DEPARTMENT OF ELECTRICAL
AND ELECTRONICS
ENGINEERING

EE491 PROJECT REPORT

High Gain Microstrip Antenna Designs for A Doppler Radar

Ahmet Yasin Bulut

250206001

Emre Nedim Hepsağ

250206012

Advisor: Fatih Yaman

DATE: 15/01/2022

ABSTRACT

There are various microstrip patch antenna array structures with different features for different purposes, such as doppler radar, mobile communication and RFID. However, it is not clear that which one has most suitable characteristic feature for doppler radar. Therefore, we tried to figure it out by comparing some significant structures of 4 patches antenna arrays. We designed our structures to match for 5.8GHz, optimized their radiation patterns on CST Studio Suite and aim for one high gain main lobe with no side lobes. Our results show that 1x4 patch array has by far best directivity for a doppler radar. By producing the antenna with PCB producing method of UV exposure, measuring the S11 at network analyzer and testing it with gain transfer method in an anechoic chamber at IZTECH, we observed that the simulation results are consistent with our measurements. We conclude that to design a proper microstrip patch antenna for a doppler radar, 1x4 patch array is the only preferable one among others.

TABLE OF CONTENTS

ABBREVIATIONS

IEEE : Institute of Electrical and Electronics Engineers

RADAR : Radio Detection and Ranging

VSWR : Voltage Standing Wave Ratio

Wi-Fi : Wireless Fidelity

GPS : Global Positioning System

RFID : Radio-Frequency Identification

NFC : Near Field Communication

FM : Frequency Modulation

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Microstrip Patch Antennas

Even though people may not be aware of it, we are surrounded by so many antennas in our lives. Just in smart phones, there are up to 13 antennas for different application areas, such as Bluetooth, Wi-Fi, GPS, RFID, NFC, and FM radio. They are not obviously seen because they are hidden for aesthetic concern and mounted to the mother board of smart phones as seen in the figure 1. On the other hand, some of them obviously seen, such as satellite dish for receiving direct-broadcast satellite television or Base Transceiver Station for supplying cellular networks.

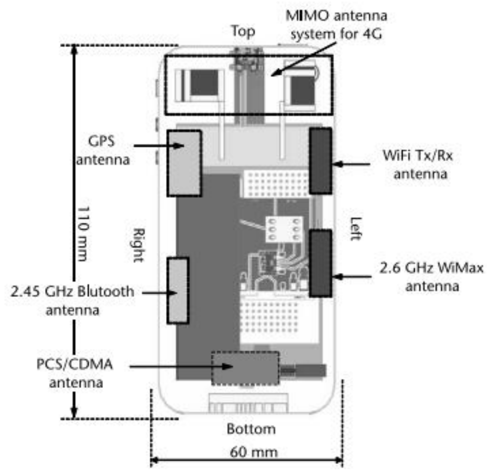


Figure 1: Inside of a smart phone [1]

Antennas are metallic structures with different shapes and sizes that converts radio electromagnetic waves into alternating current. They are being used as interface to receive and transmit the electromagnetic radiation from electric current. They are essential element of wireless communication system. There are different kinds of antennas with strengths and weaknesses which are Wire Antennas, Aperture Antennas, Reflector Antennas, Lens Antennas, Printed Antennas, and Array Antennas.

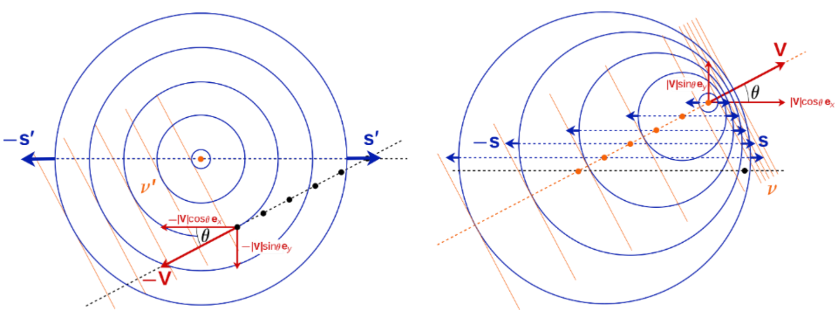
Compared to other antennas, printed antennas have interesting features for realization. They are easy to manufacture, they have low weight, and they are small. They are durable, compact and also cheap. Printed antennas are used in medical, military, spacecraft, and many wireless applications. We can see them in radars, mobile phones, satellites or gps systems. Microstrip antennas are the most popular printed antenna type, they have dielectric material on the middle which separates the patch and the ground conductor.

These antennas are mostly narrowband which is good for doppler radars. Moreover, their easy and cheap manufacturing capabilities can help us to produce and test them on the campus. For a better doppler radar application, we need to consider antenna parameters like return loss, gain and directivity. The operating frequency of doppler radars can be divided into L, S, C, X and K bands. Mostly used bands are S band 2-4 GHz, and C band 4-8 GHz [2]. We wanted to use C band for smaller antenna size and smaller power requirement. So, the project aim determined as a high gain design of microstrip patch antenna for doppler radars operating at 5.8 GHz.

1.2. Doppler Radars

RADARs are being used as electromagnetic sensor to determine the distance, angle, or velocity of an object. This happens while transmitter of the radar is sending electromagnetic waves and the receiver is listening the echo coming from the object. After this electromagnetic transmission, we can obtain some information about the object [3]. There are different types of radar, such as continuous wave radar, doppler radar, pulse radar, and bistatic radar. In this project, we are concerned with doppler radar.

Doppler is an effect which happens when an object has a velocity relation to the wave source, observer. When an object comes towards the observer, the signal reflecting from it is higher than when the object goes backwards as seen in the figure 2. Doppler radar is a type of a radar which uses doppler effect to detect speed of a distant moving object. It uses the frequency difference between transmitted and received signal to measure the speed by the formula below, which is applicable when the speed of the object is very smaller than speed of light [4].



$$f_d = f_r - f_t \approx 2v\frac{f_t}{c} \quad (1)$$

f_d: *Doppler Frequency,*
f_r: *Shifted Frequency,*
f_t: *Original Frequency*

Figure 2: Visualization of doppler effect [5]

The frequency change is very little, so it allows narrow band applications, which eliminate false signals from the environment and other objects. With using these features, we want to design an antenna for a doppler radar implementation like in the figure [7] which we use two antennas for transmitting and receiving the oscillating signal and find the difference of it as we can see the examples at various implementations [6].

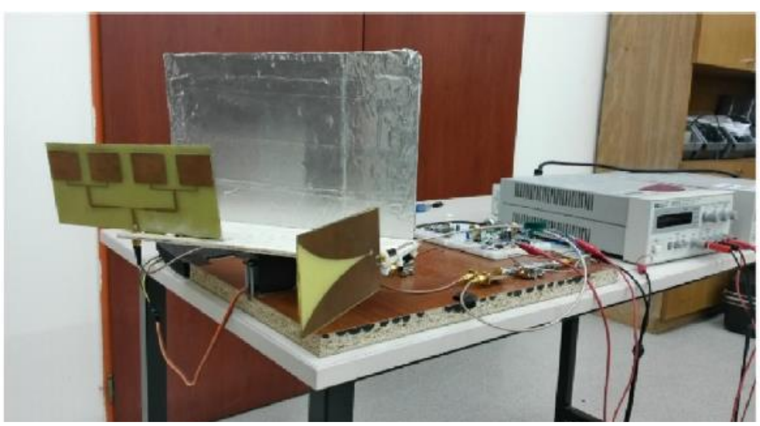


Figure 3: Example Doppler Radar Implementation [7]

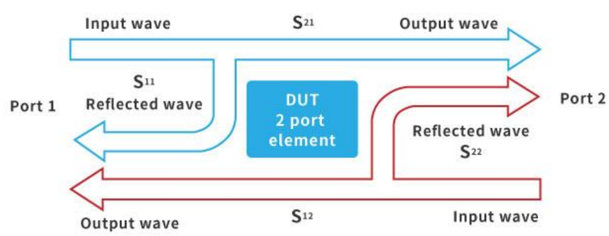
1.3. Antenna Parameters

Designing an antenna starts from selecting the antenna type and the materials, but it's very important to consider antenna parameters like return loss, bandwidth, radiation pattern, gain and impedance for designing a working antenna, because theoretical formulations are not always enough and accurate especially in designing antenna arrays.

When signal transmission occurs, some amount of power always returns back to the source which is called return loss [8]. It is one of the most important parameters for initial design, because it represents the ratio of the reflected power to the incident power as seen in the equation below. In other words, we detect the frequency range of the signal and how well its matched by observing it. In some cases, VSWR is preferred a parameter to observe. It is similar to return loss but instead it is a linear measurement.

$$Return\ Loss(dB) = 10\log_{10}\frac{P_{out}}{P_{in}} \tag{2}$$

At simulations, we see S-Parameters instead of return loss which describes the propagation behavior of energy at different ports as seen in the figure 4 [9]. In our case we are concerned with S11 parameter, and it is just negative of return loss. We aim our operating frequency to be lower than -10dB at S11 which describes bandwidth of an antenna.



$$S_{11} = \frac{\text{Reflected voltage}}{\text{Input voltage}} : \text{Forward return loss} \qquad S_{12} = \frac{\text{Output Voltage}}{\text{Input voltage}} : \text{Backward attenuation}$$

$$S_{21} = \frac{\text{Output Voltage}}{\text{Input voltage}} : \text{Forward attenuation} \qquad S_{22} = \frac{\text{Reflected voltage}}{\text{Input voltage}} : \text{Backward return loss}$$

Figure 4: S-Parameters Diagram [10]

The other important parameter is radiation pattern or far-field pattern, it shows the direction of radiated power function far from the antenna. From this pattern, we can also observe the gain and directivity parameters. Especially in doppler radar radiation patter is a crucial factor.

The directivity shows the radiation direction, mainly on high gain direction. In a doppler radar application like we planned, the antenna must be focused on one direction, and this must be narrow for not radiate to other objects or receive signal from side directions. Also, the back lobe of the pattern can reflect and affect the front main lobe, so we need to decrease the side and back lobes in optimizing the directivity in our application.

Gain is the parameter of the transmitted power in terms of direction compared to isotropic antenna which is a theoretical antenna. Isotropic antenna is a perfect sphere and radiates equally to every direction which means that it has 0 dBi, no gain. Simply, when a radiated energy concentrated instead of spreading, our gain increases because we intensify the radiation on the direction as seen in the figure 5. Gain is proportional to efficiency and physical aperture area as we can see in the formula below.

$$G = \frac{4\pi\eta A}{\lambda^2} \tag{3}$$

$G: Gain, \eta: Efficiency, A: Physical\ aperture\ area, \lambda: Wavelength$

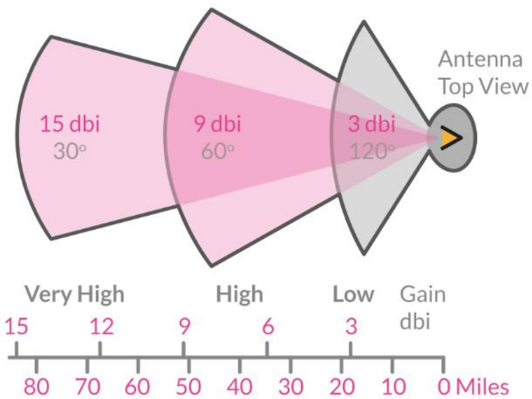


Figure 5: Directivity visualization for different angles [11]

Also, from the Friss's transmission formula [12] we can denote the gain and the distance relation. As we can see in the following equation, for same power values, the gain of the receiver and transmitter antennas can directly increase the transmission distance.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \tag{4}$$

$P_r: Power\ at\ the\ receiving\ antenna\ P_t: Output\ power\ of\ transmitting\ antenna$
$G_t: Gain\ of\ the\ transmitting\ antenna, G_r: Gain\ of\ the\ receiving\ antenna$
$\lambda: wavelength, R: Distance\ between\ the\ antennas$

2. PROBLEM DEFINITON

2.1. Antenna Size & Structure

Shape, material and sizes of antennas can change in every type. In the beginning of the project, we chose the microstrip structure for our antenna. In microstrip antenna, we can see the rectangular patch structure is very common among the designs and also fits our aim for high gain, high directional characteristics as we can see in the table 1 [13].

Parameters	Rectangular Patch	Triangular Patch	Circular Patch
Resonant frequency (GHz)	9.49	8.9	9.36
Return Loss (dB)	-23.87	-17.71	-18.74
Bandwidth (MHz)	700	400	710
Gain (dB)	4.31	3.67	4.00
Directivity (dB)	6.16	3.05	4.92
VSWR	1.15	1.32	1.26

Table 1: Parameter Comparisons of different patch shapes [13]

Also, there are various materials to use for the substrate of the structure, such as Isola, Roger or Taconic [14], but these materials are cost much and hard to supply. Although doesn't much recommended, common PCB material FR4 may be useful for an inexpensive fabrication. In the following figure, we can say that the FR4 loss is not bad for 5.8 GHz application [15]. Furthermore, we want to consider using array structures for obtaining high gain with its possible tradeoffs like operating bandwidth, cost and size.

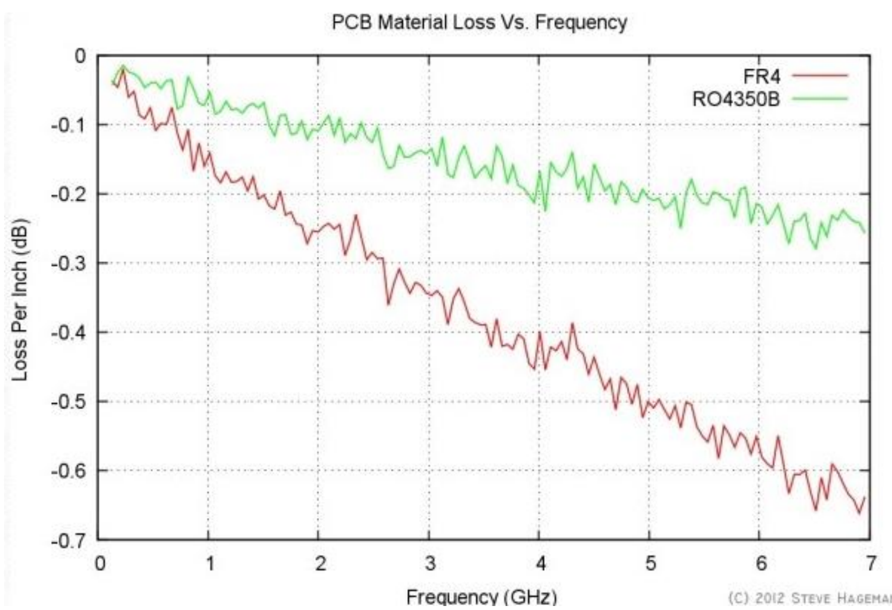


Figure 6: Loss per inch of FR4 and Rogers RO4350B [15]

2.2. Feed Methods & Feed Networks

While considering different design structures, we may need different feed or feed networks. The feed of an antenna or antenna array is the conductor or the cable part that connects the patch and feeds the current to the antenna. The feed must be adjusted to match the impedance to the patches and the outer cable to use power efficiently. Also, its position is important because the power is flowing on top of it and it can affect patches or other feed lines. Eventually, it can change some properties of our design like, fabrication process, radiation pattern, power efficiency and cost of the structure.

2.3. Directivities of Different Structures

Various patch shapes and feed systems of microstrip antennas cause different and unsymmetric radiation patterns. For a doppler radar application, the antenna directivity is important for accuracy, also we can increase the gain with decreasing the main beam width as we explained in the Chapter 1.3. Microstrip design resources [1][16][17] we reached do not provide the radiation types of the common structures, so we want to spend time on designing different structures for finding optimal directivity for our aim. In our designs, we primarily search for single dominant main lobe with small, close to -20 dB, side lobes. For our main lobe, we also want to acquire a perpendicular and narrow beam for optimal structure result.

2.4. Final Design for Fabrication

Since we lack precise information of the dielectric constant, tangent loss and some other parameters of copper clad, we are supposed to improve our antenna to have wider band to tolerate any S11 shift. Additionally, simulation and real-life circumstances are not the same. Therefore, we need to design as tolerable antenna as possible for any undesired factor.

2.5. Fabrication Cost

Even though we decided to choose one of the cheapest antenna structures, the production of the antenna can cost us more than we can provide. We can decrease the cost with choosing cheaper materials, and designing a smaller structure. For choosing cheaper materials, we can select most common conductor as copper and dielectric as FR4. The selection of FR4 can cause unreliable dielectric constant and high losses on the material. For decreasing the structure size, in fixed frequency, we can’t change our patch size so much, but we can change our array size and substrate area which is the edges of the overall antenna. After designing the low budget antenna, we needed a PCB etching method for fabrication. If we want to do on our own, we have limited options like using a chemical to etch the copper, the material and the process may be unreliable rather than the vendor production. PCB vendors mostly do mass production. Therefore, single productions such as our antenna is costly to produce at those companies. Also, vendors import their all the components from abroad. Due to the economic fluctuations, it is harder for us to afford the professional fabrication. Lastly, it takes time companies to produce our antenna and get it because of their busy schedule and logistics.

3. PROPOSED SOLUTION

3.1. Antenna Size & Structure

Antennas can have very different designs of antennas can be used for different parameter needs and operating frequency bands. We will use CST Microwave Studio to design our antennas, and simulate them to observe their function and parameters. A microstrip antenna has a conducting patch at the top, dielectric material at the middle and conducting ground at the bottom as seen in the figure 7. It radiates from the edges, so the patch length and width are the main design parameters.

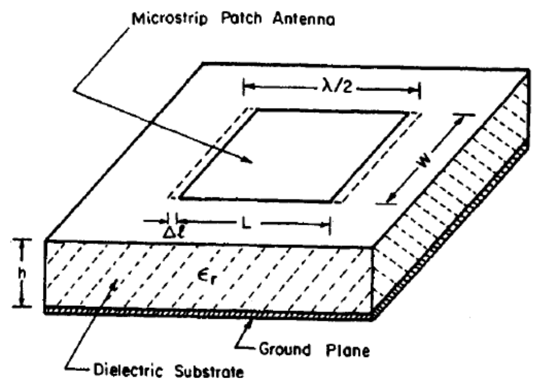


Figure 7: Microstrip Antenna Geometry [16]

In designing a patch, we first need to decide operating frequency, dielectric material and its height, and conductor thickness. We chose dielectric material as FR4 which is more accessible and cheaper.

The approximated width can be calculated from:

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{5}$$

$W: width, v_0: speed, f_r: resonant\ frequency, \varepsilon_r: dielectric\ constant$

The fringing edges cause a change on the dielectric constant, so the effective dielectric constant is:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W}}} \tag{6}$$

$\varepsilon_{eff}: effective\ dielectric\ constant, h: substrate\ height$

At the start of the designing process, from our researches, we decided to use most commonly used height and metal thickness values, check them for 5.8 GHz, and used them in design calculations, which is h = 1.6 mm and t = 0.035 mm.

Next, we need to find our length of the patch, but because of the fringing effect, we first need to calculate the fringe factor by the equation of:

$$\frac{\Delta L_{eff}}{h} = 0.412 \frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{7}$$

$$\Delta L_{eff}: fringing\ factor$$

To calculate actual L:

$$L = \frac{c_0}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\,\Delta L_{eff} \tag{8}$$

$$L: actual\ patch\ length, c_0: speed\ of\ light$$

Lastly, we are supposed to find the size of ground plate with the equations of:

$$\lambda_{eff} = \frac{v_0}{f_r}\sqrt{\varepsilon_{eff}} \tag{9}$$

$$\lambda_{eff}: effective\ wavelength$$

$$L\ of\ ground \geq \left(\frac{\lambda_{eff}}{4}\right) * 2 + L, \qquad W\ of\ ground \geq \left(\frac{\lambda_{eff}}{4}\right) * 2 + W \tag{10}$$

After deciding the patch dimensions, we need to simulate the patch. We can also improve the patch performance via changing calculated values by small adjustments. Because of the different performance of the dielectric materials at higher frequencies, especially FR4, these improvements are important for our antenna.

The other improvement on the antenna can be made by adding more patches and combine them with feed networks. The main tradeoff can be seen on table 2, that array form makes antennas more narrowband but increase the gain, so in designing array antennas, we should consider this effect. Also, in array antennas, feeding methods will be more complex and plays more crucial role. There are different feed combinations on microstrip array antennas, but we will focus on the corporate feed networks with quarter wave transformers to combine them into one main feed line.

Array Type	Array Size	Total Elements	Gain (dBi)	Bandwidth (MHz)	HPBW (Degree)	Simulation Time (Relative to Single Element)
Single	1 x 1	1	6.7	40	78	1.0x
Linear	1 x 2	2	9.7	38	39	2.5x
Planar	2 x 2	4	13.1	35	39	5.5x
Planar	4 x 4	16	19.4	32	19	19.5x
Planar	8 x 8	64	25.1	27	10	95.0x
Planar	16 x 16	256	30.2	2.5	4.5	1700x

Table 2: Example Experiment Results on Changing Array [1]

3.2. Feed Methods & Feed Networks

The feeding method design of the antenna is as much important as the patch design. In microstrip antennas, there are different methods to apply. We will use line feed methods because of their practicability. The line feed can be constructed as edge-feed, inset-feed, offset edge-feed or quarter wave transformation as seen in the figure 8. These methods change input impedances of the patches, so that the new impedance values less mismatch the feed cable impedance.

Figure 8: Different feed methods for patches [1]

We decided to use quarter wave transform and inset methods, and wanted to observe the design differences of them as well. Quarter wave transformer is a well-known method for impedance matching in microwave systems. In patch implementation, the working principle is the same, we need to add a microstrip of quarter the length of the wavelength to match the feed impedance. On the other hand, in the inset feed method, the depth of the inset defines the impedance change. The input impedance and matching approximations are well defined in [1] and [17], so that we can use the followings.

For input impedance:

$$Z_a = 90 \frac{\varepsilon_r^2}{\varepsilon_r - 1} \left(\frac{L}{W}\right)^2 \tag{11}$$

$Z_a: characteristic\ impedance$

To calculate the length and impedence of quarter wave transformer:

$$Z_0 = \sqrt{Z_1 Z_L} \tag{12}$$

$Z_0: quarterwave\ transformer\ impedance, Z_L: load\ impedance, Z_1: transmission\ line\ impedance$

$$l = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \tag{13}$$

$l: length\ of\ quarterwave\ transformer$

Where Z of the microstrip is:

$$Z = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\dfrac{8h}{W_T} + \dfrac{W_T}{4h}\right), & \dfrac{W_T}{h} \leq 1 \\ \dfrac{120\pi}{\sqrt{\varepsilon_{eff}}\left(\dfrac{W_T}{h} + 1.393 + 0.667\ln\left(\dfrac{W_T}{h} + 1.444\right)\right)} & \dfrac{W_T}{h} > 1 \end{cases} \tag{14}$$

$Z: impedance\ of\ microstrip, W_T: width\ of\ transmission\ line$

For inset feed:

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \cos^2\left(\frac{\pi}{L} d\right) \tag{15}$$

After these calculations, to improve the performance of the antenna we can add up antennas into array form. Thus, we decided to design corporate parallel feed arrays similar to figure 9 design b. However, it has some difficulties to match patch arrays with feed line. Therefore, we used quarter wave transformer method to overcome this problem.

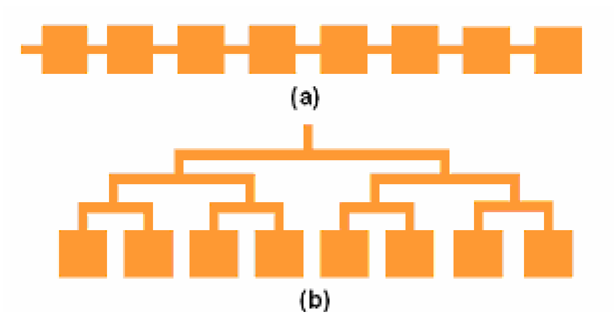


***Figure 9:** (a) Series Feed (b) Parallel Feed patch array [7]*

We also considered the coaxial feed as seen in figure 10, which helps us the decline unsymmetric main feed line on array structures. It is very common feeding method, but it is difficult to model. Because of its drill on substrate, it can change the planar effects of the antenna and decrease the better thickness effects for dielectric like providing high bandwidth

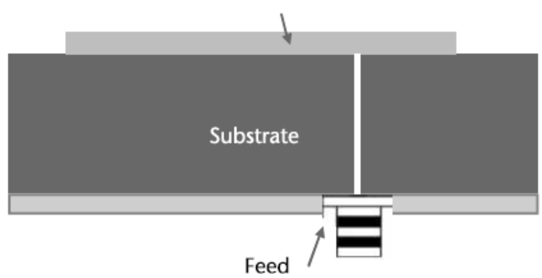


Figure 10: Coaxial-fed on patch antenna [1]

3.3. Directivities of Different Structures

I. First 1x1 Patch

The first step of our design project was creating a functional single patch antenna and observe its parameters. We wanted it to operate at 5.8 GHz and it must have 10 dB return loss. We used copper of 0.0035 mm with FR4 substrate of 1.6 mm. The first calculations are made with the equations we gave on chapter 3.1 and return loss is given in figure 11.

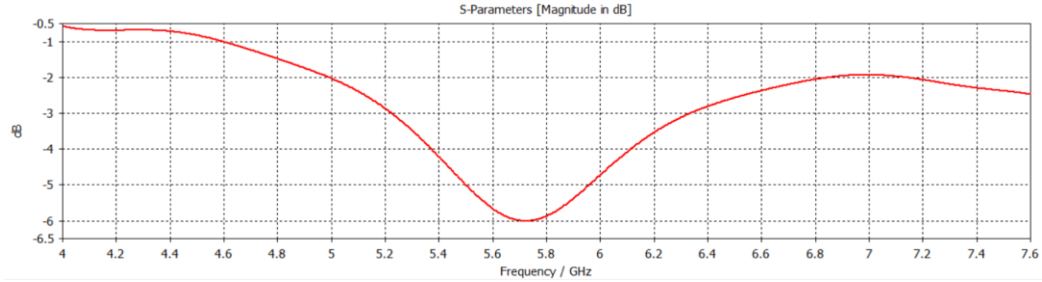


Figure 11: First S11 Result for Designed Patch

This was both an expected and unexpected result for us. The feeding method is not implemented, but the calculations are made for exact given equations. Then we realize that the effective dielectric constants change on other parameters as well. We change our length and width a bit. We use a quarter wave transformer for edge feed in the final first design. The bettered parameters are given in the table 3 and showed on the figure 12.

Parameter	**Value**
Patch length Lp	11.3 mm
Patch width Wp	15.8 mm
Dielectric constant Er	4.3
Substrate height h	1.5 mm
Copper thickness t	0.035 mm
Operating frequency f	5.8 GHz
Transformer length Lq	6.67 mm
Transformer width Wq	2.74 mm
Edge feed width	3 mm

Table 3: Improved 1x1 Parameters

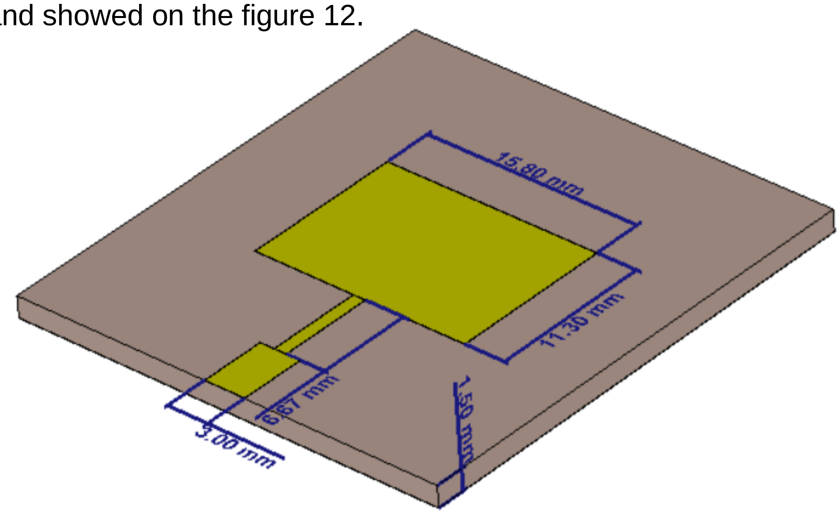


Figure 12: Improved 1x1 Patch Geometry

The resulting S11 plot for improved antenna is in the figure 13.

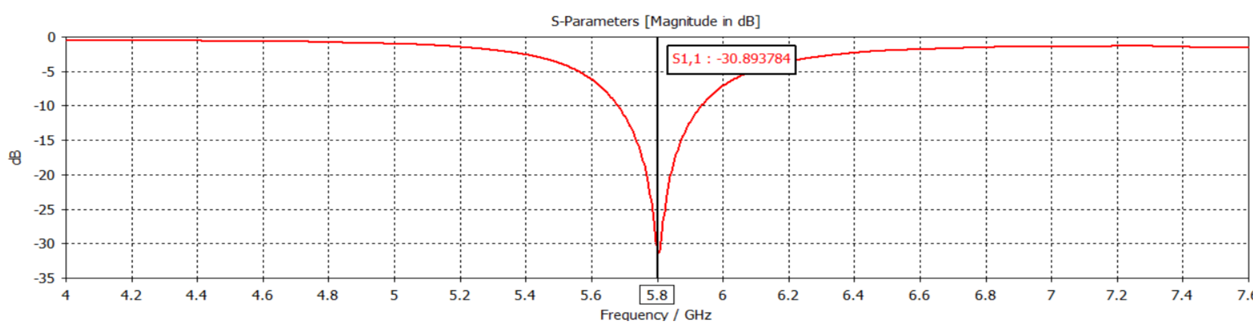


Figure 13: S11 Plot of Improved Patch

We can see the result is significantly changed and we got 30 dB return loss on 1x1 patch thanks to quarter wave transformer impedance matching. We can see that the result is very narrowband and has only 30 dB at 5.8 GHz. The directivity and the gain can be seen on the figure 14. We can see the direction of the beam, and the gain value at the bottom left part which is nearly 3.68 dBi.

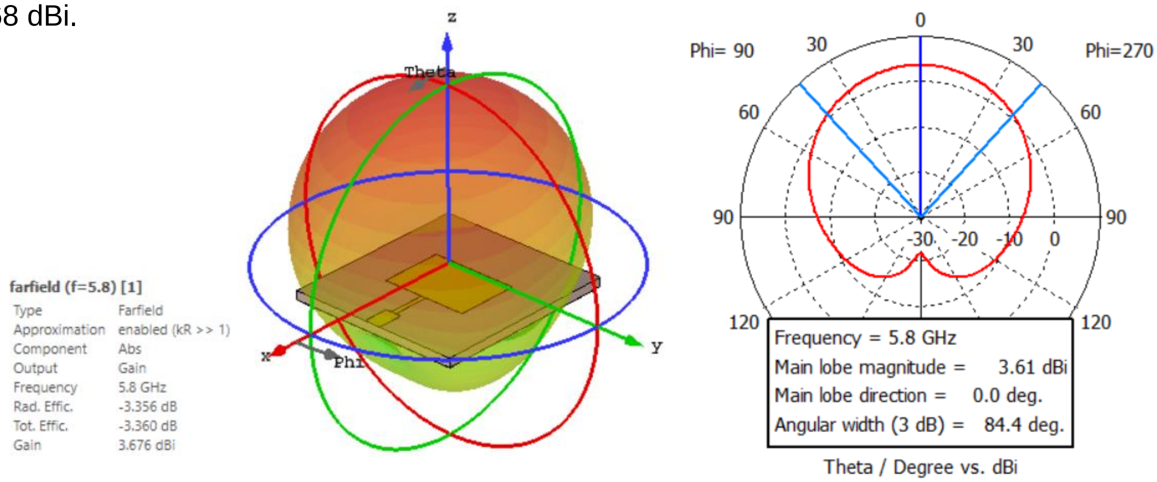


Figure 14:*1* Farfield of the Patch – 3D and Polar Gain Plots

In this structure the pattern has very big main beam, and the power is radiating all the front side, so it's directivity is bad for us. After this structure, we designed some different array antennas to search a structure that has better directivity.

II. First Antenna Array - 2x2 Patch

In the second structure we designed a 2x2 antenna array. For the feed network, we wanted to try inset matching. Inset matching can help us to decrease the impedance of the patch and can make it more compatible for different power divider implementations. We use the 50 ohm, 100 ohm 70.7 ohm power dividing technique in this design with added insets as seen in the figure 15.

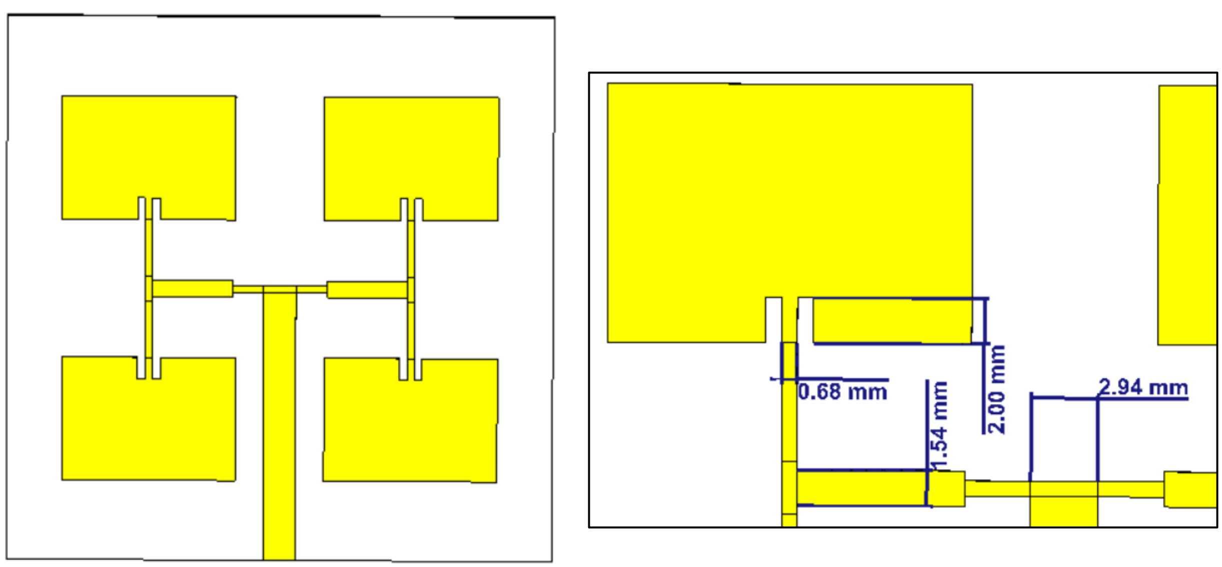


Figure 15: 2x2 Patch Array Design and Its Dimensions

In this design, the dimensions are all the same including the interelement distances but in addition there is an inset dimension y0 = 2.0 mm which is calculated and used sweep for best fit.

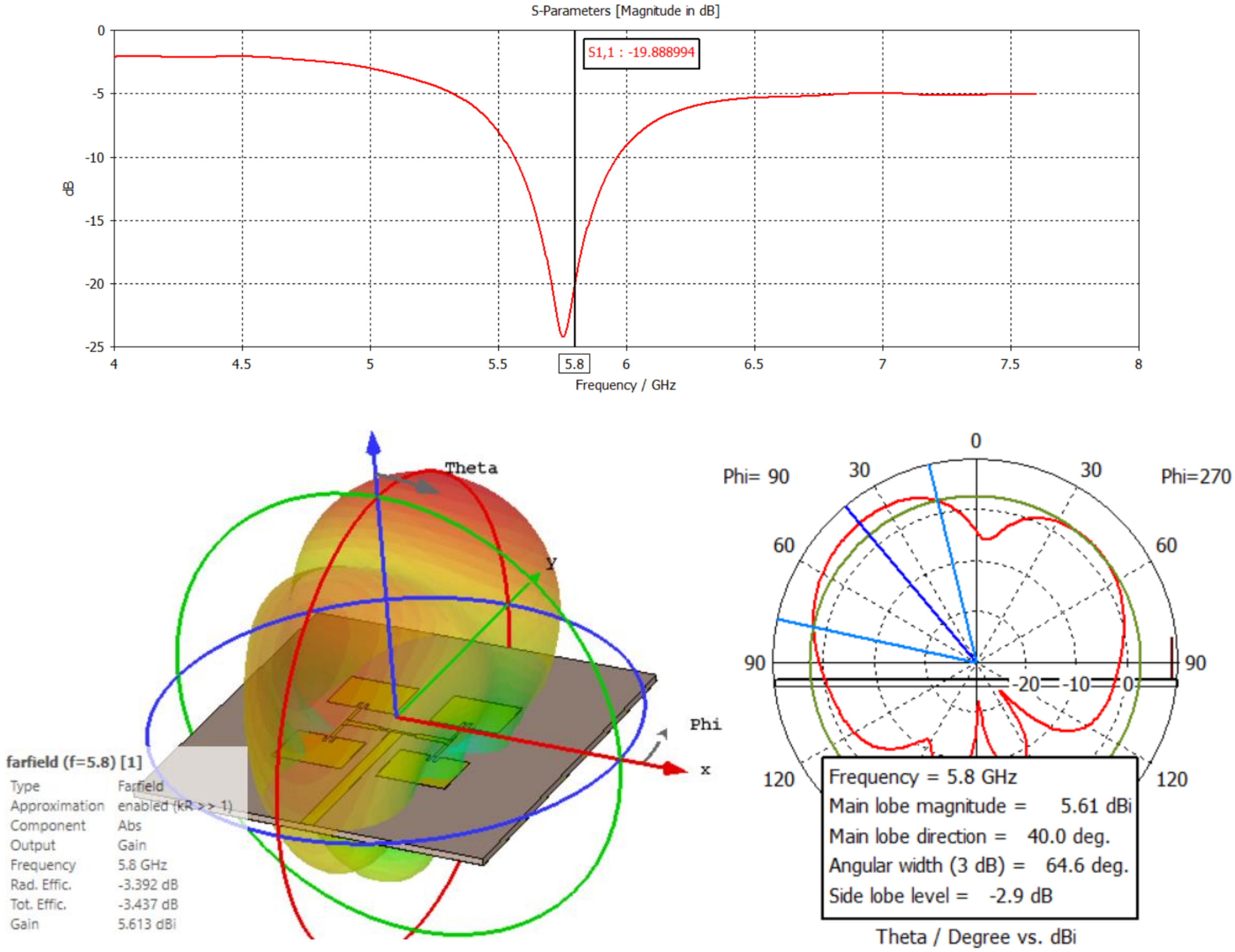


Figure 16: 2x2 Patch Array Structure Resulting Plots

From the figure 16, we can say that even with bad S11 result, increasing the patches can increase the gain. Also, we can see that the directivity is very bad for a radar application. We have two different lobes that propagates to -30 and 30 degrees, so that power propagates to sides. It might happen because of the interelement distances or the main feed line which is comes from between two patches unsymmetrically. After this design we tried different main feed positions to change the radiation pattern.

III. Side Feed 2x2 Patch

To increase the directivity of the 2x2 array, we change the main feed position to right side. So, the power less affects the feed network. Also, we changed the direction of lower two patches to increase the directivity of the array. In this way, the two sidelobes can sum up on the middle and we can create a more directive structure. We can see the geometry and the directivity of the structure in the figure 17.

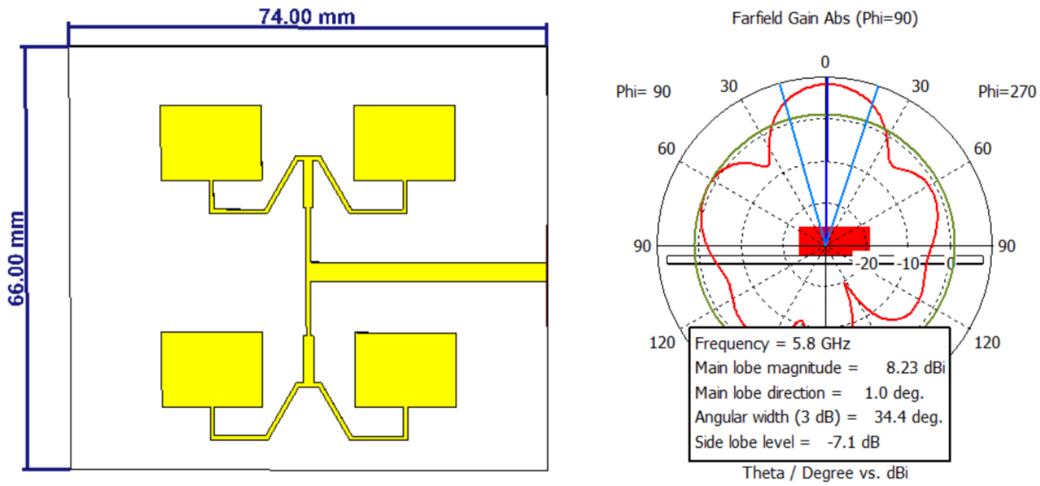


Figure 17: Side Feed 2x2 Patch Array Structure and Radiation Pattern

We can say that, despite we could create a main beam on perpendicular to the antenna board, we still have huge sidelobe, and little back lobe radiation.

IV. Coaxial Feed on 2x2 Patch

After many 2x2 feed and matching trials, we couldn't decrease the sidelobe level of the structure. So, we wanted to create a coaxial port to give power on the middle of the board. This should cancel out the sidelobe effects we got from the main feedings.

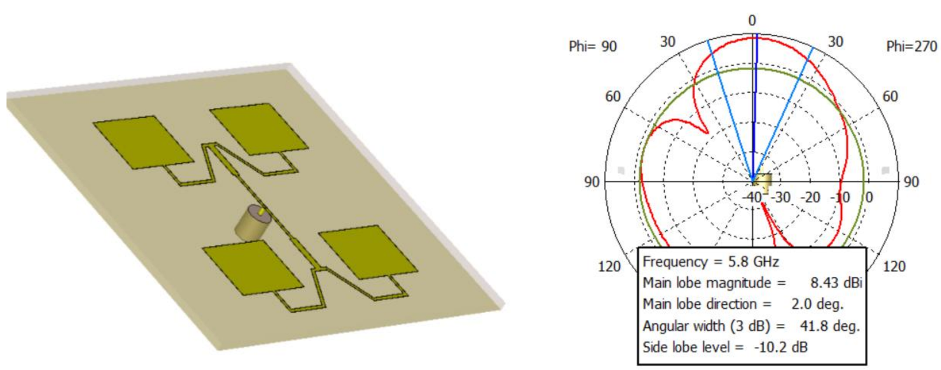


Figure 18: Coaxial Feed 2x2 Patch Array Structure and Radiation Pattern

We can see from the figure 18, side lobe level is decreased, and gain is increased. However, in this time we have a unsymmetric and huge backlobe on the left.

V. 1x4 Patch

We also created a 1x4 structure in addition to 2x2 structure. In this design, the patches are at end of the feed network and in same direction. In this way, designing feed network is become easy and unsymmetric effect of the main feed is canceled because all the patches are side by side. As seen in the figure 20, directivity of the antenna is concentrated on 0 degree with relatively small side lobes. You can see the geometry and dimensions of the discussed antenna on the figure 19 and table 4. Also, S11 parameter of simulation result is more than sufficient as seen in the figure 21, so we can move on to improve this antenna.

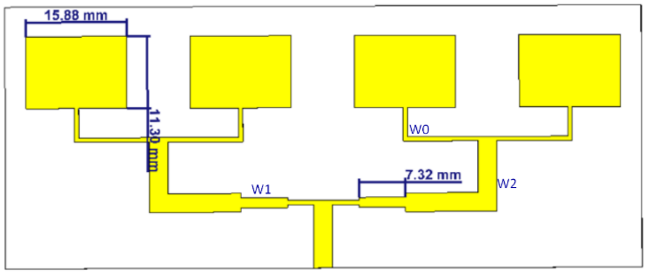


Figure 19: 1x4 Patch Array Structure

Parameter	Value (mm)	Parameter	Value (mm)
Patch Length	11.3	W0	0.678
Patch Width	15.88	W1	1.558
Patches distance	25.845	W2	2.94

Table 4: 1x4 Patch Parameters

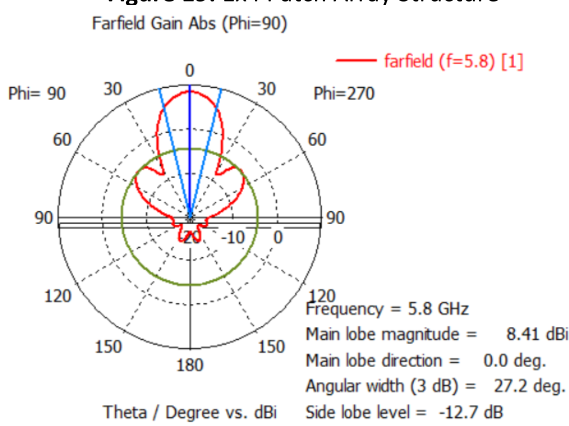


Figure 20: 1x4 Patch Array Radiation Pattern

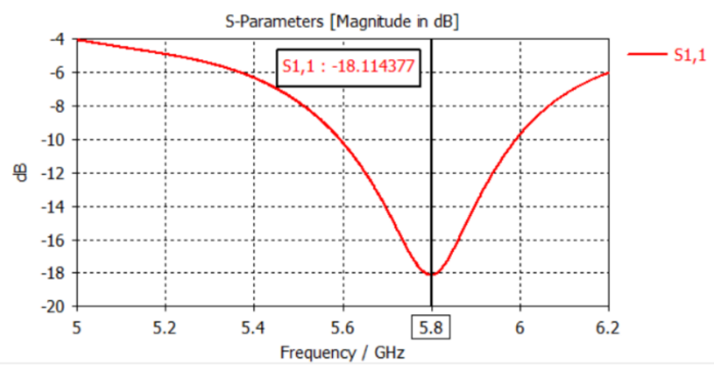


Figure 21: 1x4 Patch Array S-Parameters

VI. 45 Degree tilted 1x4 Patch

Since we had desired results from 1x4 patch antenna, we modified it by tilting the patches by 45 degrees as seen in the figure 22. S11 parameter is adequate at 5.8GHz for our purpose. Also, we expected to see differences at radiation patters in a good way, but instead we see decrement at gain and greater side lobes as seen in the figure 23, which we try to get rid of as much as possible.

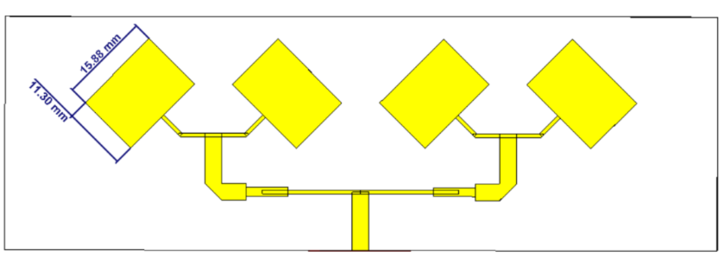


Figure 22: Tilted 1x4 Array Structure

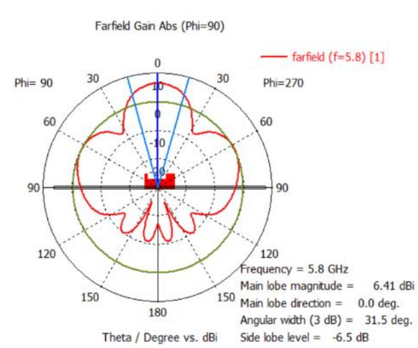


Figure 23: Tilted 1x4 Radiation Pattern

3.4. Final Design for Fabrication

After deciding the best structure and the fabrication process, we wanted to optimize the design for non-professional production. For this optimization, we changed the dielectric constant parameter of the material due to the unknown parameters of copper clad. To see it clearly, we swept the dielectric parameter on the simulation with 0.15 precision. As seen in the figure, our design works well at 5.8GHz even dielectric is 4.15 or 4.45.

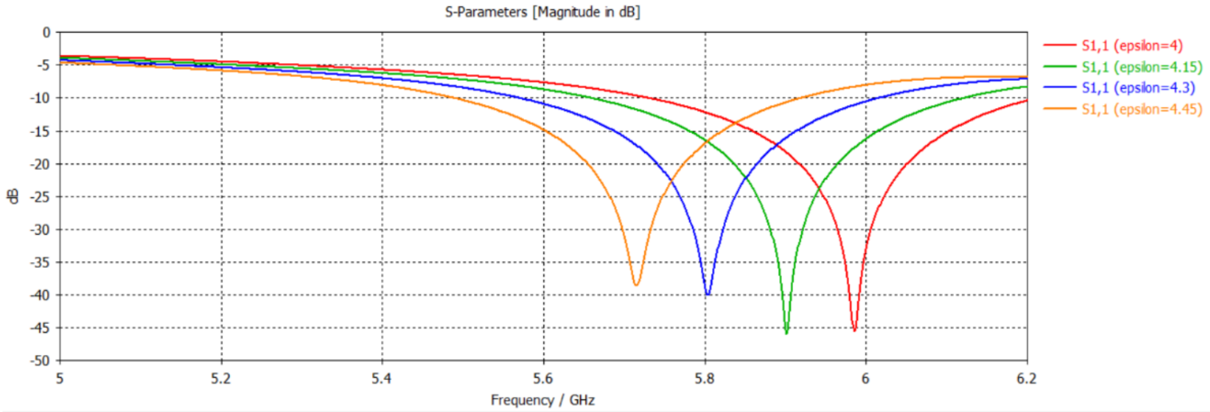


Figure 24: Dielectric Sweep S11 Results

From the results we decided to increase the bandwidth to tolerate external factors. For this bandwidth increase we tried to change the edges of the patches and feed network. The cuts of the feed edges resulted well, thus we used sweep to find the optimal cut level as seen in the figure 25.

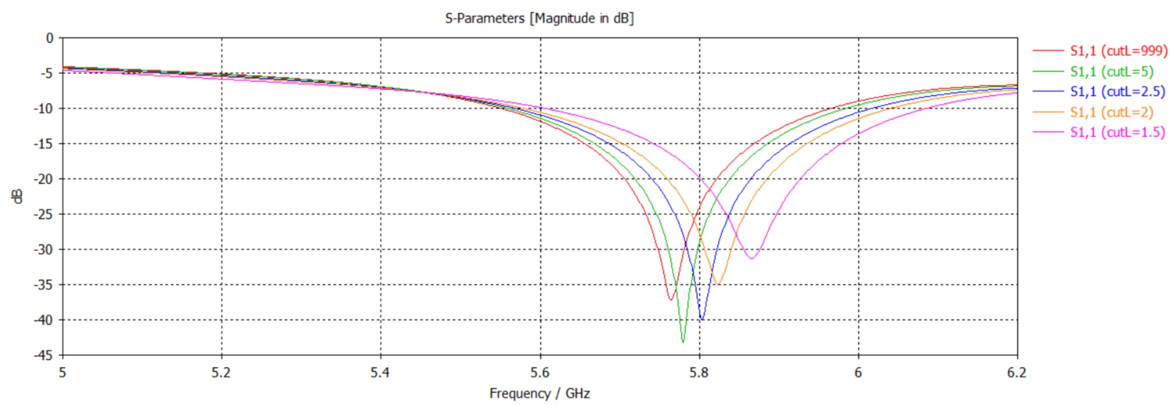


Figure 25: Cut Sweep S11 Results

So, we finalized the designed as seen in the parameters at the table 5. We concluded our antenna as seen in the figure 26. It has smoothed edges at the corners and notches at power dividers. Additionally, it does not only have wide s parameter, but also has better gain level, 8.89dBi, as seen in the figure 27. Now, it has a tolerable characteristic for small fabrication differences.

Parameter	Value (mm)	Parameter	Value (mm)
Patch Length	11.3	W0	0.678
Patch Width	15.88	W1	1.558
Ground Length	46	W2	2.94
Ground Width	100	Patches distance	25.845

Table 5: Final Patch Parameters

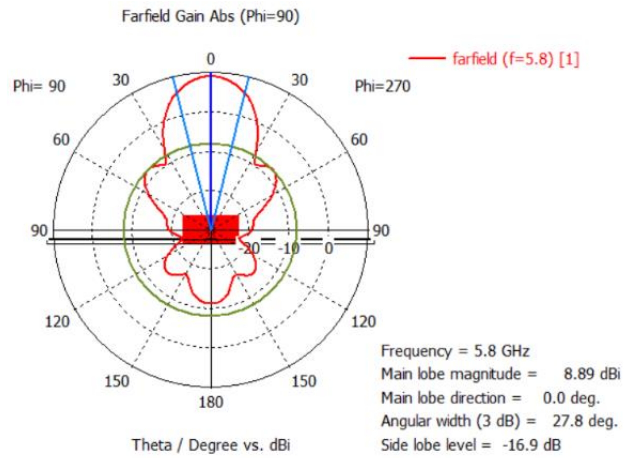


Figure 26: Final Radiation Pattern

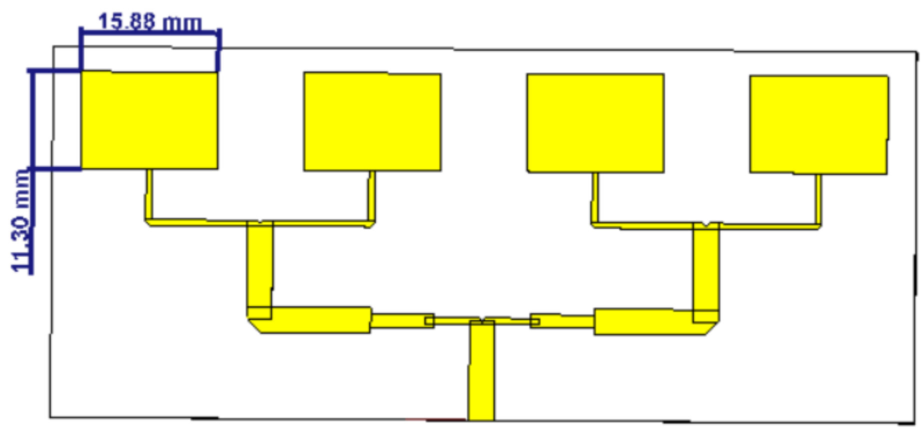


Figure 27: Final Geometry

3.5. Fabrication Costs

Since there was no preferable fabrication solution, and we found out that handmade solutions are not as erroneous as we expected, we chose to produce our antenna with UV exposure method.

For UV light PCB manufacturing, we needed:

- UV exposure device
- FR4 Positive Photoresist Copper Clad
- Antenna layout on transparent slide
- Sodium Hydroxide (NaOH) and Sodium Persulfate ($Na_2S_2O_8$)

Firstly, we applied UV expsosure to FR4 with transparent slide on it. We had Isel vacuum UV exposure device with 4 florescent tubes, 135 watt power consumption, so 3 minutes was enoug for our application. This activated photoresist layer. Next, we washed the board with sodium hydroxide (5gr/liter) at 40 degree celcius for several minutes. We took off the board when undesired photoresist has gone. We washed the board with water. Then, we started another washing process with etching solution with Sodium Persulfate (300gr/liter) at 100 degree celcius. This process dissolved the copper layer other than antenna and it took around 15-30 minutes [18]. The last step is removing the photoresist layer with acetone, trimming the excessive part off and our antenna has done for soldering coaxial socket. At the end, our antena has done as seen in the figure 28.

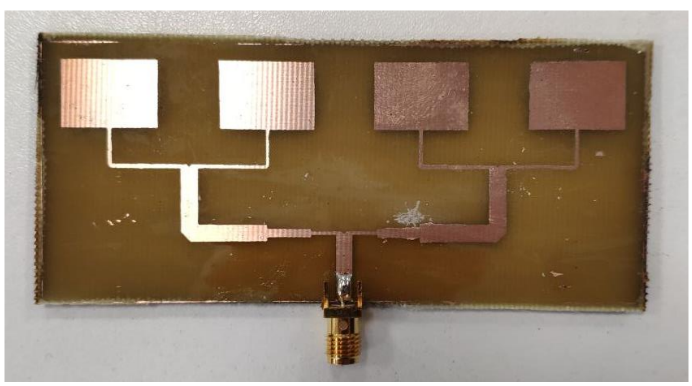


Figure 28: Fabricated Antenna

4. RESULTS AND DISCUSSIONS

After fabrication, we did parameter measurements for return loss, gain and directivity. The measured values and CST MWS simulation results are imported to MATLAB to comparing the fabrication quality and the resulted antenna parameters.

We use vector network analyzer as seen on the figure to measure the S11 parameter of the antenna. The VNA also gives polar plots for S11 results, but we don't use them to compare.

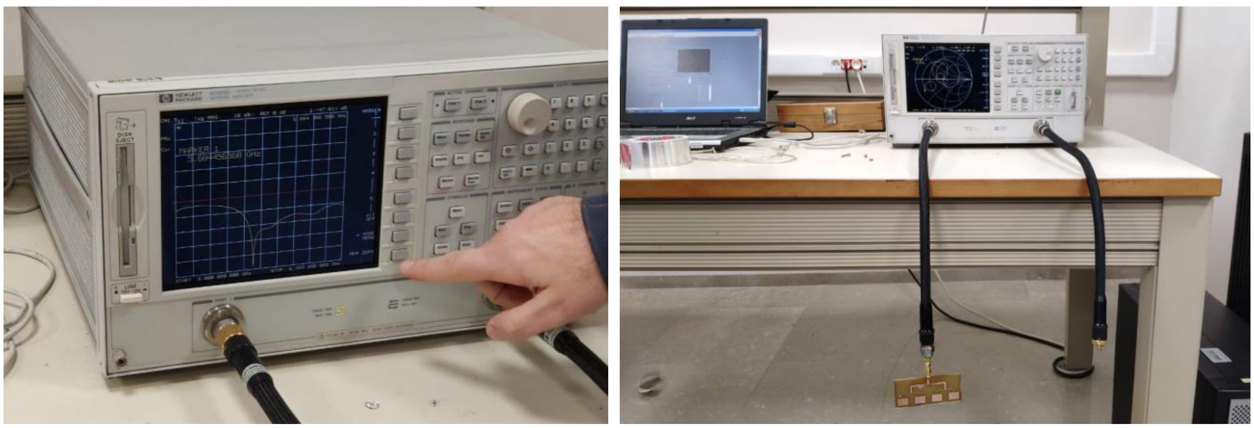


Figure 29: S11 Measurement on the Vector Network Analyzer

For the gain and direction measurement, a different process, environment and additional equipment is needed. We used an anechoic chamber at IZTECH to isolate the measurement environment. As you can see in the following figure, on left is our fabricated antenna, and it's used as a transmitter in this experiment, and on the right a reference horn antenna is used as a receiver.

Figure 30: Fabricated Microstrip Antenna (left) & Reference Horn Antenna (right)

For measurement, we used 5.8 GHz signal from signal generator for transmitter, and spectrum analyzer for receiver as we can see on the Figure 31. For reference antenna, we know its gain is 12dBi, and with additional two horn antenna configuration, we can use gain transfer method to calculate the received signal power in terms of dBi.

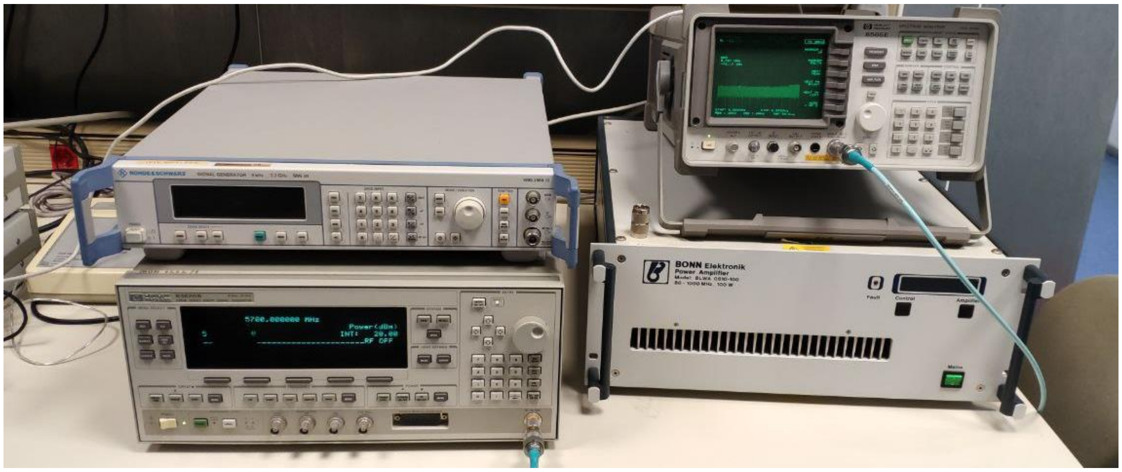
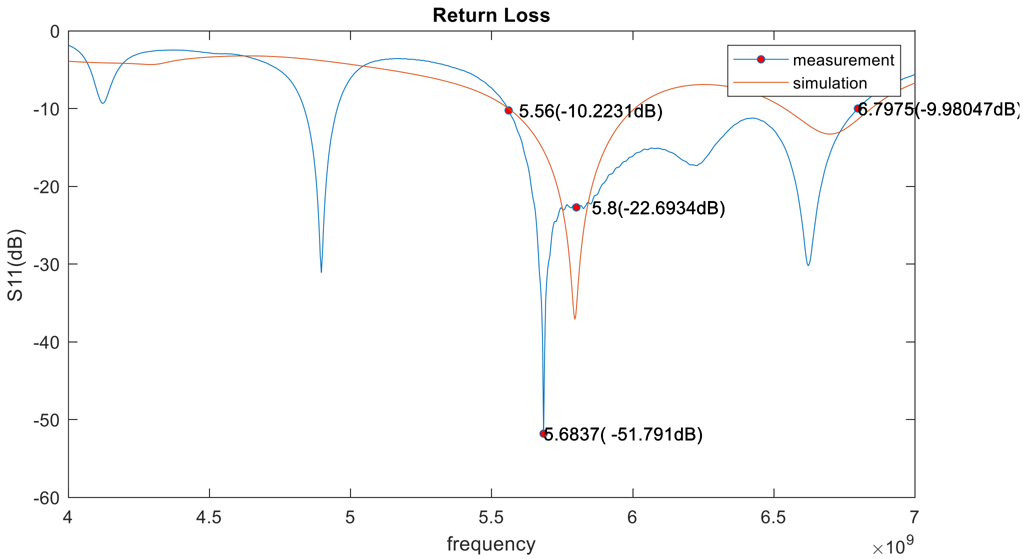


Figure 31: Signal Generator (bottom left) & Network Analyzer (upper right)

Additionally, we used a mechanical device named turn table to rotate the antenna direction precisely to observe and record the antenna gain on different angles.

With measured values, CST results and our MATLAB script, we got return loss and radiation pattern plots. In Figure 32, we can observe the deepest frequency value is shifted to 5.68 GHz with -51.8 dB, which is very narrow and useless for and implementation. But on the operating frequency, 5.8 GHz, S11 parameter plot gives a flat result for 5.75 GHz – 5.85 GHz and the S11 parameter value is -22.7 dB. These results are very satisfying and enough for our application aim. Also, we can observe that the operating bandwidth is between 5.56 GHz to 6.80 GHz, which is more than the simulation results.



.

Figure 32: S11 Parameter Measurement & Simulation Plots

On the radiation pattern plot in Figure 33, we have zero angle on the center and left and right direction angles on the sides. As we explained above, we used gain transfer method to find max dBi gain, and we used this value in normalized plot. The normalization is done for maximum simulation gain result, which is 8.98 dBi. In the figure we can see the measurement is nearly gives 8.5 dBi. Considering the bandwidth increment on the S11 result, this gain decrement is very good for our design.

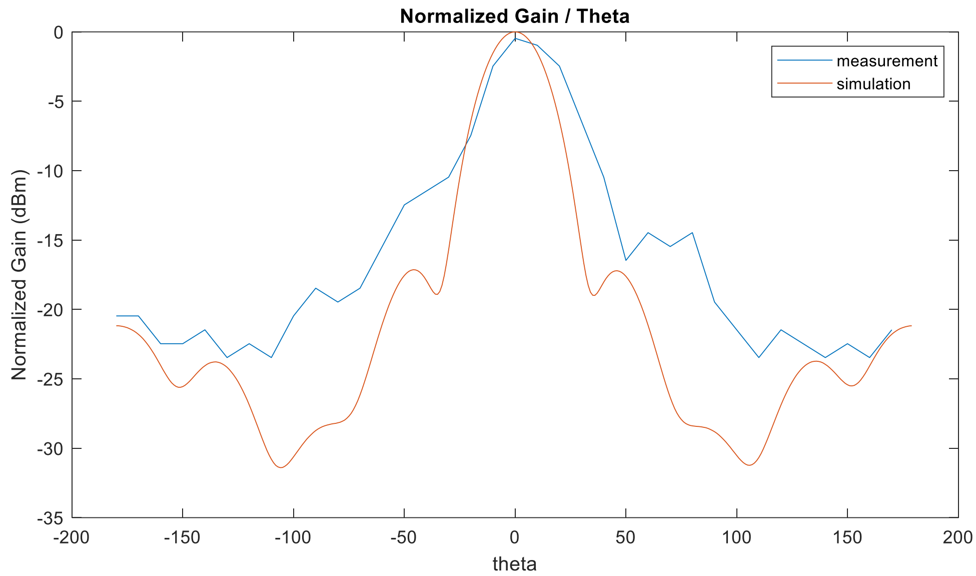


Figure 33: Radiation Pattern Measurement & Simulation Plots

Furthermore, for the directivity, we can observe that the pattern is almost matched especially on the main lobe angles. The right and left side lobe levels are higher than the simulation results. This value is not very satisfying for higher than -20 dBi values. Also, you can observe that the lower values on the -100 and 100 degrees is not matched, this is caused because of our equipment limitation. We used 15 dBm power for the signal generator, and in the transmission line we had some attenuation, so the resulting spectrum analyzer plot is limited to our maximum received power. But this case doesn't affect the main lobe measurement, because we made same experiment with horn antenna and calculate the values from that experiment.

5. CONCLUSIONS

In this project we come across several problems throughout the project. At the beginning of the project, our main concern was S11 parameter of the antenna. We aimed less than -10dB mostly -20dB at 5.8GHz. However, later we realized that -10dB is enough for our antenna and other parameters such as gain and directivity has greater importance for doppler radar production.

We expected our simulation to match with our analytical calculation, but we see that it rarely matched. Therefore, rather than calculation, iterative simulation trials spend our significant amount of time.

We thought that we will be able to finalize more than one antenna for a doppler radar but then we realized that we have great concern about directivity. Thus, by trial and error we eliminated several antenna structures and concluded only for one.

Even though, small parameter changes at material, such as dielectric constant, tangent loss, directly affects our results at simulation, in real life it does not have that big influence. For that reason, we first wanted our antenna to be fabricated professionally but due to the economic problems we could not. However, than we observed that S11 parameter of our antenna has shifted 100MHz when we produce it with UV exposure method but it was negligible for our purpose. We saw that it was not needed to produce professionally by PCB machines.

While measuring S11 parameter of the antenna, we saw differences, but it has distinct similarities with our antenna mainly on our focus area of 5.8GHz. At other sides, we observed another working region that we did not observe at simulation results which is not a problem for us.

For anechoic chamber tests, we realized that it is not possible to get accurate results without a reference point. Hence, we needed another antenna which has operating frequency at 5.8GHz with known results especially gain. In our case, it was a horn antenna with 12dBi gain.

As the main aim of the Project, we ended up a properly working 5.8GHz microstrip antenna for doppler radar implementation. For the future work, we want to use this antenna with a Vivaldi antenna for test and comparison of 2.45GHz and 5.8GHz doppler radars.

REFERENCES

[1] A. Pandey, *Practical Microstrip and printed antenna design*. London, Boston: Artech House, 2019

[2] *Radar bands*. [Online]. Available: https://www.everythingweather.com/weatherradar/bands.shtml. [Accessed: 27-Nov-2021].

[3] "Radar," *Wikipedia*, 24-Nov-2021. [Online]. Available: https://en.wikipedia.org/wiki/Radar. [Accessed: 27-Nov-2021].

[4] "Doppler effect," *Wikipedia*, 18-Oct-2021. [Online]. Available: https://en.wikipedia.org/wiki/Doppler_effect. [Accessed: 27-Nov-2021]

[5] "Talk:velocity-addition formula/archive 1," *Wikipedia*, 16-Jul-2016. [Online]. Available: https://en.wikipedia.org/wiki/Talk:Velocity-addition_formula/Archive_1. [Accessed: 27-Nov-2021].

[6] G. L. Charvat, Small and short-range radar systems. Boca Raton: CRC Press, Taylor & Francis, 2017.

[7] A. Karatay, D. Orcan, C. Özkal, and F. Yaman, "Implementation and experimental verifications of microstrip antennas for angular scanning of a Doppler radar," *AEU-International Journal of Electronics and Communications*, vol. 101, pp. 76–84, 2019.

[8] "What is Return Loss?," *everything RF*, 10-Nov-2018. [Online]. Available: https://www.everythingrf.com/community/what-is-return-loss. [Accessed: 13-Jan-2022].

[9] A. Henkel, "What are S-Parameters?," everything RF, 06-Aug-2019. [Online]. Available: https://www.everythingrf.com/community/what-are-s-parameters. [Accessed: 13-Jan-2022].

[10] "Main characteristics of chip attenuators and Pat Series: Susumu Deutschland GmbH," SSMSUSUMU. [Online]. Available: https://www.susumu.co.jp/france/tech/highfrequencychip03.php. [Accessed: 13-Jan-2022].

[11] "What is antenna gain," NetXL Blog, 10-Jul-2019. [Online]. Available: https://www.netxl.com/blog/networking/antenna-gain/. [Accessed: 13-Jan-2022].

[12] H. T. Friis, “A note on a simple transmission formula,” Proceedings of the IRE, vol. 34, no. 5, pp. 254–256, 1946.

[13] R. Kiruthika and T. Shanmuganantham, “Comparison of different shapes in microstrip patch antenna for X-band applications,” 2016 International Conference on Emerging Technological Trends (ICETT), 2016.

[14] “RF/Microwave PCB laminate material,” Epec Engineered Technologies - Build to Print Electronics. [Online]. Available: https://www.epectec.com/pcb/rf-microwave-laminate-material.html. [Accessed: 13-Jan-2022].

[15] “What PCB material do I need to use for RF?,” PCBway, 20-Dec-2013. [Online]. Available: https://www.pcbway.com/blog/Engineering_Technical/What_PCB_material_do_I_need_to_use_for_RF_.html. [Accessed: 13-Jan-2022].

[16] D. M. Pozar and D. H. Schaubert, “basic microstrip antenna elements and feeding techniques,” in *Microstrip antennas: The analysis and design of microstrip antennas and arrays*, New York: Institute of Electrical and Electronics Engineers, 1995, pp. 60–90.

[17] C. A. Balanis, *Antenna theory: Analysis and design*. Hoboken: John Wiley, 2016.

[18] G. Bozdağ, “Novel microstrip antennas for multiband and wideband applications,” M.S. thesis, ECE, IYTE, Izmir, Turkey, 2014. Accessed on: 13-Jan-2022. Available: https://hdl.handle.net/11147/4169