ESE498

Patch Antenna

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Abstract

The goal of this project is to design a patch antenna which would pick up cellphone frequency. I preformed additional experiments to understand the antennas and their characteristics, derived the theoretical equations, and used measuring equipment to analyze the results. The prototype of the design was made first for a higher frequency which leads to a smaller antenna and would fit in the board more accurate. Successions of simulations have been proven to optimize the physical factors of the antenna for the desired resonant frequency, bandwidth and input impedance. Then the cellphone frequency was defined, and the design was developed based on that frequency. Some adjustments were made to make the new design works with limitations. The results were analyzed based on the gain, return losses, radiation pattern, and VSWR values, which are the most significant characteristics of any antenna. The simulation analysis was executed using the commercial antenna and network analyzer. The Microstrip patch antennas are new, and are designed for higher frequencies. Patch antennaes have opened new doors to new technology, and have replaced many previously designed antennas. This proposal has been done to familiarize RF microwave designers with the design structure and performance of the patch antenna. The designed antenna can be used in lab experiments in which there is a need for an antenna which would capture certain frequencies of 842MHZ or 2.105GHZ. The transmission and reflection coefficients should prove the accuracy and good performance of the designed antenna. The more similar and more advanced design is used in mobile antenna design, GPS navigation and network communication.
Acknowledgment

I wish to express my sincere gratitude to Professor Spielman for his guidance and helpful feedbacks through the project process and providing me the required equipment for this project.

I would also wish my special thanks to Professor Morely for providing me an opportunity to do my design work on “The patch Antenna Design”.
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1. Introduction

1.1 Problem statement

The problems of making this design are briefly mentioned here, and they will be explained in more detail included with proper solutions in the paper. The first challenge was to understand how to work with new equipment and how to analyze my data, results and graphs. I have done three experiments of measuring and analyzing the S parameters of 10dB, 30dB, and 705S coupler, and I only included the results for 10dB in the report as introduction to my experiment. I have enclosed a preview in the introduction which makes it easier for the reader of this article. The second challenge, which is also considerable, in any test is the reliability and accuracy of the measurements and results. There might be more errors in experiments of higher frequencies so the calibration process is required for the better results. The third part was the recognizing orientation of the antenna, which was done experimentally and by reading. The fourth problem was finding the dimensions of the antenna, and the instruction for this part was given by professor Spielman. For the specific cellphone frequency experiment, the challenges were to measure the frequency of the cellphone. The other challenge was to adjust the type of feed in since the antenna did not fit with the board size. Trimming was another challenge because it took a long time to find the correct and fixed results before the copper tape lost its stickiness. I have discussed all the results with professor Spielman, and necessary adjustments were recommended.

1.2 Literature Review

The best article that helped me for this design was given by professor Spielman. The *antenna theory* by Balanis was other good source of the theory and explanation of the electric and magnetic fields orientation of the antenna design. The article The
Fundamental of patch Antenna Design and Performance by Gary Breed gave me a good understanding of the polarization pattern and some characteristics of antenna design. Another article, Design of New Multi Standard Patch Antenna GSM/PCS/UMTS/HIPERLAN for Mobile cellular phones by M. Ben Ahmed about the rectangular patch design in mobile phones was a little helpful. Most of the articles already have the same explanations, and many of them used the same type of design with different shape and feed in. Rectangular shape with either direct inset feed or coaxial Probe feed was recommended in most articles.

1.3 Concept Generation and Reduction

I started this with the guidance professor Spielman provided for me. There was a brief written guideline available which gave me the general idea of what needs to be done, but I had to understand the reason for each step. I also searched for the other possible solutions. After I finished the design for 2.105MHz frequency, then we came to the idea of designing it for cellphone frequency. Since I have seen articles that mentioned about new patch antenna design and their applications such as GPS navigation, network communication, and mobile devices, I found it interesting to have an experiment of designing a practical patch antenna for cellphone frequency. I knew that the design might be larger compared to the cellphone antenna and I might not be able to have it so advanced and small, but it was a good practical experiment which can be improved by more advanced studying of magnetism and antenna design.

2. Preview

2.1 $S$ parameters and network analyzer

In order to understand the results and procedure of this project, there is a need for an introduction that explains the operation of the network analyzer and the parameters of this system.
The network analyzer is used to measure the S parameters (scattering parameters) of a one-or two-port device. In the case of high frequency, the traditional network characterization of impedance and admittance parameters would not be done by simple open-short circuit measurement, and instead it will be done by S parameters. S parameters are defined as the behavior of the port or input-output relation of the network by travelling waves moving along the transmission line and reflected waves.

In this experiment we have a two port device. Figure 1 shows the S parameters as well as the ports of the device. In the figure and following formulas, $a_1$ is the incident power wave at port one. $b_1$ is reflected power wave at the port one. $a_2$ is the incident power wave at port two. $b_2$ is the reflected power wave at port two.

![Figure 1 shows the incident and reflected power at each port](image1.png)

![Figure 2 shows the S parameters for two port system](image2.png)

Output power at port one: $b_1 = S_{11} a_1 + S_{12} a_2$

Output power at port two: $b_2 = S_{21} a_1 + S_{22} a_2$
$S_{11} = \left| a_{2} = 0 \right| = \text{--------------------------------------}$

In the $S_{11}$ parameter we are trying to find out how much input power is reflected at port one. If there is no reflection, then $S_{11}$ should be equal zero or be very small, which can be a big negative number in dB. If all the power is being reflected, then $S_{11}$ should be 1 or 0 dB.

$S_{21} = \left| a_{2} = 0 \right| = \text{--------------------------------------}$

In this case, we are trying to find out how much input power at port one is being transmitted to port two, or we are trying to find forward transmitted. $S_{21}$ should be one or 0 dB, if all the input power from port one is being transmitted. $S_{21}$ should be 0 or -db, if none or very small amount of input power is being transmitted to port two.

$S_{22} = \left| a_{1} = 0 \right| = \text{--------------------------------------}$

In this case, we are estimating the amount of output reflected or we are trying to find out how much input power at port two is being reflected at port two.

$S_{12} = \left| a_{1} = 0 \right| = \text{--------------------------------------}$

The equation above is for the case of calculating the reverse transmission. In this case we are trying to find out how much power from port two is being transmitted to port one.

- S parameters at port one and two would be the same numbers or close. For example $S_{11}=S_{22}$ and $S_{12}=S_{21}$. So for most of the experiments we only measure the values of $S_{11}$ and $S_{21}$ since we are interested in checking the transmission.
- The S parameters can be used to find the amount of reflection or transmission power.
2.2 S parameters for 10dB coupler

In the 10dB coupler, 10% of the power should be coupled. The rest should be transmitted through the output port. $S_{11}$ is the reflected power from port one, which should be a small number. In this case, it is -25dB which means almost no power is being reflected.

Figure 3: The ports and structure of the 10dB coupler

Figure 4: The amplitude of $S_{11}$ for 10dB coupler (In-Out Connection)
$S_{21}$ is transmitted power which is 90% for the 10dB coupler, which means 90% of input power should be transmitted through port two. So $S_{21}$ should be close to 1 or 0dB.

![Figure 5: The amplitude of $S_{21}$ for 10dB coupler (In-Out Connection)](image)

10% of the power is being coupled in the couple port. So the amplitude of $S_{21}$ for the coupler is -10dB.

![Figure 6: The amplitude of $S_{21}$ for 10dB coupler (In-Coupler Connection)](image)
The ideal VSWR for the coupler is about 1.5 or less. Based on the specification sheet, the VSWR for the 10dB coupler is about 1.15. Since $S_{11}$ is very small, then the value of VSWR should be either 1 or infinity which corresponds to the range of $S_{11}$ between 0 and 1. The VSWR for the 10dB coupler I measured is about 1.1, which is very close the expected VSWR.

![Figure 7: The VSWR of 10dB coupler](image.png)

### 3.0 Network analyzer Calibration

In any experiments, there are always systematic errors due to the connections, cables or any kind of input. In order to reduce the percentages of error, I did calibrations which would help me to improve the performance of our experiment and get more reliable results.

Before I started our experiment I needed to calibrate the network analyzer to a set of standards; open, short, load and zero length transmission line (direct connection of input-output). The method of calibration used in this experiment was mechanical calibration. Calibration characterizes non-ideal elements and compensates for losses due to cables and adapters. In other words I standardized the network analyzer internally to get error free $S$ parameters and improve measurement accuracy. In order to calibrate, I use a calibration kit which has all the characterized switches for short, open, and in-out transmission.
Calibration can also fix any kind of systematic errors such as frequency, isolation between signal paths, and mismatch between port impedance and leakage in the test set up.

- At the beginning of the experiment I needed to calibrate the network to the specific frequency range of the experiment. Calibration has to be done every time cables or type of connections to the system change. Calibration also checks the type of connections for us. In this case I used two port N type input connections.

- After finishing the calibration, I checked and measured the S parameters for open, short, zero length transmission at each port to make sure calibration was done correctly.

Table 1: The type of calibration kits used for different antenna and connections

<table>
<thead>
<tr>
<th>Type of connection</th>
<th>Type of calibration kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial antenna</td>
<td>T Shape 1250 Calibration kit</td>
</tr>
<tr>
<td>NCM-NM-36-M02 Cable</td>
<td>T Shape 1250 Calibration kit</td>
</tr>
<tr>
<td>Patch Antenna</td>
<td>85033F Calibration kit</td>
</tr>
<tr>
<td>SCA 52086-36 Cable</td>
<td>85033F Calibration kit</td>
</tr>
</tbody>
</table>

After the calibration was done, I analyzed the graphs for open circuit, short circuit, load and direct connection at each port to make sure that calibration was done correctly. The graphs of the experiment for port one which are available at appendix.

### 4.0 Far field distance:

The radiation pattern is different in different distances to the antenna. Far field or radiation field refers to the field pattern at larger distances. Antenna patterns usually are measured in the far field region. It’s important to choose the farthest distance based on the dimensions of the antenna and wavelength. The formula for the distance is \( r = 2 \frac{D}{\lambda} \). \( D \) is largest dimension of the antenna which is \( W \) in this design.

For frequency of 842MHz, \( W = 125.912\text{mm} \) and the distance is \( r = 2 \frac{125.912}{842} = 8.89\text{cm} \).

For the commercial antennas the distance is about 20cm.
5. **Selection of the tool to measure the results**

After finishing the experiment on the patch antenna I needed a type of antenna that would be connected to the network analyzer to show the $S_{21}$ parameters or the transmission from the designed antenna. The antenna that I needed should have good band width and beam width to show all the parameters of the designed antenna. Commercial antennas are known for having a broad bandwidth, and I also did an experiment to check the performance of commercial antennas.

- **Experiment Setup**

  For this part I calibrated the network analyzer for the frequency range of 2MHz-6GHz. The type of cables is CNM-NM-36-M02/X. Two commercial antennas were attached to a pole with the height of 35 cm from the counter. Each antenna was connected to the ports of the network analyzer. Antennas were separated 20 cm apart, and this distance was fixed for the entire experiment. 20 cm is the distance of far field for the antenna, which was in the orientation of the antenna. Antenna number one is connected to the left port of the network analyzer, and antenna number two is connected to the second port of the network analyzer on the right.
Figure 8: The experiment set up for commercial antennas

Figure 9 shows the $S_{21}$ for two commercial antennas facing each other.

- As we see from the graph, the commercial antenna has a broad bandwidth.
- Experiment results: The beam width of the commercial antennas
First, I set both antennas facing each other (0 degrees) and began rotating the antenna connected to port 1 counter clockwise from 0 to 360 degrees, incrementing by 15 degrees. While doing this, I measured and saved $S_{21}$ values as .S2p files. After I took the measurements, I graphed values of $S_{21}$ at different frequencies. I chose frequencies of 0.85GHz, 1.0GHz, 1.5GHz, 2.0GHz because they were evenly spaced in the frequency range of the antenna specification, 800-2500MHz. Then I graphed the gains at different frequencies and angles. The beam width varied for different frequencies. At 850MHz, the -3dB points were approximately 30 degrees and -35 degrees, which add up to a bandwidth of 65 degrees. At 1GHz, the -3dB points are 30 degrees, and -30 degrees for a bandwidth of 60 degrees. At 1.5 GHz, the -3dB points are 15 degrees and -30 degrees, for a beam width of 45 degrees. Finally, at 2.0 GHz, the -3 dB points are 20 degrees and -25 degrees, for a beam width of 45 degrees. These numbers show that the beam width is not the same for different frequencies.
Table 2: The values of $S_{21}$ at $f=850MHz$ and $1.5MHz$ for 0-360 degree rotation

<table>
<thead>
<tr>
<th>Degree</th>
<th>850MHz=.85GHz</th>
<th>1.0GHz</th>
<th>1.5GHz</th>
<th>2.0GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>-10.33977864</td>
<td>-12.03042351</td>
<td>-16.64382347</td>
<td>-16.41081555</td>
</tr>
<tr>
<td>30</td>
<td>-12.21415304</td>
<td>-13.66608256</td>
<td>-17.69955957</td>
<td>-20.20086162</td>
</tr>
<tr>
<td>45</td>
<td>-16.18804273</td>
<td>-18.03166084</td>
<td>-21.26090042</td>
<td>-23.93649929</td>
</tr>
<tr>
<td>60</td>
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<td>-20.93481079</td>
<td>-23.1763286</td>
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<td>-31.4606492</td>
<td>-34.41390817</td>
<td>-32.62361148</td>
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<tr>
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<td>-46.0852088</td>
<td>-43.24873563</td>
<td>-39.88205055</td>
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<tr>
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<td>-33.60975955</td>
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<td>-36.69075381</td>
<td>-35.17920179</td>
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<tr>
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<td>-33.52094259</td>
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<td>-33.16931823</td>
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<td>-47.08384198</td>
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<td>-35.44592088</td>
</tr>
<tr>
<td>300</td>
<td>-17.13859705</td>
<td>-19.63706623</td>
<td>-23.72769369</td>
<td>-23.19283392</td>
</tr>
</tbody>
</table>

Tables have information of antenna performance at different frequencies.

Table 3: The beam width of commercial antenna at different frequencies

<table>
<thead>
<tr>
<th>Frequency</th>
<th>.8GHz</th>
<th>1.0GHz</th>
<th>1.5GHz</th>
<th>2.0GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Width</td>
<td>60 degrees</td>
<td>70 degrees</td>
<td>45 degrees</td>
<td>45 degrees</td>
</tr>
</tbody>
</table>
As we see from the graphs, the commercial antennas are the best for checking the results because they have a broad bandwidth and beam width and they are symmetric at 180 degree. So they can capture most frequencies at different orientations. More graphs are available in the appendix.
6. **Orientation of the antenna:**

The patch antenna is an array of two radiating narrow slots, each of width \( w \) and height \( h \), separated by a distance \( L \). The open edges of the patch antenna behaves like wire dipole antenna. The only difference is that their electric (E) and magnetic (H) fields due to slots are reversed compared to the E and H of the wire dipole.

There is a magnetic current density around the side of the patch radiating into free space. The microstrip antenna can be represented as two radiating slots along the length of the patch with width \( W \) and height \( h \). The slots are separated by the very low impedance of \( L \) which acts like a transformer, and its length is \( \lambda/2 \). Maximum radiation is in the direction perpendicular to the ground plane or normal to the path. Both slots, radiating the same fields with magnetic current density \( M \), have the same magnitude and phase along the slots. The other two slots have the same current density. Their current density on each slot has the same magnitude but opposite direction so the radiated electric and magnetic fields will cancel each other out, so those two slots are called non-radiating slots. When we measure the gain of the designed antenna, both antennas (transmitter and receiver) should be in the position that their electric fields are parallel to have the maximum power transmitted.

7. **Dimensions of the patch antenna**

The dimensions of the antenna, length and width are based on the resonant frequency. Due to the fringing of electric fields; we have to consider other parameters in the calculations. In the other type of antennas, the length should be half the wavelength, which is close in this case and there are other factors added because of dealing with two dielectric constants of air and substrate. The board was available so I had no option of changing the dielectric contestant or other characteristics of board. I calculated the dimension of the patch antenna, and the patch was already made. In general the patch antenna is made of
the two slots separated by the dielectric material. The bottom one is the ground plane and the top one is the metal plane.

Figure 12: The structure of the designed patch antenna

- **Design specifications**

  \( f_r \): The resonant which is the desired frequency the design is based on.

  \( h \): The thickness of patch substance, the height of the dielectric substrate.

  \( \varepsilon_r \): Is the dielectric constant of substrate.

  \( L_{\text{eff}} \): \( \lambda / 2 \) is the effective length. For better performance the length of the patch is less than half wavelength.

  The extension of the actual length \( L \) on each edge due to account for fringing effects

  \( \varepsilon_{\text{eff}} \): The effective relative permittivity or dielectric constant.
L: The physical length of the patch.

\( f_r = 2.105 \text{GHz} = 2.105 \times 10^9 \text{ Hz} \)

\( \mu_0 = 4\pi \times 10^{-7} \text{ N} \cdot \text{A}^{-2} \approx 1.2566370614 \times 10^{-6} \text{ N} \cdot \text{A}^{-2} \)

\( \epsilon_0 = 8.85 \ldots \times 10^{-12} \)

\( h = 0.062 \text{ inch} = 0.0015748 \text{ m} \)

\( = 3.0 \text{ F/m} \)

\( C = 3 \times 10^8 \)

\( W_0 = 1 \text{ mm} \)

- **Design calculations**

**Fringing effect:**

The fringing of the electric fields along the length is due to the finite dimensions of the patch. Since part of the electric field lines are in the air and outside of the substrate, the pure transverse electric (TEM) magnetic mode of transmission would not be possible. The fringing is the effective dielectric constant \( \epsilon_{eff} \) is due to the fringing electric field and should be considered because it affects the resonant frequency. Fringing is a function of dielectric constant and depends on the ratio of the length of the patch over the height of the substrate.

\[
\epsilon_{eff} = \epsilon + \frac{1}{\epsilon} - 1
\]

\[
\epsilon_{eff} = \epsilon + \frac{1}{\epsilon} - 1
\]

\[
\epsilon_{eff} = 2.852736
\]

As we see, the effective dielectric constant is a little less than dielectric constant because some of the electric fields are spread in the air rather than all being concentrated within the
dielectric substrate. As we see the effective dielectric constant is in the range of $1 < \varepsilon_{eff} < 10$ ($r = 3.0$).

As the frequency increases most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like homogeneous line of one dielectric constant of the substrate. And effective dielectric constant approaches the value of the dielectric constant of the substrate.

Because of the fringing effects, electrically the patch of the microstrip patch looks greater than its physical dimensions by value of $\frac{1}{\varepsilon_{eff}}$. This decrease of length depends on the width to height ratio and effective dielectric constant.

$$\frac{1}{\varepsilon_{eff}} = 0.412h$$

$$= 0.412(0.0015748) \left[ \frac{1}{40.775819} \right]$$

$$= 0.7755819\text{mm}$$

Since the electric length has been increased, so the effective length of the patch should be:

$$L_{eff} = L + 2 = 42.17067409\text{mm}$$

If we didn’t have the fringing effect, the length would be $\frac{\lambda}{2}$.

$$L = L_{eff} - 2$$

$$L = 42.17067409 - 2(0.7755819)$$

$$L = 40.61951\text{mm}$$
The width $W$ of the patch controls the input impedance and also increase the bandwidth. By increasing the width, the impedance can be reduced. Values of $\mu_0 = 4\pi \times 10^{-7} \text{ N} \cdot \text{A}^{-2} \approx 1.2566370614\ldots \times 10^{-6} \text{ N} \cdot \text{A}^{-2}$, $\varepsilon_0 = 8.85\ldots \times 10^{-12}$ are the free space characteristics.

\[
W = \frac{\lambda}{2}
\]

$W = 50.36471 \text{mm}$

$\lambda = \frac{c}{f}$

$\lambda = 0.08437977 \text{m}$

8. **Feed in method**

This type of feed in requires the direct connection of the smaller width conducting strip to the edge of the microstrip patch. The benefit of this type of connection is that the feed can be fixed on the same substrate to provide a planar configuration, and this type of feeding is easy to fabricate, easy to design and impedance matching. Also it would be the best choice that fit with my board without reshaping the board.
9. **Impedance matching**

Since the impedance of the feed in and the patch are not the same, there will be a lot of return losses. To decrease the power reflected, I used the method of impedance matching.

The inset cutting in the patch is essential for impedance matching of the feed line to the patch. In this experiment, I made a short circuit by cutting a narrow strip of 1mm width and half-length long close to feed in. Then I changed the amount of that short circuit by putting a slide of copper tape on cuts at the top of the antenna patch where the cuts were and then keep trimming toward the center till I get close to the desired frequency. By doing this I will increase the impedance of the patch in the middle so the impedance of the feed in won’t be larger than the impedance of the patch in the middle. $Y_0$ is the amount of the length of the trimmed copper slide. When $Y_0$ is zero which is the edge of the slot, voltage is maximum and current is minimum so the impedance is maximum. The minimum value of the impedance is at the center of the patch where $Y_0 = L/2$. At that point the voltage is zero and the current is maximum. The resonant input impedance decreases as the inset feed moves from edges toward the center of the patch.
10. Analyzing the results for 2.105GHz

I checked the functionality of our design antenna by measuring the return losses $S_{11}$ and transmission power $S_{21}$ by the commercial antennas.

- Return losses in the antenna for the frequency of 2.105GHz was about -25dB, which is very low. So it means that most of the power is being transmitted and not much gets reflected back to the antenna. Less loss is when $Y_0$ is adjusted to 17mm.

*Figure 13: The experiment set up of measuring the performance of designed patch antenna using commercial antenna*

*Figure 14: $S_{11}$ for $f=2.105GHz$ when $Y_0=17mm$*
10.1 Gains of the designed antenna for different angles

Table 4: $S_{21}$ values (gain) for microstrip path rotation around the commercial antenna

<table>
<thead>
<tr>
<th>Angle</th>
<th>Gain (dB)</th>
<th>Angle</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-16.28073058</td>
<td>180</td>
<td>-40.44997899</td>
</tr>
<tr>
<td>15</td>
<td>-17.89214097</td>
<td>195</td>
<td>-44.52429886</td>
</tr>
<tr>
<td>30</td>
<td>-19.29793127</td>
<td>210</td>
<td>-38.02957486</td>
</tr>
<tr>
<td>45</td>
<td>-21.27857448</td>
<td>225</td>
<td>-42.92626802</td>
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<tr>
<td>55</td>
<td>-25.66198108</td>
<td>240</td>
<td>-33.62181621</td>
</tr>
<tr>
<td>60</td>
<td>-27.39451594</td>
<td>255</td>
<td>-31.33233539</td>
</tr>
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<td>-32.22522327</td>
<td>270</td>
<td>-32.31772858</td>
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<tr>
<td>165</td>
<td>-41.53829272</td>
<td>345</td>
<td>-17.01356375</td>
</tr>
</tbody>
</table>

10.2 The Beam Width of the designed antenna

Figure 15: The polarization of designed patch antenna for $f=2.105\text{GHz}$
11. **Distinguish cellphone frequency**

In this case I had a cellphone in front of the commercial antenna and as soon as I started sending the signal by calling, the peak appeared in the frequency of the commercial antenna band. As we see, the commercial antenna was a good choice since it has such a broad band and the peak shows very clearly.

*Figure 16: the peak for cellphone frequency of 842MHz*
12. The dimensions of the patch antenna for 
f= 842MHz

\( f_r = 842\text{MHz} = 842\times10^6 \text{Hz (Cellphone peak frequency)} \)

\( C= 3\times10^8 \)

The width \( W \) of the patch controls the input impedance and also increase the bandwidth. By increasing the width, the impedance can be reduced

\[
W = \frac{125.91212}{((3+1)/2) + ((3-1)/2) (1+12(0.0015748/0.12591212)) ^ {-0.5}} = 0.412 \text{h}
\]

\[
= \frac{0.412(0.0015748)}{(235.2379227/215.9751027) (6.488176\times10^{-4})} = 7.066856435\times10^{-4} = 0.7066856 \text{mm}
\]

\( L_{\text{eff}} = L + 2 = 103.9835325 \text{mm} \)

\( \lambda = 0.2080618 \)

\( L = L_{\text{eff}} - 2 = 103.9835325 - 2(0.7066856) = 102.5701613 \text{mm} \)

\( Y_0=102.5701613 / 2=51.25 \text{mm} \)
13. Adjustments of feed in method:

As we see from the below graphs, there is a lot of reflection due to the 90 degree connection, so I tried to find a good angle for the connection. The second graph is when I trimmed the connection angle from 90 degree edges to 45 degree. As we see there is a lot less reflection in the 45 degree connection than in the 90 degree, so I chose to adjust the feed in connections to about angle of 45 degree angle.
Graph 19: The losses of 45 degree feed in connection

14. Results

Figure 20: The measurement set up of checking designed patch antenna for f= 842MHz by an iPhone
Figure 21: Peak frequency of 842MHz of designed patch frequency in commercial antenna

Figure 22: S11 for Y0= 51mm
As we see from figure I started by not putting the cover tape at the top of the antenna and that is the case when \( Y_0 = 51 \text{mm} \) and the losses \( S_{11} \) is big around -5dB for frequency of 842MHz and by laying down the tape toward the edge of the patch I got to the value of \( Y_0 = 15 \text{mm} \) where I have least amount of losses which is around -50dB for frequency of 842MHz which is very low. After I kept putting more copper tape, for \( Y_0 = 10 \) the losses started increasing so I got to the conclusion that \( y_0 = 15 \text{mm} \) was the best experimental value for this frequency. As we see the antenna met the requirement performance and the only issue is the size of the antenna. The next goal for the future adjustments is to make a more compact design which would fit in the cellphone and also to extend this concept to a multiband design. If I could use a dielectric that has a higher dielectric constant and smaller value for \( h \), then it would reduce the required size for the given frequency.
• **Equipment & Costs:**

This is the list of equipment used for the experiments.

1. N9923A RF Vector Network analyzer
2. P/N 1250-3605 Load 25 dB max Calibration Kit (T shape)
3. 2 TDI 800-2500 LC-8.5 LPDA Antennas
4. Roller
5. Adapter
6. 2 Cables of Type CNM-NM-36-M02/X
7. LPDA Commercial Antenna (TDI800~2500MHz, Gain:8.5dBi)
8. 2 SCA52086-36 Cables
9. Copper Tapes (50 )
10. 85033F, 3.5mm Calibration Kit
11. Kits for cutting copper tapes
12. SM4203 Adapter
13. SMA Female 50 Load

The lab, where I conducted my project had all the equipment, so the cost was $0.00.

• **Safety**

There is no safety hazard is required for this experiment.
• References:

(Breed, 2009)

(Balanis, 2005)

warehouse.cec.wustl.edu\home\links\sn10\winprofile\Desktop\cellphone antenna article.htm

http://highfrequencyelectronics.com/Archives/Mar09/HFE0309_Tutorial.pdf

http://classes.engineering.wustl.edu/ese331/331Project10.pdf