Chinese University of HongKong
Electronic Engineering

Antenna Laboratory
(ELEG3204)

Mini-project Report

Patch Antenna Design and Measurement

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1 Introduction

1.1 objectives

The objective of this exercise is to study and understand some properties of antenna.

In particular, we are going to:

1. Design a patch antenna using ADS.
2. Fabricate the patch antenna.
3. Get familiar with the measurement techniques of antenna.

2 Design Criteria

The Criteria of this lab are:

- Antenna type: patch antenna with rectangular shape
- FR4 substrate with $\varepsilon_r = 4.3$ and $h = 0.8mm$
- Resonant frequency $f_r = 3GHz$ and $S_{11} \leq -25dB$
- Characteristic impedance = 50 Ω

3 Design and Simulation

3.1 Dimensions of the Device

According to the given equations and constraints, we can calculate the dimensions of the path antenna we want to design with the help of Matlab and ADS,.

First, Use ADS we can get the width of the feeding line, that is $W_0 = 1.5323mm$

Then we calculate the width of the antenna,

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = 30.7mm$$

where $v_0 = 3 \times 10^8 m/s$, $f_r = 3 \times 10^9 Hz$, $\varepsilon_r = 4.3$

After that,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}} = 4.0836$$

$$k_0 = \frac{2\pi\sqrt{\varepsilon_{reff}}}{\lambda_0} = 127.0728$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} = 3.7243 \times 10^{-4}m$$

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L = 24mm$$

$$I_1 = \int_0^{\pi} [\frac{\sin(\frac{k_0 W}{2}\cos\theta)}{\cos\theta}]^2 \sin^3\theta d\theta = 4.0310$$

$$G_1 = \frac{I_1}{120\pi} = 0.0034$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi} [\frac{\sin(\frac{k_0 W}{2}\cos\theta)}{\cos\theta}]^2 J_0(k_0 L\sin\theta)\sin^3\theta d\theta = -5.7348 \times 10^{-4}$$

$$R_{in} = \frac{1}{2(G_1 + G_{12})}$$

$$y_0 = 7.714mm$$

Professor also showed us an online calculator during lecture, so I also use that to calculate the dimensions of the patch antenna. Although the results of W and L correspond to my calculation, I found that the input impedance is different from my result. And according to that input impedance, that is $R_{in} = 238.5$, we will get $y_0 = 8.36mm$. Since we still need to use the trial and error method to determine all the parameters, I did not pay much attention to this difference.

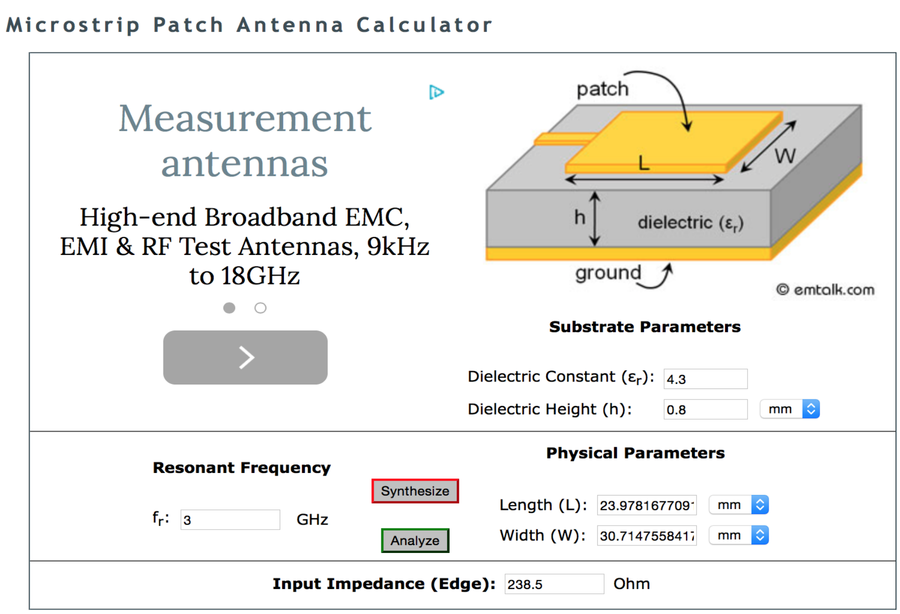

Figure 1: Results of the Online Calculator

3.2 ADS Simulation

After the trial and error, we finally determined the dimensions of the patch antenna which can satisfy the design criteria.

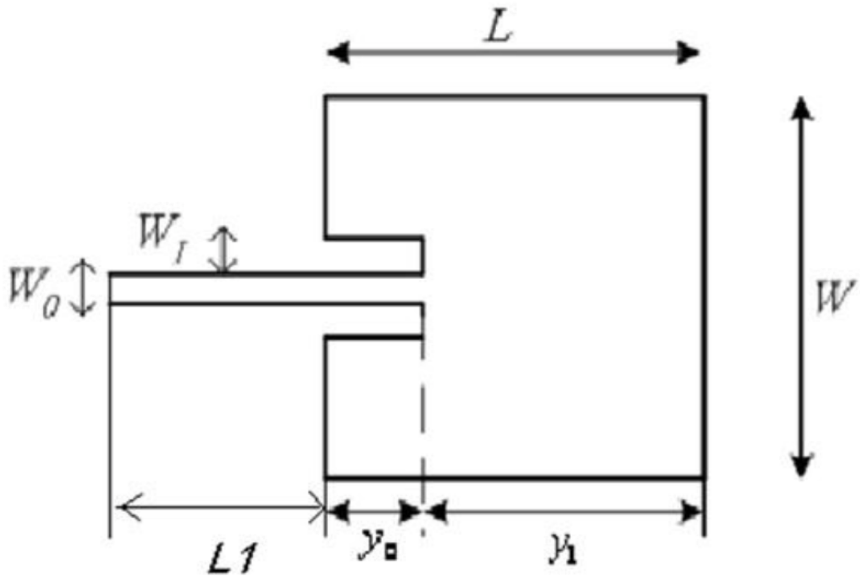

Figure 2: Dimensions of the patch antenna

Item	Dimension (mm)
W_0	1.5323
W_1	1.5
W	30
L_1	10
L	24.16
y_0	5

Table 1: Dimensions of the patch antenna

And the simulation results are shown below.

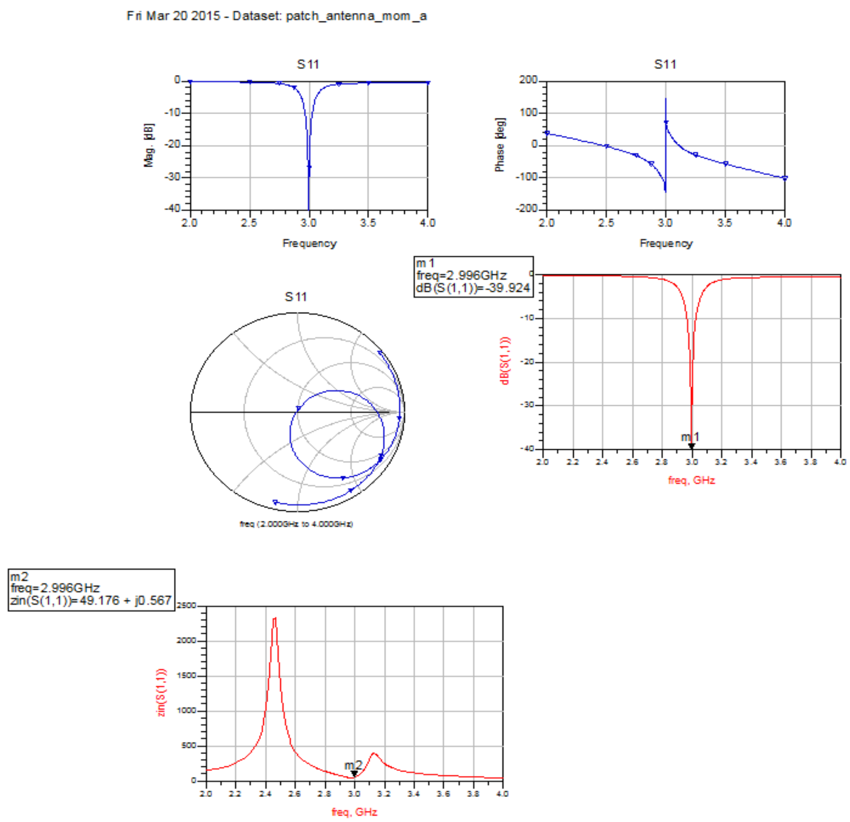

Figure 3: Simulation Result

We can see that the reflection coefficient $S_11 = -39.924$ at $f_r = 2.996GHz$. And $Z_{in} \approx 50\Omega$. All satisfy the requirement.

4 Fabrication

With the help of our TA, we finish the fabrication of the path antenna without any trouble.

Follow the following steps when fabricating patch antenna,

1. Clean the PCB and dry carefully to get rid of any grease.
2. Coat photoresist on PCB with uniform thickness.
3. Place the mask on top of the photoresist and expose the PCB to UV light.
4. Remove the mask and develop the PR by using developer mixture.
5. Etch the exposed copper in ferric chloride etching tank.
6. Remove the cellophane tape on the bottom and the PR on the top.

And below is a photo of our patch antenna.

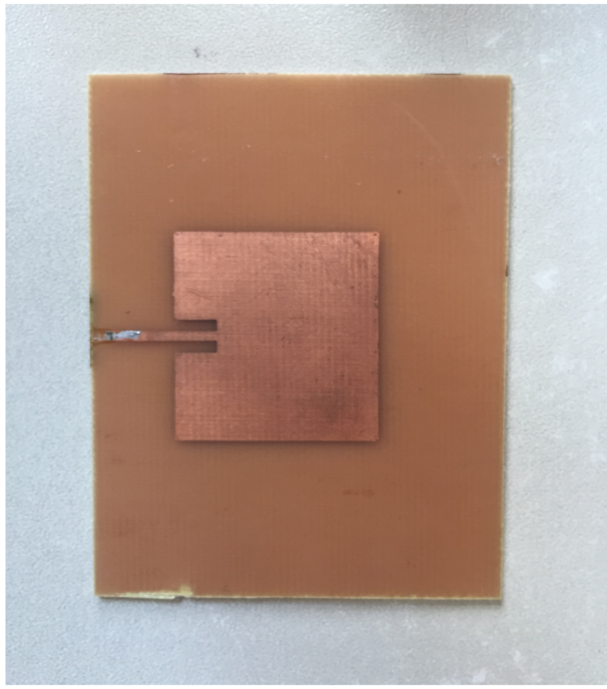

Figure 4: The antenna

5 Measurement and Result

5.1 Reflect Coefficient

In this part, we used network analyzer to get the reflect coefficient as well as the 10dB band width. The following figure shows the results of the measurement.

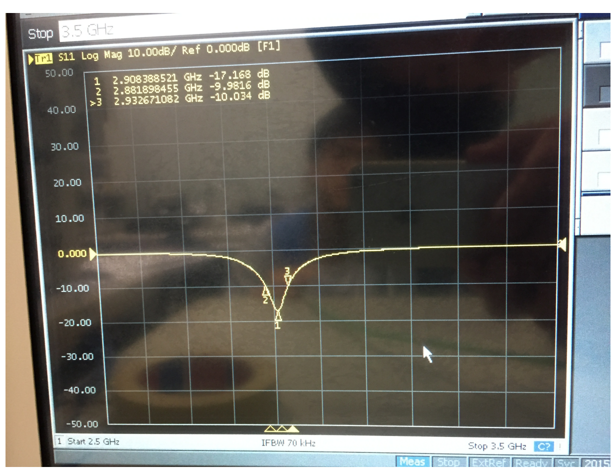

Figure 5: The result from network analyzer

We can see that the resonant frequency of the patch antenna is $f_r = 2.908GHz$, and the reflect coefficient at resonant frequency is $S_{11} = -17.168dB$. And the 10bB band width is 0.05077GHz.

5.2 Resonant Frequency

In this part and all the following part, we connect two patch antenna to a signal generator and a spectrum analyzer respectively. To find the resonant frequency, we change the frequency of the signal generated by the signal generator from 2.5GHz to 3.2GHz with a step length of 0.1GHz. We can determine the resonant frequency by finding the maximum receiving power at the spectrum analyzer since we have fixed the transmitted power.

The results are shown in the following table.

Frequency (GHz)	Received Power (dBm)
2.5	-62.03
2.6	-59.57
2.7	-58.43
2.8	-48.23
2.9	-39.21
3.0	-43.59
3.1	-56.18
3.2	-59.04

Table 2: Resonant frequency

We can see that we got the maximum received power at 2.9GHz, again we can determine that the resonant frequency is $f_r = 2.9GHz$.

5.3 Antenna Gain

We have three sets of data for this part.

Distance (m)	Received Power (dBm)
0.93	-36.53
0.67	-34.17
0.46	-31.23

Table 3: Antenna Gain

Note that there exists cable loss, and that is 1.65dB. So the actual transmitted power is -1.65dBm. And,

Distance (m)	Actual Received Power (dBm)
0.93	-34.88
0.67	-32.52
0.46	-29.58

Table 4: Actual Received Power

I will use two methods to calculate the antenna gain.
First by solving Friis equation directly and then get the average value of the results.

$$P_R = G\frac{P_T}{4\pi r^2}G\frac{\lambda^2}{4\pi}$$

Take the first set of data as an example, we got that $r = 0.93m$ and $\lambda = \frac{c}{f} = \frac{3}{29}m$.

$$G = \sqrt{\frac{16\pi^2 r^2 P_R}{P_T \lambda^2}} = 2.46$$

Other results are listed in the following table,

Distance (m)	Antenna Gain (Absolute value)
0.93	2.46
0.67	2.34
0.46	2.24
Average	2.35

Table 5: Antenna Gain

The second method is based on the relationship,

$$\log(\frac{P_R}{P_T}) = -2\log(\frac{4\pi r}{\lambda}) + 2\log(G_A)$$

Find some data points and linear fit them, then we can find the antenna gain based on the intersection of the line with y axis.

The result is shown below,

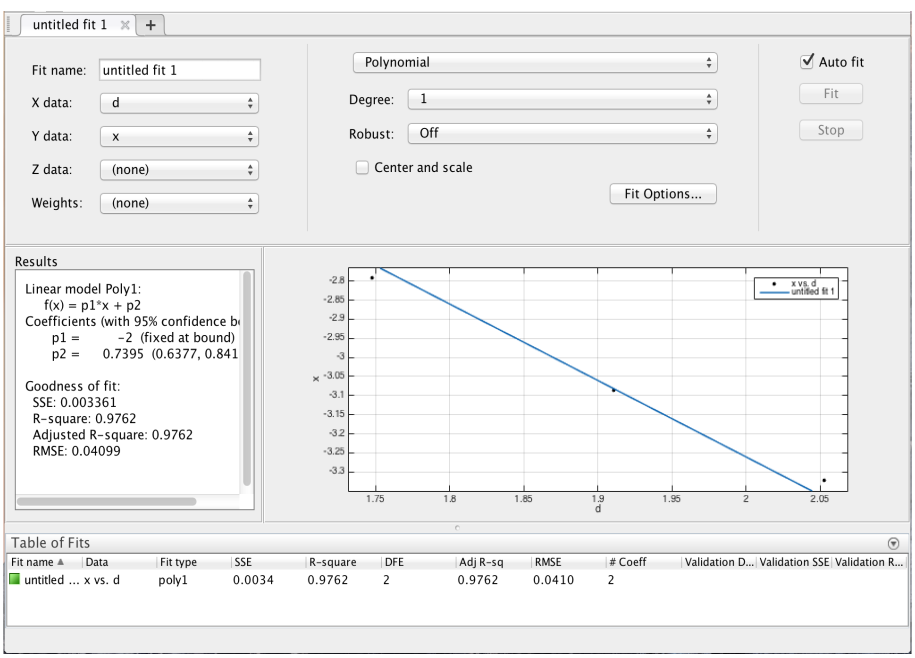

Figure 6: Linear Fit

We can see that $p_2 = 0.7395$, which means $2\log(G_A) = 0.7395$. The antenna gain $G_A = 2.34$

5.4 Multi-path Fading Effect

We change the height of the metal plate to find three maximum point and three minimum point of the received power. And the results are shown below.

Height (cm)	Received Power (dBm)
65.0	-35.14
59.6	-51.00
54.0	-33.51
49.0	-45.70
46.0	-33.46
42.0	-42.39

Table 6: Multi-path Fading Effect

We can observe this kind of phenomena because except the direct path from the transmitting antenna to the receiving antenna, there is also a path from transmitting antenna to the metal plate and then to the receiving antenna. Two signal meet at the receiving antenna, and they have different phases. If the phases are same, then it is constructive interference, and we get the maximum received power; If the phases are opposite, then it becomes destructive interference, and we get the minimum received power.

5.5 Polarization Effect

We changed the angle of the receiving antenna to observe the polarization effect. And the results are shown below.

Angle (Degree)	Received Power (dBm)
0	-37.73
45	-43.67
90	-58.15

Table 7: Polarization Effect

The two antenna are identical, and have the same polarization. When they are both set up horizontally, we have the maximum received power, because they have same polarization. When the transmitting antenna is set up horizontally and the receiving antenna is set up vertically, we have the minimum received power.

6 Conclusion and Discussion

There is no error analyzation part in this report, because all the measurements are pretty rough and the aim of this lab is to help us to get familiar with those basic methods of design, fabricate and measure an antenna.

And I think we have achieved all the objectives of this laboratory.

7 Reference

ELEG3204 Mini Project—Patch Antenna Design Project Manual