EE463 Project Report

Aydın Uzun
2015401210

I. Abstract

In this project, a rectangular microstrip patch antenna is designed using HFSS software and simulated on computer, fabricated in the laboratory at Bogazici University and finally simulated using Vector Network Analyzer(VNA). The designed antenna has a resonating frequency of 1.8 GHz which is applicable to GSM (Global System for Mobile communications). One can see the GSM frequency bands used in Turkey by different network providers. The design is made on FR-4 Epoxy dielectric material with dielectric constant ε_r = 4.4 and thickness 1.6mm.

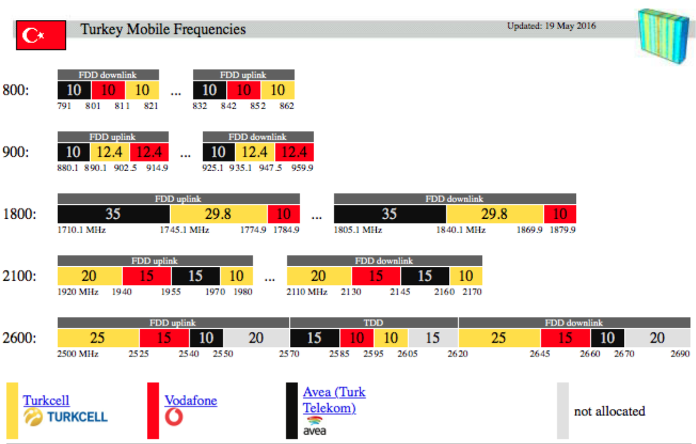


Fig. 1: GSM frequnecy bands in Turkey

II. Introduction

Microstrip antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance.
Major operational disadvantages of microstrip antennas are their low efficiency, low power, high Q and very narrow frequency bandwidth. But in some applications, such as in government security systems, narrow bandwidths are desirable.

However, there are a lot of methods to increase bandwidth of the designed antenna, such as increasing the height of the substrate or the the dielectricity constant of the substrate. However, as the height increases, surface waves are introduced which usually are not desirable. The surface waves degrade the antenna pattern and polarization characteristics. Surface waves can be eliminated, while maintaining large bandwidths, by using cavities.

III. Background

A. History

Microstrip antenna was first introduced in the 1950s. However, the technology of Printed Circuit Board (PCB) was later introduced in 1970s.Therefore, from that time microstrip antennas had become a very common antenna having wide range of applications due to their advantages.

B. Simple Geometry

Microstrip antennas, as shown on Figure 2, consist of a very thin metallic strip (patch) placed a small fraction of a wavelength(usually 0.003 $\lambda_0 \leq$ h $\leq$ 0.05 λ_0) above a ground plane. For a rectangular patch, the length L of the element is usually λ_0 /3 < L < λ_0 /2.

For good antenna performance thick substrates whose dielectric constant is lower is more preferable because they provide better efficiency, larger bandwidth but at the expense of larger element size. I used FR4 epoxy material with ε_r = 4.4 in my design this material is mostly used in antenna designs because of its lower cost. A RT/duroid with ε_r = 2.2 would definitely give better results.

The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. Rectangular patches are most common ones because of ease of analysis and fabrication, so I used a rectangular patch in my design.

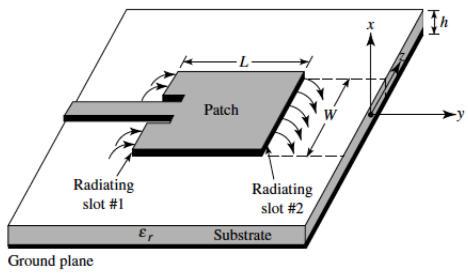


Fig. 2: Microstrip antenna geometry

C. Feeding Techniques

There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling.
The microstrip feed line is a conducting strip, usually of much smaller width compared to the patch.The microstrip line feed is one of the easiest to fabricate, and simple to match, using quarter-wave transform method.

IV. Design

A. Analysis method

The most popular models are the transmission-line and cavity models. The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate. Compared to the transmission-line model, the cavity model is more accurate but at the same time more complex. I decided to use transmission-line model to analyse my design.

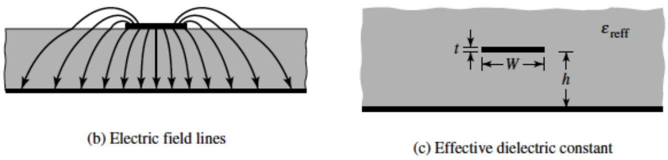
B. Transmission Line Model

Basically the transmission-line model represents the microstrip antenna by two slots, separated by a low-impedance Z_c transmission line of length L.

1) Fringing effects: Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. This is illustrated along the length in Figure 3.a. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. (See eqaution 1.)

For a microstrip line typical electric field lines are shown in Figure 3.a. This is a nonhomogeneous line of two dielectrics; typically the substrate and air. As can be seen, most of the electric field lines reside in the substrate and parts of some lines exist in air. Since some of the waves travel in the substrate and some in air, an effective dielectric constant $\varepsilon_{\text{reff}}$ is introduced to account for fringing and the wave propagation in the line. It is defined as the dielectric constant of the uniform dielectric material so that the line of Figure 3.b has identical electrical characteristics.

$$\varepsilon_{\text{reff}} = \frac{(\varepsilon_{\text{r}}+1)}{2} + \frac{(\varepsilon_{\text{r}}-1)}{2} \times [1+12\frac{h}{W}]^{\frac{-1}{2}} \tag{1}$$



(a) Electric field lines (b) Definition of $\varepsilon_{\text{reff}}$

Fig. 3: Considering fringing effects

2) Effective Length, Resonant Frequency, and Effective Width: Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the xy-plane, this is demonstrated in Figure 4 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant $\varepsilon_{\text{reff}}$ and the width-to-height ratio. A very popular and practical approximate relation for the normalized extension of the length is

$$\Delta L/h = 0.412 \times \frac{(\varepsilon_{\text{reff}}+0.3)\times(\frac{W}{h}+0.264)}{(\varepsilon_{\text{reff}}-0.258)\times(\frac{W}{h}+0.8)} \tag{2}$$

Since the length of the patch has been extended by δ L on each side, the effective length of the patch is now

$$L_{\text{eff}} = L + 2\Delta L \tag{3}$$

For the dominant TM_{010} mode, the resonant frequency of the microstrip antenna is a function of its length. Usually it is given by

$$(f)_{010} = \frac{1}{2L\sqrt{\varepsilon_{\text{r}}}\sqrt{\varepsilon_0\mu_0}} \tag{4}$$

C. Proposed antenna geometry

On figure 4, one can see the antenna geometry my design based on.

D. Antenna parameters calculation

The task is to design a 1.8 Ghz microstrip patch antenna on a 1.60 mm substrate with a dielectric constant of 4.4 which is applicable to GSM and we have to match the input impedance of the patch to the 50 Ω characteristic impedance of the feed line using the quarter-wave transform method. Therefore our known parameters are

$(f)_{\text{r}} = 1.8Ghz$ $\varepsilon_{\text{r}} = 4.4$ and $h = 1.6mm$

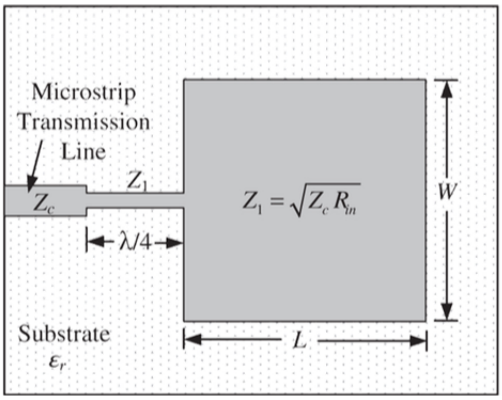


Fig. 4: Antenna geometry using microstrip line feed and $\lambda/4$ transformer

1) Calculate width of the antenna: For an efficient radiator, a practical width that leads to good radiation efficiencies is

$$W = \frac{1}{2(f)_{\text{r}}\sqrt{\varepsilon_0\mu_0}} \times \sqrt{\frac{2}{\varepsilon_{\text{r}}+1}} \tag{5}$$

Using this formula I calculated the width of the rectangular patch antenna as

$W = 5.1cm$

2) Calculate effective dielectric constant of the microstrip antenna: Using the given formula (1) effective dielectric constant is calculated as

$\varepsilon_{\text{reff}} = 3.48$

3) Calculate the extension of the length: W and $\varepsilon_{\text{reff}}$ was calculated. Using the given formula (2) the extension of the length ΔL is calculated.

$\Delta L = 6.69mm$

4) Calculate the the actual length of the patch: The actual length of the patch can now be determined with the equation

$$L = \frac{1}{2(f)_{\text{r}}\sqrt{\varepsilon_{\text{reff}}}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L \tag{6}$$

$L = 3.128cm$

5) Calculate the resonant input impedance: The resonant input impedance of the antenna can be calculated with the formula

$$Z_{\text{in}} = R_{\text{in}} = \frac{1}{2G_1} \tag{7}$$

where

$$G_1 = \frac{W}{120\lambda_0} \times (1 - \frac{1}{24} \times (k_0 h)^2) \tag{8}$$

when $\frac{h}{\lambda_0} < \frac{1}{10}$. Using this formula Z_{in} is calculated as 199 Ω.

This concludes the design procedures required for the microstrip patch portion of the antenna design. The next portion of the design involves the quarter-transform matching section, where the input impedance of the patch will be matched to the characteristic impedance of the transmission line.

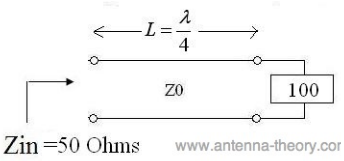
6) Calculate the length of the $\lambda/4$ microstrip section: With the formula

$$l_{\lambda/4} = \frac{1}{4f_{\text{r}}\sqrt{\varepsilon_{\text{reff}}}\sqrt{\varepsilon_0\mu_0}} \tag{9}$$

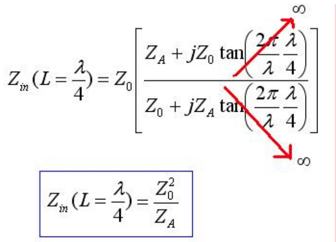
the length of the $\lambda/4$ microstrip section is calcuated as 2.23 cm.

7) Calculate the characteristic impedance of a transmission line of length $\lambda/4$: Recall the formula for the input impedance of a transmission line of length L with characteristic impedance Z_0 and connected to a load with impedance Z_{A} .(See figure 5.a)

An interesting thing happens when the length of the line is a quarter of a wavelength.(See Figure 5.b). Using the formula on Figure 5.b the characteristic impedance of quarter-wavelength transmission line is calcualated as $Z_{0,\text{quarter}} = 99.75$ Ω



(a) Matching model



(b) special case when the length of the line is a quarter of a wavelength

Fig. 5: Transmission line model

8) Calculate the width of the $\lambda/4$ microstrip section: Using the formula

$$w_{\lambda/4} = h\frac{2}{\pi}\times(B-1-ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\times(ln(B-1)+0.39-\frac{0.61}{\varepsilon_r})) \tag{10}$$

where

$$B = \frac{120(\pi)^2}{2Z_{0,\text{quarter}}\sqrt{\varepsilon_r}} \tag{11}$$

the width of the $\lambda/4$ microstrip section is calculated as 0.633 mm.

9) Calculate the feed width: Using the formula

$$w_{\text{feed}} = h\frac{2}{\pi}\times(B-1-ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\times(ln(B-1)+0.39-\frac{0.61}{\varepsilon_r})) \tag{12}$$

where

$$B = \frac{120(\pi)^2}{2*50*\sqrt{\varepsilon_r}} \tag{13}$$

the feed width is calculated as 3.06 mm.

This concludes the design portion of the quarter-wavelength matching section of the microstrip patch antenna. We have designed the complete microstrip patch antenna and corresponding matching network. The calculated parameters can be seen on Table 1.

Parameter	Value
Antenna Width	5.1 cm
Antenna Length	3.128 cm
$\lambda/4$ section width	0.633 mm
$\lambda/4$ section length	2.23 mm
feed width	3.06 mm
feed length	arbitrary

TABLE I: Calculated parameters

E. Antenna designed using HFSS

Using the built-in model in HFSS (See Figure 6) and the parameters I calculated I created a microstrip patch antenna whose model can be seen on Figure 7.

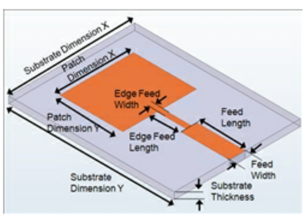


Fig. 6: Built-in microstrip patch antenna geometry in antenna toolbox of HFSS

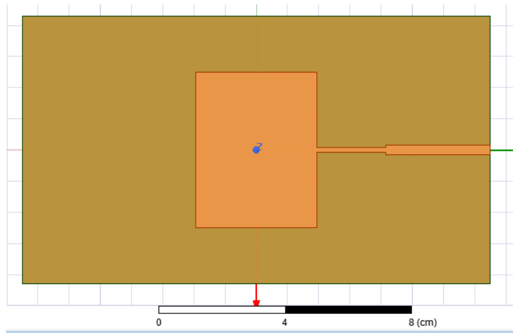


Fig. 7: Antenna geometry using microstrip line feed and $\lambda/4$ transformer

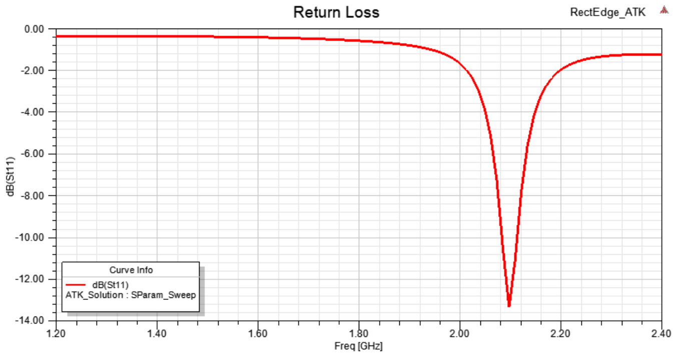


Fig. 8: first simulation

1) Decide the length of the antenna: After simulation with the calculated parameters (See Figure 8.) I noticed that the resonant frequency of this antenna is not at 1.8 Ghz. Therefore my first parametric analysis was on the length of the patch (patchY dimension on Figure 6). (See Figure 9.)

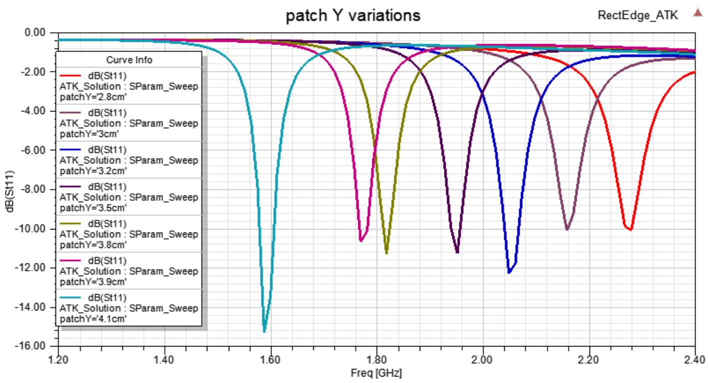


Fig. 9: second simulation

From Figure 9 I noticed that the length of the patch antenna should lie between 3.8 cm and 3.9 cm. Then I decided to run a simulation for patchY variables between 3.8 cm and 3.9 cm and then pick the most accurate one.

From Figure 10 I noticed that the most accurate result I get is when length of the antenna is 3.86 cm. I changed the length parameter of the antenna from 3.128 cm to 3.86 cm.

A takeaway from this step will be the fact that the resonant frequency of the antenna is highly dependent on the length of the antenna, as the formula (4) on page 2 indicates.

2) Decide the width of the antenna: At this step I run a simulation on the width of the patch.(See Figure 11) The best result is when the width of the patch is 5 cm. I changed the width parameter of the antenna from 5.1 cm to 5 cm.

3) Decide the length of the $\lambda/4$ microstrip section: At this step I run a simulation on the length of the $\lambda/4$ microstrip section.(See Figure 12) The best result is when the length of

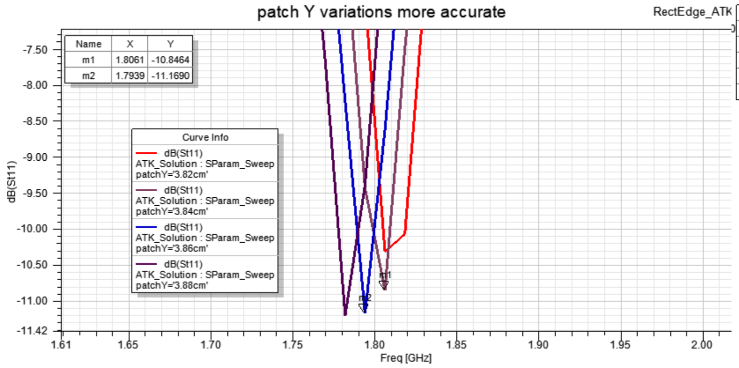


Fig. 10: third simulation

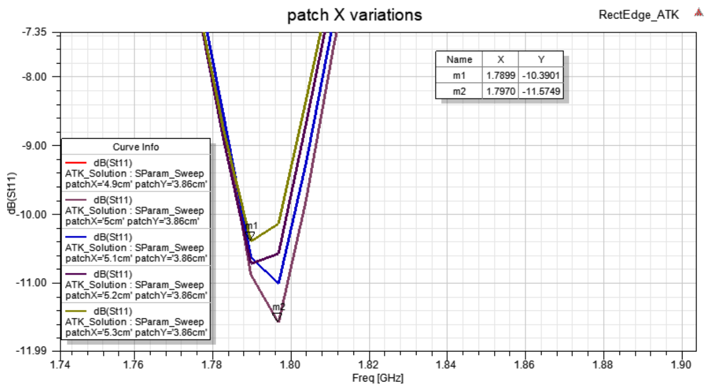


Fig. 11: fourth simulation

the $\lambda/4$ microstrip section is 2.23 cm. There's no need to change this parameter.

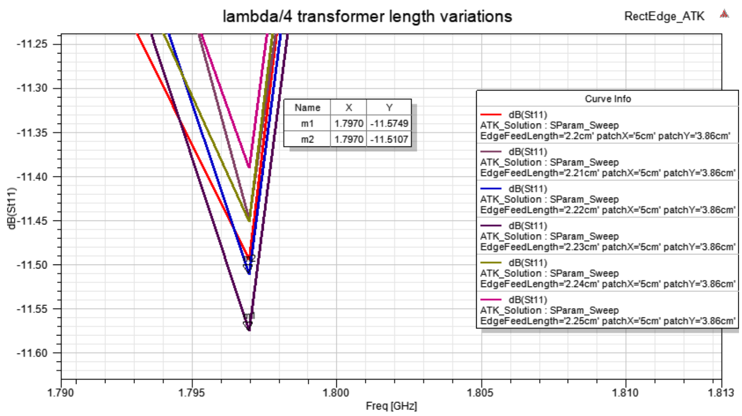


Fig. 12: fifth simulation

4) Decide the width of the $\lambda/4$ microstrip section: At this step I run a simulation on the width of the $\lambda/4$ microstrip section.(See Figure 13) The widest bandwidth at -10 dB is when the width of the $\lambda/4$ microstrip section is 1.6 mm. Therefore I changed the width parameter of $\lambda/4$ section from 0.633 mm to 1.6 mm.

A takeaway from this step will be the fact that the bandwidth of the antenna at -10 dB and the deepest point on the return-loss graph are highly dependent on the width of the $\lambda/4$ microstrip section.

5) Decide the width of the edge feed: At this step I run a simulation on the width of the edge feed.(See Figure 14) The bandwidth at -10 dB does not change in a drastic way as it was when we changed the width of the $\lambda/4$ section. I noticed that the result is already satisfactory when the width of the edge feed is 0.3 cm. In order to handle with more accurate numbers I changed the width parameter of the antenna from 3.06mm to 3 mm.

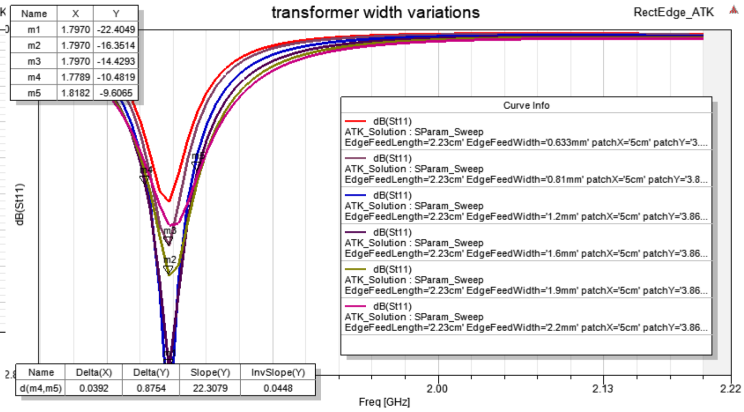


Fig. 13: sixth simulation

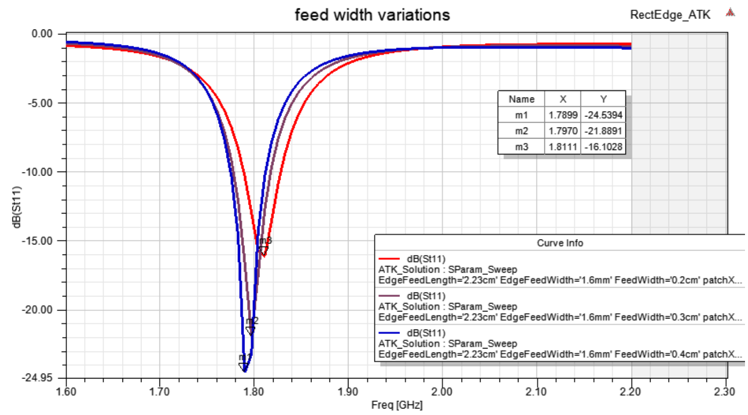


Fig. 14: seventh simulation

V. Simulations

The final parameters can be seen on Figure 15. The final

Name	Value	Unit	Evaluated Value	Type
Antenna Dimensions				
patchY	3.86	cm	3.86cm	Design
patchX	5	cm	5cm	Design
Substrate Dimensions				
subY	15	cm	15cm	Design
subX	8.6	cm	8.6cm	Design
subH	0.16	cm	0.16cm	Design
Feed Dimensions				
FeedWidth	0.3	cm	0.3cm	Design
FeedLength	subY/2 - EdgeFeedLength - patchY/2		3.34cm	Design
EdgeFeedWidth	1.6	mm	1.6mm	Design
EdgeFeedLength	2.23	cm	2.23cm	Design

Variables

Fig. 15: parameters

simulation results can be seen on Figures 16 to 19.

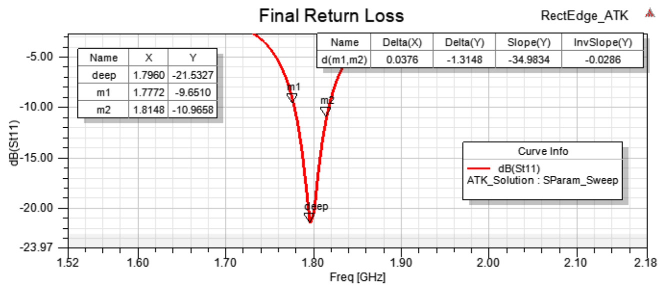


Fig. 16: Return Loss

The deepest point on return loss table is approximately at -21.5 dB. The bandwidth at -10 dB is approximately 37.6 Mhz covering the band between frequencies 1.78 Ghz and 1.82 Ghz.

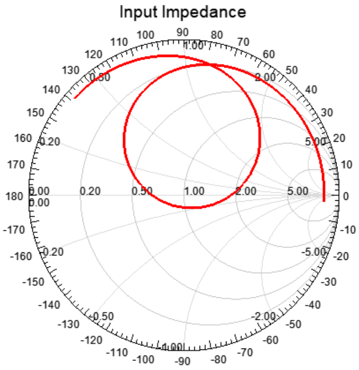


Fig. 17: Input Impedance

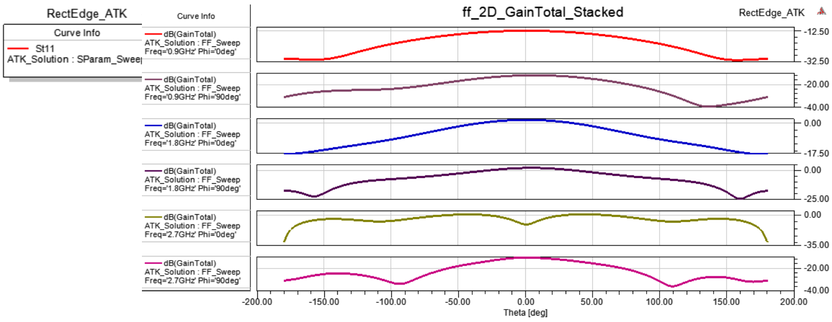


Fig. 19: 2D Gain

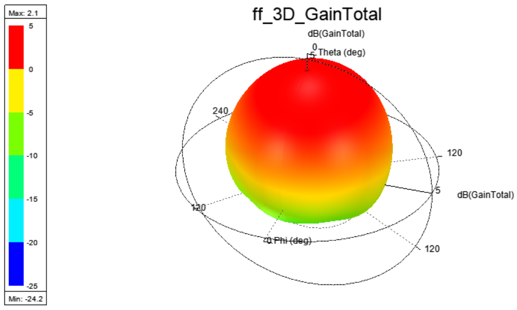


Fig. 18: 3D Gain

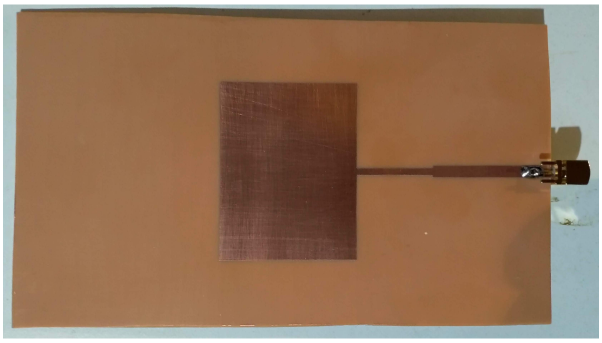


Fig. 20: Fabricated Antenna

VI. Fabrication

The Microstrip Patch Antenna dimensions obtained from the simulation are used to fabricate the antenna. The antenna is fabricated using Etching Technique. For this particular design, an SMA connector can simply be soldered onto the edge of the feed line to introduce signals to and from the patch antenna.

The Fabricated antenna can be seen on Figure 20.

VII. Experimental Results

The return loss for the fabricated antenna can be measured on a network Analyzer. The result can be seen on Figure 21. The resonant frequency is 1.974 Ghz and the bandwith at -10 dB is approximately 55 Mhz covering the band between the frequencies 1.945 Ghz and 2.0 Ghz.

A. Comparison of Simulation Results and Experimental Results

The simulated results and experimental results do not overlap. Some possible reasons for this case may be the fact that, in simulation the program uses perfect material and substrate. The substrate I used was FR4-epoxy which have the dielectric constant 4.4 in the ideal case. But in reality we don't have to chance to measure the dielectric constant of the substrate. It is also very likely that the thickness of the substrate is not equal to 1.6 mm as the computer aided tool assumed. In addition to that I do not simulate my antenna in an anechoic chamber which means that the reflection phenomena occurs. This influences my results highly.

VIII. Conclusion

In this project a microstrip patch antenna is successfully designed at a resonant frequency of 1.8 GHz and fabricated at a resonant frequency of 1.974 Ghz. My task was to design an antenna which is applicable to GSM. In Turkey GSM 1800 covers the frequency band between 1.71 and 1.88 Ghz. The simulated antenna does not cover this range, because the patch antenna has some limitations. Increasing the height of the substrate and decreasing the dielectricity constant of the substrate would increase the bandwidth of the designed antenna. But that was commercially not possible in my case. Introducing a cavity to my designed antenna would also increase the frequency band.

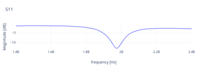


Fig. 21: Output of VNA