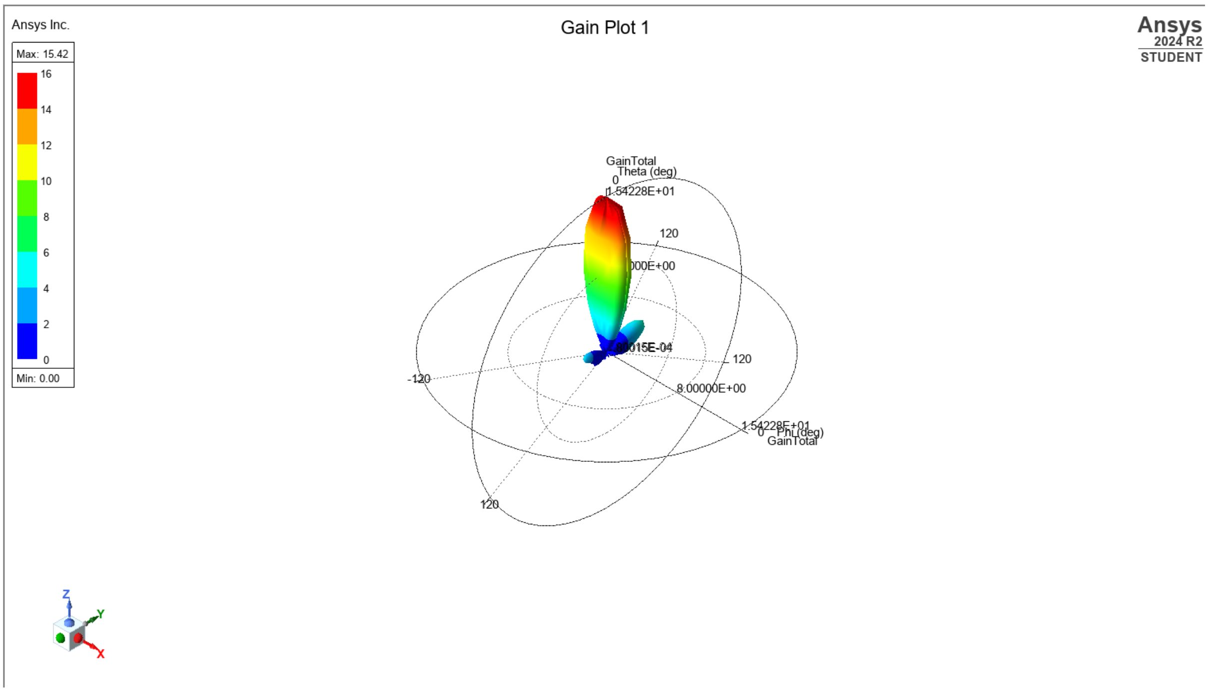
S Parameter Plot

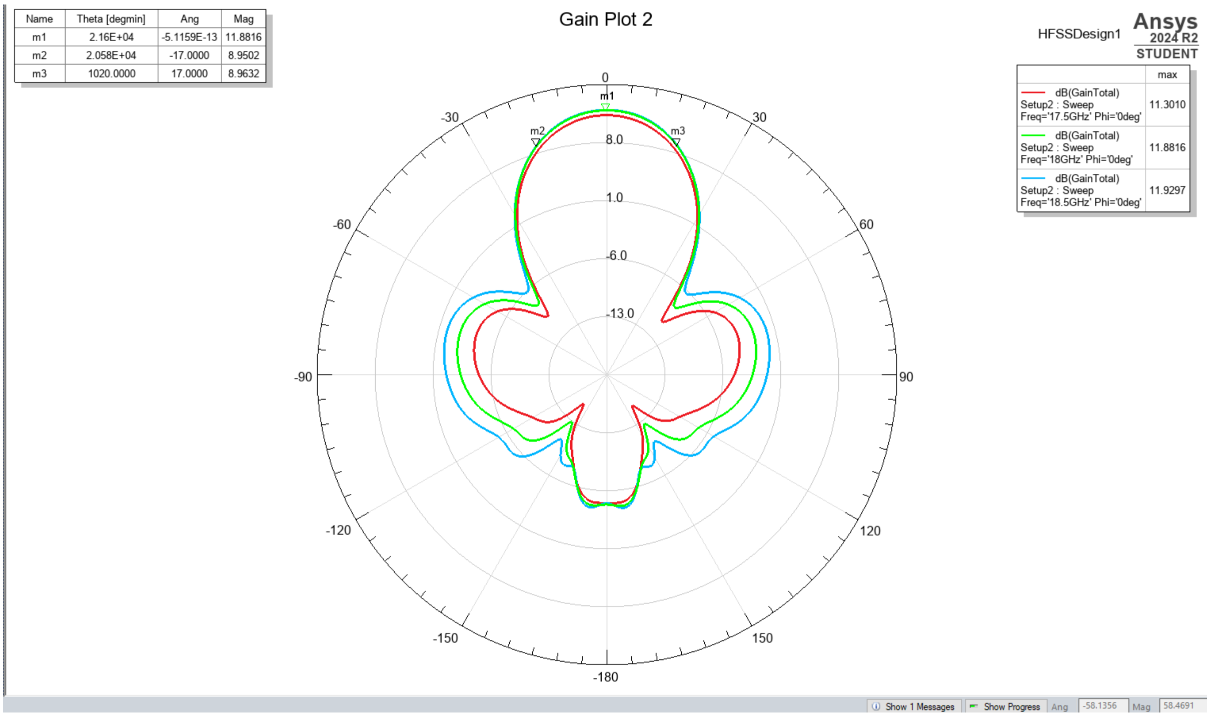


We are very satisfied with the S parameter plot. We can infer from the plot that the losses are negligible within our frequency range, specifically, in the operating frequency. Furthermore, the bandwidth that we got exceeds the specifications (looking at the -10dB points, the bandwidth is approximately 19%, a lot more than the required 5%).

Also, the VSWR is a lot higher than 2, which is also great.

3D Gain Plot + 2D Gain Plot





From the 3D gain plot we can see that the radiation pattern is centered at 0 degrees, meaning that the antenna is radiating broadside. A 2x2 microstrip patch array should have a gain around 13-16 dBi, our antenna has a maximum gain of 15.4 dBi, meaning the array is functioning properly. The main lobe is much stronger than the sidelobes, which is a good sign.

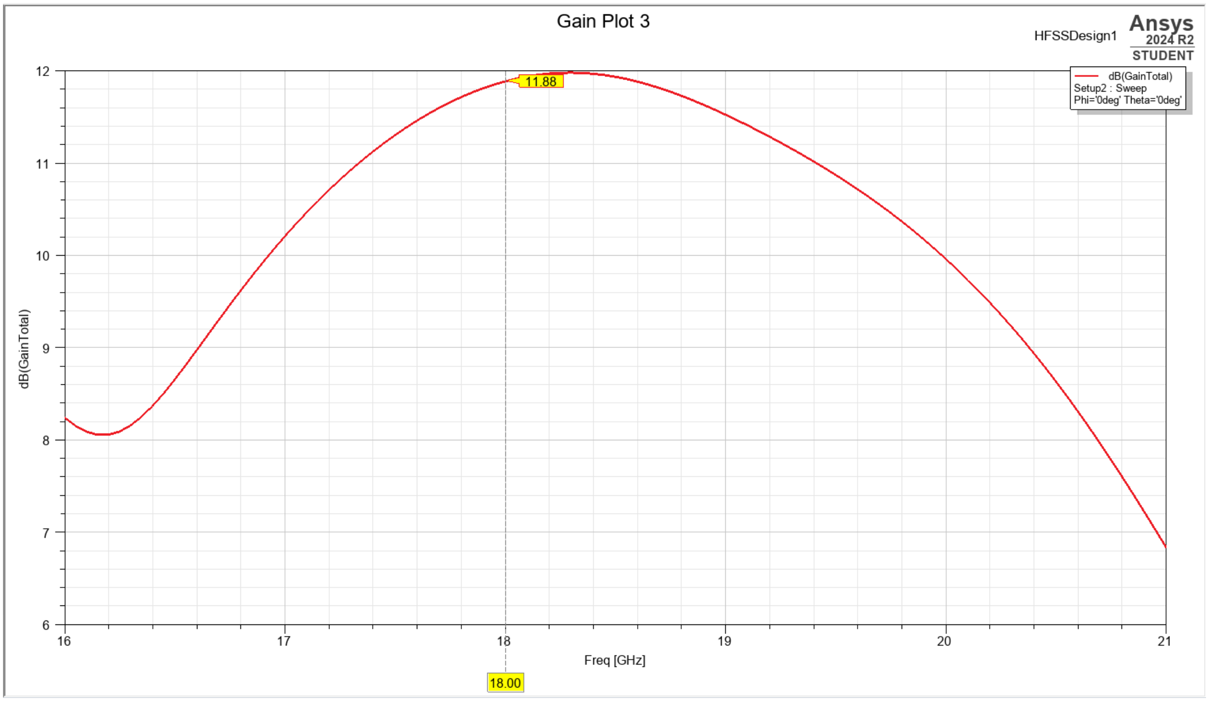
From the 2D gain plot, we can calculate from the 3dB points that our antenna has a beamwidth of 30 degrees, which is lower than the optimal specifications.

After research, in order to increase the beamwidth, we need to change: element spacing/reduce the number of elements/use a different patch shape or feeding network/increase substrate thickness or trying different feeding techniques.

All the changes that are mentioned above will result in deviation of our given specifications. Therefore, we will not try to change the beamwidth.

Other than that, we are pleased with the results of the graph.

Gain Plot



The gain of our antenna is much greater than 5 dBi across the relevant frequencies.