SINGLE SLOT DUAL BAND MICROSTRIP ANTENNA FOR WIMAX APPLICATION

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Approval of the Graduate School of Natural and Applied Sciences, Atılım University.

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ABSTRACT

Single Slot Dual Band Microstrip Antenna for Wimax Application

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In the present-time communication, antennas cover a wide range of applications in different areas, such as mobile communication, satellite navigation, internet services, automobiles and radars. Especially they are applied to microstrip antennas, because of its characteristics like low profile, lightweight and low power handling capacity. However, gain and bandwidth are sometimes low and not sufficient in most of applications. Modification of shape and using special materials could be useful to solve such backlashes of this type of antennas. In case of dual polarization and dual band application, microstrip antennas have a good reputation. This thesis presents a way of getting dual band antennas for Wimax application IEEE 802.16e-2005, where the antenna is mainly intended for reception of Wimax base station signal. The design parameters of the antenna have been calculated using the transmission line model, and HFSS electromagnetic software has been used for the simulation process, which is based on Finite Element Method (FEM). In this work, the dual band antenna is designed by a slot being added to the top of the patch. In the beginning, the idea of dual feed antenna enjoyed a considerable attention, but the problem of matching makes the simulation and realization of this antenna a little hard. In summary, the antenna has been simulated and fabricated.

ÖZ

Wimax Uygulaması için Çift Bantlı Tek Slotlu Mikroşerit Yamal' Anten

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Günümüzde iletişimde, mobil iletişim, uydu navigasyonu, internethizmetleri,otomobiller ve radarlargibi farklı alanlarda antenler birçok uygulamada kullanılmaktadır. özellikle de mikroşerit antenler kullanılmaktadır çünkü bu tür antenler düşük profilli, hafif, ve düşük kuvvetle çalışabilme özelliklerine sahiptirler. Bu tür antenlerin dezavantajlarını ortadan kaldırmak için özel malzemelerin kullanılması ve şeklinde modifikasyona gidilmesi sağlanabilir. Çift polarizasyon ve çift bant uygulaması durumunda, mikro şerit antenler iyi bir itibara sahiptirler. Bu tez, antenin temel olarak Wimax baz istasyonu sinyali için kullanılmasının amaçlandığı Wimax uygulaması IEEE 802.16e-2005 çift bantlı antenlerin sağlamasına yönelik bir tasarımı sunmaktadır. Antenin tasarım parametreleri iletim hattı modeli kullanılarak hesaplanmıştır ve HFSS elektromanyetik yazılım Sonlu Elemanlar Modeline (FEM) dayalı olan simülasyon süreci için kullanılmıştır. Bu çalışmadaçift bant anten yamanın üst kısmına eklenen bir slot ile tasarlanmıştır. Başlangıçta çift beslemeli bir anten fikrine çok fazla ilgili duyulsa da eşleştirme sorunu bu antenin simülasyonunun yapılmasını ve antenin gerçekleştirilmesini zorlaştırmaktadır. Özet olarak söz konusu anten simüle edilmiş ve üretilmiştir.

To My Grandmother Soul, Allah Mercy be up on you,

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All praise is for the almighty Allah for blessing, protecting and guiding me throughout this thesis. Without the faith in almighty Allah, I could not be able to finish and success in my work. I would like to express great thanks, deep gratitude and I have pleasure to do that, to all people who supported me throughout my work, and they have important contribution in making this thesis possible.

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Table of Contents

PLAGIARISM iii
ABSTRACT iv
ÖZ v
DEDICATION vi
ACKNOWLEDGMENT..vii
TABLE OF CONTENTS viii
LIST OF TABLES xi
LIST OF FIGURES xii
LIST OF ABBREVIATIONS xv

1. INTRODUCTION 1
   1.1 Wireless technology 1
2. MICROSTRIP ANTENNA 3
   2.1 Microstrip antenna history and definition 3
   2.2 Construction and Geometry 3
   2.3 Microstrip antenna types 4
   2.4 Feeding methods..5
   2.4.1 Microstrip feed 5
   2.4.2 Coaxial probe feed..5

2.4.3 Aperture coupling 5

2.4.4 Proximity coupling 5

2.5 MSA analysis (Transmission Line Model) 6

2.5.1 Transmission Line Model 6

2.5.2 Width 10

2.5.3 Length 10

2.5.4 Ground planes.. 10

2.6 Bandwidth 11

2.7 Radiation pattern 12

2.8 Gain 14

2.9 Directivity 15

2.10 Return Loss 15

2.11 The Voltage Standing Wave Ratio 16

2.12 Wimax band 17

2.13 Examples of Microstrip Antennas for Wimax Technology 18

2.13.1 L-slot Rectangular Microstrip Patch Antenna for WiMAX and WLAN Applications 18

2.13.2 Design of Double L-Slot Microstrip Patch Antenna for WiMAX and WLAN Application 19

3. ANTENNA DESIGN AND SIMULATION 21

3.1 INTRODUCTION 21

3.2 Antenna Design 22

3.3 Design Specifications 23

3.4 Design calculations for Single Slot Antenna 25

3.5 Measurements and Results 26

3.5.1 Return Loss 27

3.5.2 Voltage Standing Wave Ratio (VSWR) 27
3.5.3 Radiation Pattern 28
3.5.4 Gain 29
3.5.5 Current Distribution on the Antenna 30
3.6 The Effect of Changing Slot Dimension 31
3.7 The Effect of Changing Slot Position 32
3.8 Thesis Work Load 33
3.9 Dual Band Double T Slot Antenna 33
3.9.1 Antenna Return Loss 34
3.9.2 Voltage Standing Wave Ratio VSWR 35
3.9.3 Radiation Pattern in 2D 35
3.9.4 Radiation Pattern in 3D 36
3.9.5 Antenna gain 37

4. ANTENNA FABRICATION AND MEASUREMENT 38
4.1 Introduction 38
4.2 Fabrication Machine 38
4.3 Antenna Fabrication Process 39
4.3.1 Double T-Slot Microstrip Antenna 39
4.3.2 Single Slot Microstrip Antenna 41
4.4 Comparison between Simulated Results and Fabricated Results 43
5. CONCLUSION 45
5.1 Conclusion 45
REFERENCES 47

LIST OF TABLES

TABLE

1. Table 2.1 Wimax current licensed and unlicensed bands 17

2. Table 3.1 Wimax current and future licensed and un-licensed bands 23

3. Table 3.2 Effect of changing slot dimension 31

4. Table 3.3 Effect of changing slot position 32

5. Table 3.4 Effect of changing the feed line width... 32

6. Table 4.1 Comparison between Simulated results and fabricated results 43

LIST OF FIGURES

FIGURES

2.1 Microstrip antenna, (a) top view and (b) side view 4

2.2 Effect of relative permittivity on S_{11} for (a) ε_r= 6.15 Rogers RO 3006 and (b) ε_r = 10.2 Rogers RO 3010 4

2.3 Different MSA shapes 5

2.4 Microstrip antenna Feeding methods

(a) Microstrip line feed (b) Probe feed (c) Aperture-coupled feed (d) Proximity-coupled feed 6

2.5 Equivalent circuits for typical feeds

(a) Simple transmission line model, (b) transmission line model with mutual coupling, (c) Probe, (d) Aperture-coupled and (e) Proximity-coupled 7

2.6 Microstrip line feed model 7

2.7 The Electric field lines in Transmission Line 8

2.8 TM dominant modes in microstrip antenna 8

2.9 The Electric fieldlines on both edges of microstrip antenna 9

2.10 (a) The electric current for the patch, (b) The magnetic current for the patch mode 12

2.11 Radiation pattern (E- and H-plane) 14

2.12 Geometry of the first example Proposed Antenna 18

2.13 Return Loss versus Frequency 18

2.14 Dimensions of the second example proposed antenna 19

2.15 Return Loss versus Frequency 20

3.1 The proposed single slot microstrip patch antenna for Wimax application in HFSS environment, (a) in 3D, (b) in 2D 23

3.2 The TX-line tool calculation 24

3.3 Single slot dual band microstrip antenna dimensions 26

3.4 S_{11} parameters they are -13and -17db at 2.5 GHz and 5 GHz respectively 27

3.5 VSWR values are 1.6038 at 2.5 GHz and 1.3421 at 5 GHz 27

3.6 antenna radiation pattern at (a) 2.5 and (b) 5 GHz at different values of Phi 0,45 and 90 deg 28

3.7 antenna radiation pattern 3D 29

3.8 Antenna gain 3.3 dBi 30

3.9 Current distribution on the antenna as (a) magnitude 30

(b) Vector 31

3.10 Dual T slot antenna dimensions 33

3.11 Dual T slot antenna in 3D 34

3.12 Double T slot antenna return loss 34

3.13 Double T slot antenna VSWR 35

3.14 Double T slot antenna radiation pattern in 2D at (a) 2.5 GHz 35

(b) 5 GHz 36

3.15 Double T slot antenna radiation pattern in 3D at 2.5 GHz 36

3.16 Double T slot antenna gain 6.92 dBi 37

4.1 LPKF ProtoMat C100/HF PCB Machine 39

4.2 Antenna during fabrication 40

4.3 Antenna after fabrication 40

4.4 Vector analyzer S_{11} plot for Dual T slot antenna 41

4.5 Fabricated single slot microstrip antenna 42

4.6 Antenna connected to Vector analyzer for measurement in laboratory 42

4.7 Vector analyzer S_{11} plot for Single slot antenna 43

LIST OF ABBREVIATIONS

2^{nd} G	second generation
EDGE	Enhanced Data Rate for Global Evolution
IP	Internet Protocol
OFDM	Orthogonal Frequency Division Multiple Access Technique
WiMAX	Wireless Interoperability for Microwave Access
VOIP	Voice over IP
DSL	Digital Subscriber Line
HFSS	High Frequency Simulator Structure
MSA	Microstrip Antenna
MSPA	Microstrip Patch Antenna
TM	Transfer Magnetic
TEM	Transfer-Electric-Magnetic
BW	Bandwidth
f_C	Center Frequency
f_H	Upper Frequency
f_L	Lower Frequency
$\boldsymbol{E}$	the electric field
$\hat{n}$	The outward pointing unit-normal vector

dB	decibel
dBi	decibel isotropic
VSWR	Voltage Standing Wave Ratio
P_{ref}	Reverse power
P_{fwd}	Forward power
Wi-Fi	Wireless Fidelity
OC-x	Optical Carrier Levels
FIT	Finite Integration Technique
FEM	Finite Element Method
RF	Radio Frequency
LHM	Left Handed Material
PCB	Printed Circuit Board
IEEE	Institute of Electrical and Electronics Engineers

CHAPTER 1

INTRODUCTION

1.1 Wireless Technology

The wireless technology has been developed rapidly in the last twenty years. With respect to the history of mobile communication generations, the First Generation (1st G) that employed it was in the beginning of 80s when one could make a voice call. In the Second Generation (2nd G), the demand for services was more than just calling. The text messaging had been introduced in order to give the customer more services and facilities .Apart from 1G, it uses digital signals, such as EDGE (Enhanced Data Rate for Global Evolution), which is assigned to provide good internet speed and bandwidth. After that series of development were done, new services and applications appeared which were also considered as the backbone of the progress in the area. The IP devices make the technologies mentioned above too weak to tackle the new challenges, so the Third Generation (3rd G) had acquired the internet service with high speed. At the present time, the Fourth Generation (4th G) is the latest technology in this field, which is the use of OFDM (Orthogonal Frequency Division Multiple Access Technique), so that this division technique gives 4th G applications a higher bandwidth. WiMAX (Wireless Interoperability for Microwave Access) is one of the latest wireless technologies. This technology can be used in numerous number of applications: the broadband services such as Voice over IP (VOIP) is one of these applications. WiMAX 802.16 can be a hot topic these days, it can solve the problem of unsatisfied infrastructure for wired services in remote areas or rural areas where large coverage is needed, and there is less population than big cities.

The WiMAX is defined in two categories: fixed wireless and mobile. The fixed version, known as 802.16d-2004, was designed to be a replacement or supplement for broadband cable access or Digital Subscriber Line (DSL). A recent version, the fixed wireless application, can be supported by 802.16e-200; the roaming through the base station is also allowed. Thus, these two standards are generally known as *fixed* WiMAX and *mobile* WiMAX.

The thesis goal is to design dual band micro-strip patch antenna to operate in two wimax bands, where some countries use 2.5 GHz and some use 5 GHz. The proposed antenna has been designed as two T-shape slots with quarter wavelength matching technique. Antenna simulation is done by HFSS software. Due to some obstacles, another antenna has been designed and fabricated, which is named as “Single Slot Dual Band Microstrip Antenna”.

This thesis includes five chapters, starting from basic information about wireless technology in Chapter One. Chapter Two covers microstrip patch antenna structure, design and behavior. Simulation of the proposed antenna has been introduced in Chapter Three. Chapter Four is written in order to give an ideal result for fabricated antenna and compare those results with simulated one from the previous chapter. Chapter Five is about discussing how the thesis results in such a design in practice, and deals with software data.

CHAPTER 2

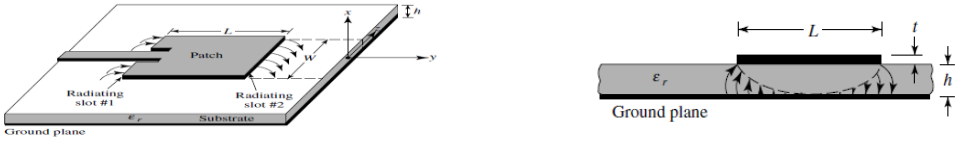
MICROSTRIP ANTENNA

2.1 A History and Definition of Microstrip Antenna

In the early 1970s, microstrip antennas got more interest than before; however, it had first appeared in the 1950s. Nowadays, they are widely used for government and commercial applications. The availability of good substrate with low loss tangent and attractive thermal and mechanical properties make these antennas develop rapidly. The low profile (small occupation space) is the most important parameter in such antennas. For example, in mobile and other wireless communications, there is a space for a couple of millimeters. Furthermore, the ease of its fabrication and its low cost and capability of dual and triple band operations make microstrip antenna very important. These points are considered as advantages of microstrip antennas. On the other hand, narrow bandwidth and spurious feed radiation, low efficiency, low power and very narrow frequency bandwidth are the disadvantages of microstrip antenna [1].

2.2 Construction and Geometry

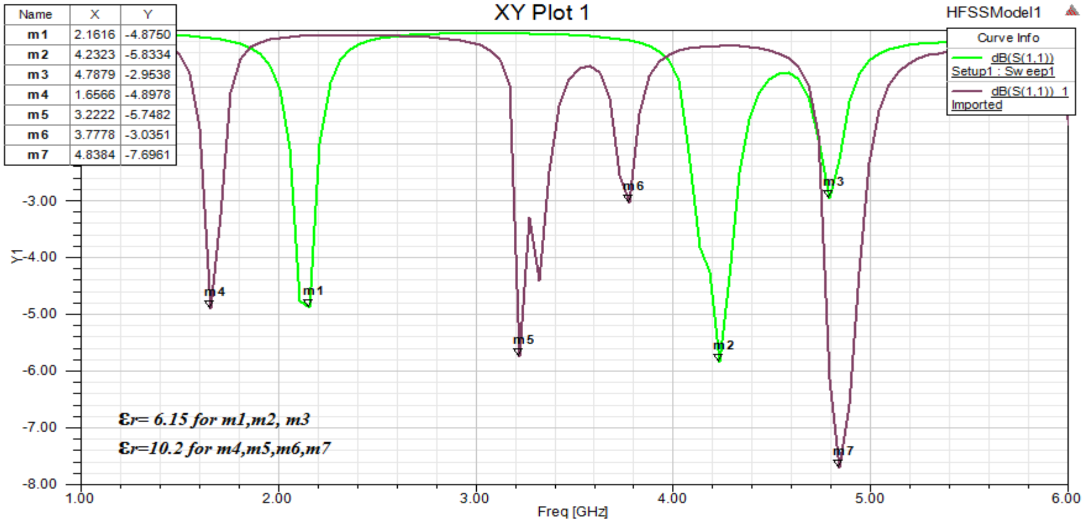
Microstrip antennas are mostly thin metallic patches of diverse shapes etched on dielectric substrates of height *h* figure 2.1 .The thickness of thin radiating patch ($t << \lambda_0$, where λ_0 is the free-space wavelength), the metallic strip (patch) occupied a small portion of a wavelength ($h << \lambda_0$, usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$) above a ground plane. The microstrip antennas (MSA's) are suitable in the GHz range ($f > 0.5$ GHz). For frequencies lower than this, the problem of large dimensions will appear. The substrate with height $\boldsymbol{h}$ comes with various relative permittivity $\boldsymbol{\varepsilon_r}$ and the range is ($2.2 \leq \varepsilon_r \leq 12$). From Figure 2.2, it can be said that when the value ε_r increased, the resonant frequency decreased. The substrates that are most desirable for good antenna performance are thick ones, whose dielectric constant is in the lower end of the range because they provide better efficiency [2].



(a) Top view

(b) Side view

Figure 2.1. Microstrip antenna, (a) top view (b) side view



Name	X	Y
m1	2.1616	-4.8750
m2	4.2323	-5.8334
m3	4.7879	-2.9538
m4	1.6566	-4.8978
m5	3.2222	-5.7482
m6	3.7778	-3.0351
m7	4.8384	-7.6961

Figure 2.2. Effect of relative permittivity on S_{11} for (a) ε_r= 6.15 Rogers RO 3006 and (b) ε_r = 10.2 Rogers RO 3010

2.3 Microstrip Antenna Types

The MSA came in many different shapes: rectangular, square, circular, triangular, etc. The rectangular MSA is mainly considered as patch antenna. However, the types like square, rectangular, dipole (strip), and circular are the most common ones. Where the ease of analysis, fabrication and good performance characteristics are considered, these types are widely used. Figure 2.3 shows these types.

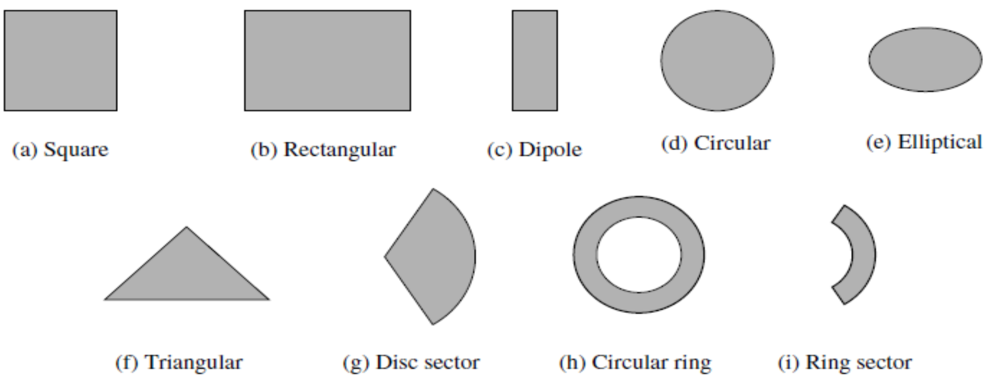


Figure 2.3. Different MSA shapes.

2.4 Feeding Methods

There are a lot of feeding methods that can be used for microstrip antenna. Four methods will be described, which are considered as the most famous methods. Their advantages and disadvantages are listed below. Figure 2.4 shows these feeding methods.

2.4.1 Microstrip Feed

In this technique, it is easy to match the attachment position by calibrating. The fabrication is not hard, but when the substrate thickness increases, surface waves and fake feed radiation increase as well. Figure 2.4 (a)

2.4.2 Coaxial Probe Feed

This type is easy to fabricate and has low spurious radiation, it is difficult to model accurately, and it has narrow bandwidth of impedance matching. Figure 2.4 (b).

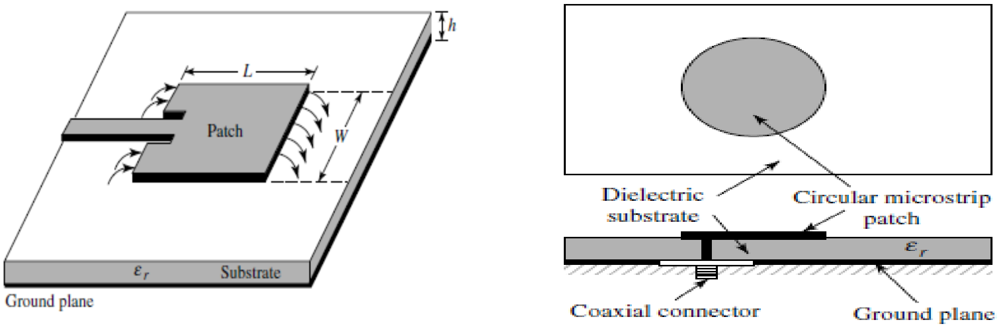
2.4.3 Aperture Coupling (no contact)

Both sides of ground plane are occupied; one with feed line and the other one with radiating patch. Coupling aperture is in the ground plane and has low fake radiation. It is hard to get good matching, and it has a narrower bandwidth. Figure 2.4 (c).

2.4.4 Proximity Coupling (no contact)

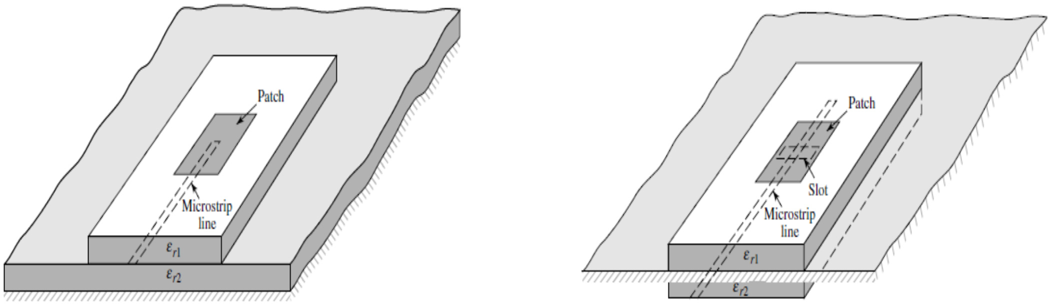
This type is the opposite of the aperture coupling type, where microstrip feed line and radiating patch are on the same side of the ground plane. It has large bandwidth, and it is simple to fabricate. Figure 2.4 (d).

In this thesis, microstrip feed model has been used. That is why only one analysis method is given, called the Transmission Line Model.



(a) Microstrip line feed

(b) Probe feed



(c) Aperture-coupled feed

(d) Proximity-coupled feed

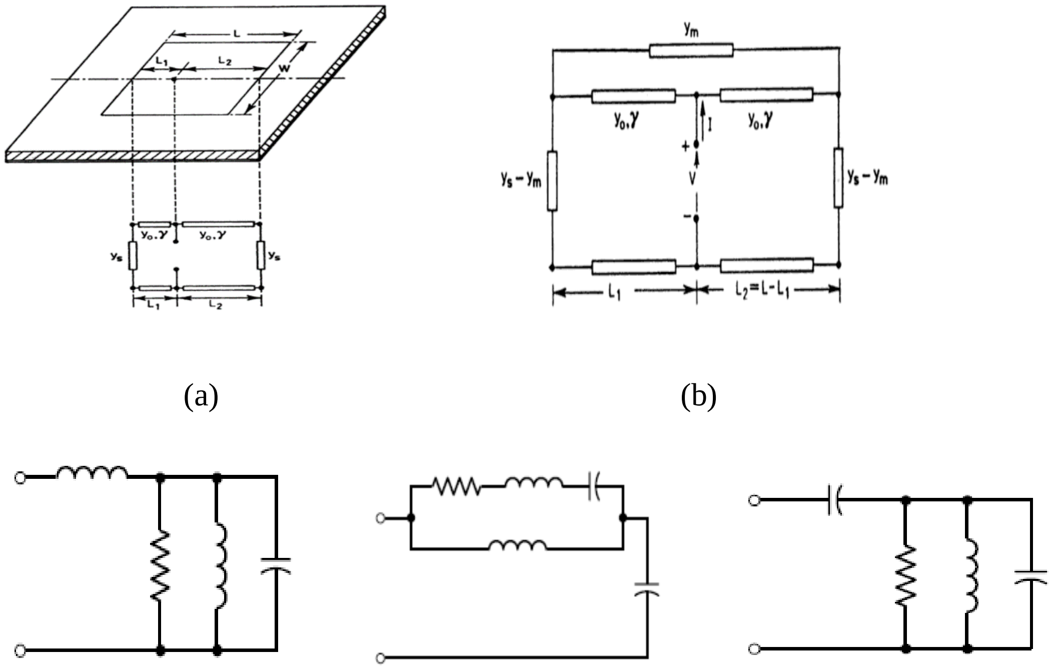
Figure 2.4. Microstrip antenna Feeding methods

2.5 MSA Analysis

There are many methods of MSA analysis. However, four famous methods are used widely. Their names are transmission line model, cavity model, generalized cavity model, and multiport network model. As it is mentioned in section 2.4, only the transmission line model will be used. Because of the square and rectangular microstrip, patch antennas are simple in shape and structure, which means they are easy to be analyzed.

2.5.1 Transmission Line Model

Transmission line method is the easiest method compared to the rest of the methods. This method represents the rectangular microstrip antenna as an array of two radiating slots separated by a low impedance transmission line of certain length as shown in Figure 2.5 (a) and (b).



(a) (b)

(c) (d) (e)

Figure 2.5. Equivalent circuits for typical feeds (a) Simple transmission line model and (b) Transmission line model with mutual coupling, (c) Probe, (d) Aperture-coupled, (e) Proximity-coupled

In Figure 2.6, the MSA is shown with microstrip feed line (Transmission Line Model).

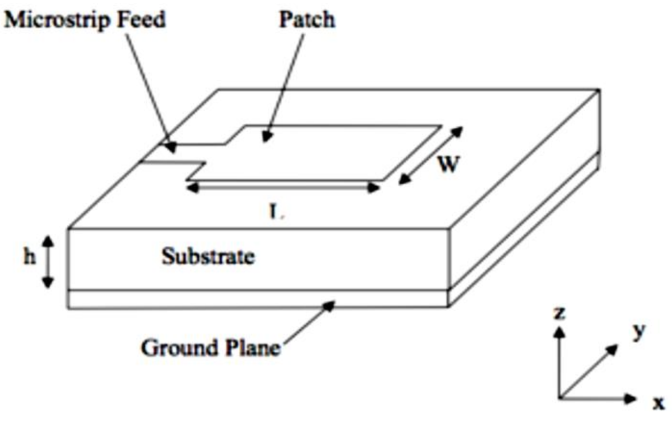


Figure 2.6. Microstrip line feed model

In the propagation modes for any antenna, the MSPA mode is TM, which is considered as the dominant mode, and to work on TM mode the patch length must be less than $\frac{\lambda}{2}$ where:

$$\lambda = \frac{\lambda_0}{\varepsilon_{reff}} \qquad 2.1$$

By looking to the distribution of electric field lines in a transmission line mode, as shown in Figure 2.7, which has thickness of *t*, it is led to the fact that transmission line cannot support transfer-electric-magnetic TEM, where TEM refers to direct transfer of electric field lines to the dielectric. As seen in the Figure 2.7, this cannot be approved because some of the electric field lines are going into the air before entering the dielectric substrate.

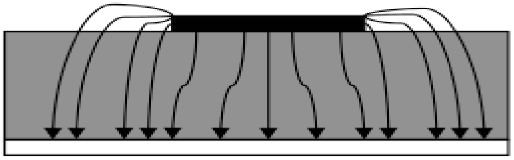
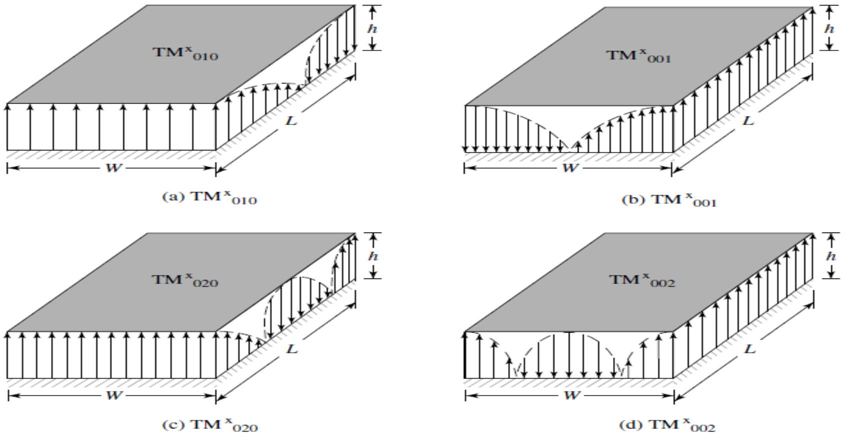


Figure 2.7. Electric field lines in a transmission line.

The dominant modes $TM_{a,b}$ are shown in Figure 2.8.



(a) TM^{x}_{010} (b) TM^{x}_{001}

(c) TM^{x}_{020} (d) TM^{x}_{002}

Figure 2.8. TM dominant modes in microstrip antenna

Related to this problem of transferring fieldlines into air before it enters the dielectric, relative permittivity $\varepsilon_r$will be replaced with ε_{reff}, which is somewhat less than ε_r and it is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left[1 + 12\,\frac{h}{W}\right]^{-\frac{1}{2}} \quad , \quad \frac{w}{h} > 1 \qquad 2.2$$

where ε_r, h, w, are the substrate dielectric constant, the dielectric substrate height and the patch width respectively.

In the design, the length of the patch will be extended on both sides due to the move of electric fieldlines through the air as illustrated in Figure 2.9.

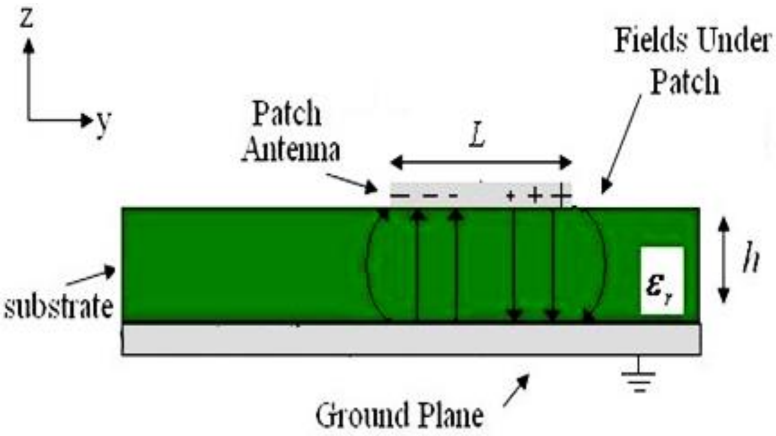


Figure 2.9. The Electric Fieldlines on both edges of microstrip antenna.

According to Figure 2.5 (a), two slots represent the patch antenna (at each end one), where length L separates them. Both ends are open circuited, voltage is maximum on the width way and the current is at minimum because of open ends. Again, according to Figure 2.9, the electric fieldlines on both edges of the width are in opposite ways for vertical polarization (E_v). Actually, they eliminate each other due to the out-of-phase condition. On the other hand, the horizontal polarization (E_h) are in phase. This results in maximum radiated field by merging the resulting fields. It seems logical to say that the two slots of Microstrip Patch Antenna (MSPA) are responsible for antenna radiation.

ΔL is calculated by the following formula:

$$\Delta L= 0.412.h.\frac{(\varepsilon_{reff}+0.3).\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258).\left(\frac{W}{h}+0.8\right)} \qquad 2.3$$

As the width is too extended, calculating the width extension is not worthy, because of the cancelation between the electric fields. Now, antenna length, width and ground planes will be described.

2.5.2 Width

The following equation is used to calculate the width w:

$$\mathrm{w} = \frac{c}{2.f_c.\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad 2.4$$

where, c is the speed of light, f_c and ε_r are respectably the resonance frequency and the dielectric constant of the substrate.

2.5.3 Length

The effective length L_{eff} can be calculated by the following equation:

$$L_{eff} = \frac{c}{2.f_c.\sqrt{\varepsilon_{reff}}} \qquad 2.5$$

then the actual length of the patch is given by the following equation:

$$L=L_{eff} - 2.\Delta L \qquad 2.6$$

2.5.4 Ground Planes

Essentially, the transmission line model is applicable to an infinite ground plane only. However, it has been shown that a finite ground plane can also be used, if the ground plane is six times larger than the height of the dielectric substrate, plus the used length or width. The ground plane width and length can now be calculated respectively as:

$$w_g = 6.h + w \tag{2.7}$$

$$L_g = 6.h + L \tag{2.8}$$

2.6 Bandwidth

When the antenna performance works well in some frequency range (return loss is small), this range of frequency around resonance frequency is called antenna bandwidth. While the concept bandwidth is used for other useful definitions such as polarization, directivity and effective bandwidths, it is mostly used as impedance bandwidth. As it is known by measuring VSWR of the antenna over the required range of frequencies, it can be useful to estimate whether the antenna is efficient or not. It is by comparing this issue with the return loss to find the antenna bandwidth. Calculation of the desired bandwidth can be made by the following equation:

$$BW_{broadband} = \frac{f_H}{f_L} \tag{2.9}$$

$$BW_{narrowband}(\%) = \left(\frac{f_H - f_L}{f_C}\right).100 \tag{2.10}$$

where f_H, f_L and f_C are the Upper Frequency, the Lower Frequency and the Center Frequency respectively, which is defined as the arithmetic average of the upper and lower frequencies.

It can be said that an antenna is broadband when $BW_{broadband}$ is greater than two.

2.7 Radiation Pattern

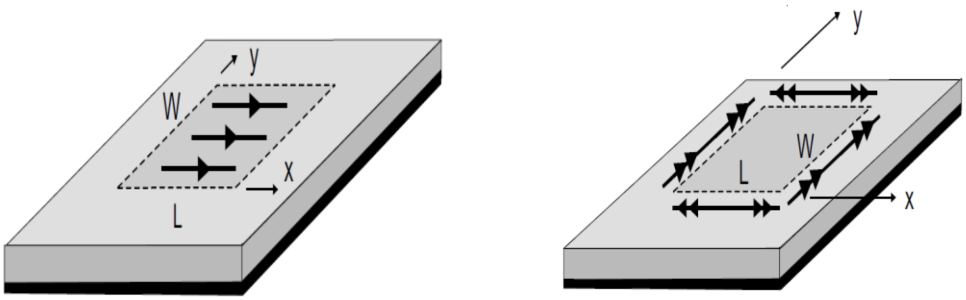
Generally, there are two ways to extract the radiation pattern of MSA, the electric current model or a magnetic current model. To begin with, the electric current model, the equation 2.12 will be used directly to find the far-field radiation pattern. The electric current for the patch (1, 0) is shown in the Figure 2.10 (a). If the substrate is replaced with air in order to calculate the radiation pattern. The pattern may be evaluated directly based on image theory. The reciprocity method may be used to determine the far-field pattern when the substrate is considered. At the second one, the magnetic current model, the equivalence principle is used to replace the patch by a magnetic surface current that flows on the perimeter of the patch. The magnetic surface current is given by:

$$M_s = -\hat{n} \times E \ , \qquad 2.11$$

$$J_{sx}(x) = A_{10}\left(\frac{\pi/L}{j\omega\mu_0\mu_r}\right) sin\left(\frac{\pi x}{L}\right) \qquad 2.12$$

where, E is the electric field of the cavity mode at the edge of the patch and $\hat{n}$ is the outward pointing unit-normal vector at the patch boundary.

Figure 2.10 (b) shows the magnetic current for the patch mode (1, 0). Again, the far field pattern might be evaluated by image theory or reciprocity, whether the substrate is considered or not.



(a) (b)

Figure 2.10. (a) The electric current for the patch, (b) the magnetic current for the patch mode

According to the electric current model, accounting for the infinite substrate, the far-field pattern is given by:

$$E_i(r,\theta,\phi)=E_i^h(r,\theta,\phi)\left(\frac{\pi WL}{2}\right)\left[\frac{\sin\left(\frac{K_y\ W}{2}\right)}{\frac{K_y\ W}{2}}\right]\left[\frac{\cos\left(\frac{K_x\ L}{2}\right)}{\left(\frac{\pi}{2}\right)^2-\left(\frac{K_x L}{2}\right)^2}\right] \qquad 2.13$$

where,

$K_x = K_0 \sin\theta \cos\phi$

$K_y = K_0 \sin\theta \sin\phi$

In addition, E_i^h is the far-field pattern of an infinitesimal (Hertzian) unit-amplitude *x*-directed electric dipole at the center of the patch. This pattern is given by:

$$E_\theta^h(r,\theta,\phi) = E_0 \cos\phi\, G(\theta) \qquad 2.14$$

$$E_\phi^h(r,\theta,\phi) = -E_0 \sin\phi\, F(\theta) \qquad 2.15$$

where,

$$E_0 = \left(\frac{-J\omega\mu_0}{4\pi r}\right)e^{-jk_0 r} \qquad 2.16$$

$$F(\theta) = \frac{2\tan(k_0 hN(\theta))}{\tan(k_0 hN(\theta))-j\frac{N(\theta)}{\mu_r}\sec\theta} \qquad 2.17$$

$$G(\theta) = \frac{2\tan(k_0 hN(\theta))\cos\theta}{\tan(k_0 hN(\theta))-j\frac{\varepsilon_r}{N(\theta)}\cos\theta} \qquad 2.18$$

and,

$$N(\theta) = \sqrt{n_1^2 - \sin^2\theta} \qquad 2.19$$

$$n_1 = \sqrt{\varepsilon_r \mu_r} \qquad 2.20$$

An example of radiation pattern (E- and H-plane) for rectangular patch is given here. An infinite substrate of permittivity ε_r = 2.2 and thickness h / λ_0 = 0.02 are shown in Figure 2.11.

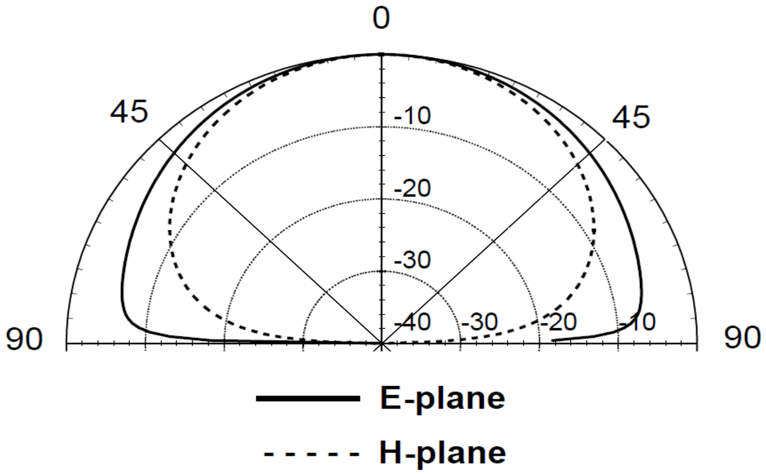


Figure 2.11. Radiation pattern (E- and H-plane)

2.8 Gain

Antenna gain is known as the ratio of maximum radiation intensity at the peak of main beam to the radiation intensity in the same direction related to isotropic radiator with the same input power. The hypothetical antenna is considered with gain equal to unity. The gain function is written as:

$$G(\theta, \phi) = \frac{P(\theta,\phi)}{\frac{W_t}{4\pi}} \qquad 2.21$$

where P (θ, ϕ) is the power radiated per unit solid angle in θ, ϕ direction and W_t is the total radiated power.

One of the disadvantages of microstrip antenna is poor gain, which is related to poor radiation efficiency; it is possible to improve the microstrip antenna gain by modification on antenna shape.

2.9 Directivity

The ratio of normalized power density at the peak of the main beam to the average power density is called the directivity. The directivity of the antenna is given by:

$$D = \frac{P_{max}}{P_{av}} \quad 2.22$$

2.10 Return Loss

This can be defined as the reflection of signal power from the input of a device in transmission line or other conductor. The unit of expression is dB. The return loss is given by:

$$RL \mid dB = 10\log\frac{P_r}{P_i} \quad 2.23$$

where, P_r is the reflected power and P_i is the power supplied by the source.

In the case of voltage, v_i and v_r indicate the amplitude of the incident wave and the reflected wave, so the return loss can be expressed in terms of the reflection coefficient ρ as:

$$RL = -20\log|\rho| \quad 2.24$$

In addition, the reflection coefficient ρ can be expressed as:

$$\rho = \frac{V_r}{V_i} \qquad 2.25$$

It is better to have the return loss less than -10 dB to make the antenna radiate well.

2.11 The Voltage Standing Wave Ratio

The voltage standing wave ratio (VSWR) is a crucial parameter in antenna design, which means that if the transmission line is concluded with a mismatch in impedance, a portion of entered power is reflected back down, in which case the incident signal will be mixed with the reverse signal. This causes a voltage standing wave pattern, in which the ratio of maximum to minimum voltage is known as VSWR. Many methods could be used in VSWR measuring such as Return Loss, Mismatch Loss and Reflection Coefficient. The common one is reflection coefficient, which can be calculated in several ways, and ultimately used to calculate VSWR. To measure the reflection coefficient, the following formula can be used:

$$\rho = \frac{E_r}{E_i} \qquad 2.26$$

where $E_r$is the reflected voltage and $E_i$is the incident voltage.

$$\rho = \frac{Z_1 - Z_2}{Z_1 + Z_2} \qquad 2.27$$

where Z_1 and Z_2 are the mismatched impedances in ohms.

$$\rho = \sqrt{\frac{P_{ref}}{P_{fwd}}} \qquad 2.28$$

where P_{ref} is the reverse power, P_{fwd} is the forward power.

The reflection coefficient can be used to calculate VSWR by using the following formula:

$$\text{VSWR}= \frac{1+\rho}{1-\rho} \qquad 2.29$$

There are other methods such as Return loss. The Return Loss is the measure in dB of the Ratio of forward and reverse power. The return loss can be calculated by the following formula:

$$\text{Ret Loss} = 10\log\left[\frac{P_{fwd}}{P_{rev}}\right] = = 20\log\left[\frac{E_r}{E_i}\right] = -20log\left[\frac{VSWR-1}{VSWR+1}\right] = -20log\rho \qquad 2.30$$

To guarantee efficient performance of an antenna, the VSWR value should be in the range between 1 to 2.

2.12 Wimax Band

Wimax (worldwide interoperability for microwave access) technology offers greater range and bandwidth than Wireless Fidelity (Wi-Fi), and it is considered as an alternative to wired technologies like Digital Subscriber Line (xDSL) and Optical Carrier Level (OC-x) Technologies. In theory, Wimax can reach a 30-mile coverage and achieve 75 Mbps even at long range, which means that Wimax can deliver data rate approximately the same as the wired broadband services deliver. In fact, there are two bands of Wimax, licensed and unlicensed. The Licensed Bands are 2.5 GHz and 3.5 GHz. License-Exempt Band is 5 GHz. Table 2.1 shows those bands and their availability.

Table 2.1 Wimax current licensed and unlicensed bands.

Band	Frequencies	License required	Availability
2.5 GHz	2.5 to 2.69 GHz	Yes	Allocated in Brazil, Mexico, some Southeast Asian countries and the US (The WiMAX Forum also includes 2.3 GHz in this band category because it expects to cover [2.3 GHz] with the 2.5 GHz radio.)
3.5 GHz	3.3 to 3.8 GHz but primarily 3.4 to 3.6 GHz.	Yes in some countries	In some countries, the 3.4 GHz to the 3.6 GHz band is allocated for broadband wireless.
5 GHz	5.25 to 5.85 GHz	No	In the 5.725 GHz to 5.85 GHz portion, many countries allow higher power output (4 watts), which can improve coverage.

In this side, some antenna examples have been given which are work in such bands.

2.13 Examples of Microstrip Antennas for Wimax Technology

There are many types and shapes of microstrip antennas, which were designed to work in Wimax band such as c-slot, E-shape and others. Because of diverse shapes, just two examples will be presented here.

2.13.1 L-slot Rectangular Microstrip Patch Antenna for WiMAX and WLAN Applications

The designed antenna is shown in Figure 2.12. The dimension of the antenna were 31.1145 mm in length (L) and 37.11 mm in width (W), the thickness (h) is 1.5 mm. The substrate was RT Duroid 5880 having dielectric constant of 2.4, the patch was cut into slot with widths, 3.5 mm for w1, w2 is 3 mm, and w3 is 1 mm for the L-shape [3].

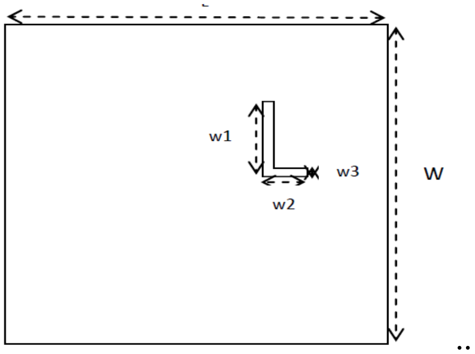


Figure 2.12 Geometry of the first example Proposed Antenna

Here is a designed antenna result:

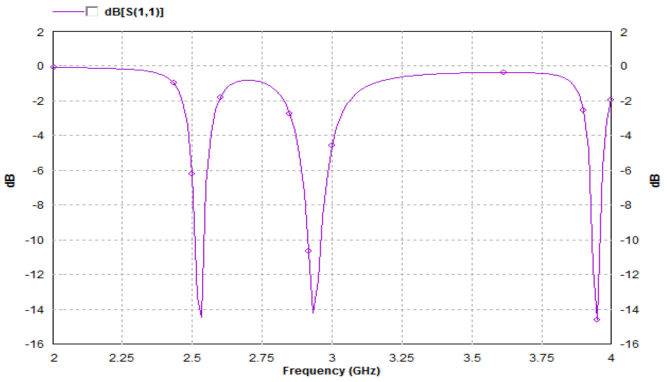


Figure 2.13 Return Loss versus Frequency

As seen in the Figure 2.13, the Return loss at 2.63 GHz is -14.2 dB, and at 2.92 GHz, it is -14.1 dB and at 3.95GHz, it is -14.4 dB.

2.13.2 Design of Double L-Slot Microstrip Patch Antenna for WiMAX and WLAN Application

In an other work, this antenna was proposed: finite ground coplanar waveguide (CPW) fed dual-band antenna which is shown in Figure 2.14. The FR4 substrate with dielectric constant 4.4 was used with 1.6 mm in thickness. The antenna structure was chosen to be a rectangular patch element with dimensions of width W and length L, and with a vertical spacing of 'd' away from the ground plane. A conventional CPW fed line designed with a fixed signal strip thickness of W_f and a gap distance of 'g' between the signal strip and the coplanar ground plane was used for exciting the radiating patch element. Two finite ground planes with the same size of width of W_g and length of L_g were situated symmetrically on each side of the CPW feeding line patch, ground length and width calculated by using transmission line model. The optimum parameters were obtained with the aid of Ansoft HFSS software [4].

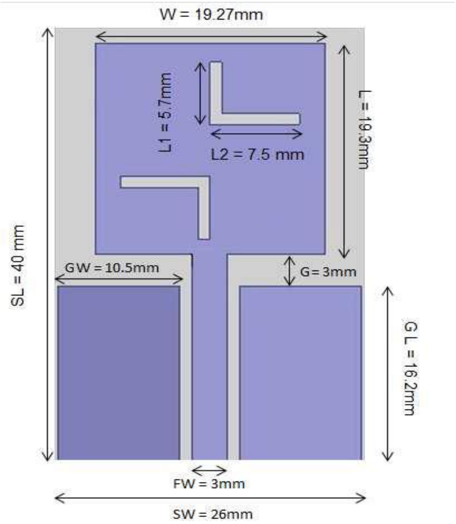


Figure 2.14 Dimensions of the second example proposed antenna.

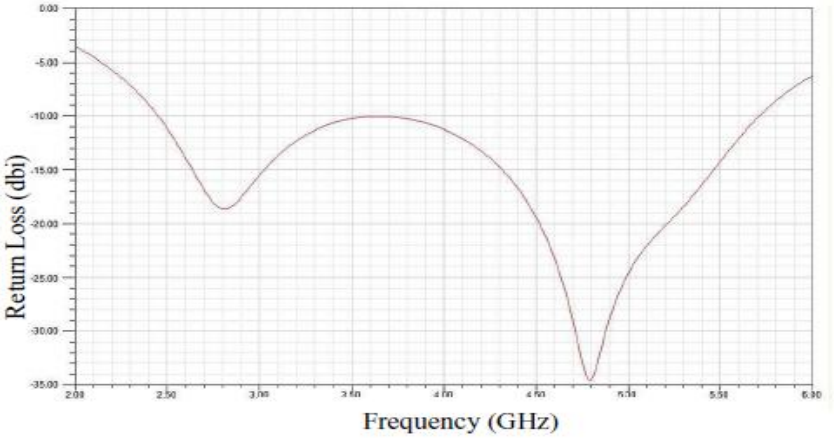


Figure 2.15 Return Loss versus frequency.

This antenna has good bandwidth. It has a band range of 4 GHz to 5.5 GHz with total gain approximately of 7.68 dBi.

CHAPTER 3

ANTENNA DESIGN AND SIMULATION

3.1 Introduction

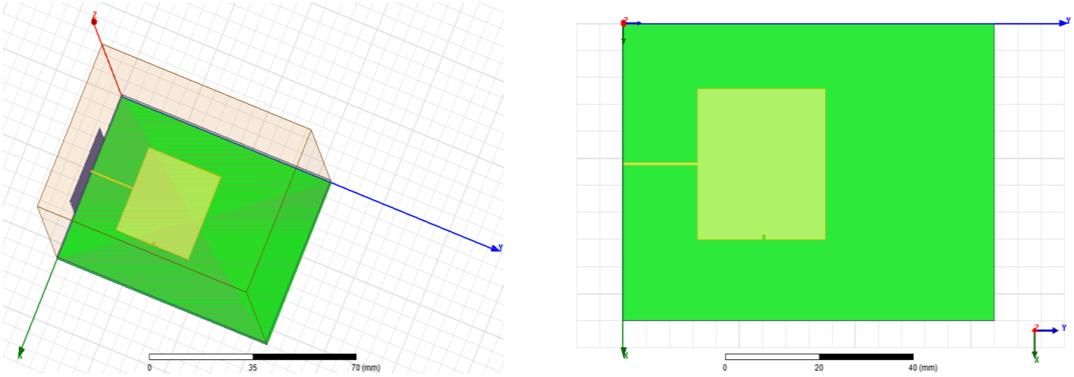
There are many software, which can be used to study electromagnetics and the related problems or issues. These software are different from each other in the analysis method. For example, HFSS (High Frequency Structural Simulator), which is commercial electromagnetic structures solver that uses finite element method. On the other hand, CST (microwave studio) is based on Finite integration technique (FIT). Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. The finite element method is illustrated with the help of the plane stress and plane strain formulation [5] while the finite integration technique (FIT) is a spatial discretization scheme to numerically solve electromagnetic field problems in time and frequency domain. It preserves basic topological properties of the continuous equations such as conservation of charge and energy. FIT was proposed in 1977 by Thomas Weiland and has been enhanced continually over the years. This method covers the full range of electromagnetics (from static up to high frequency) and optic applications and is the basis for commercial simulation tools. The basic idea of this approach is to apply the Maxwell equations in integral form to a set of staggered grids. This method stands out due to high flexibility in geometric modeling and boundary handling as well as incorporation of arbitrary material distributions and material properties such as anisotropy, non-linearity and dispersion. Furthermore, the use of a consistent dual orthogonal grid (e.g. Cartesian grid) in conjunction with an explicit time integration scheme (e.g. leap-frog-scheme) leads to compute and memory-efficient algorithms, which are especially adapted for transient field analysis in radio frequency (RF) applications [6]. In this chapter, we will present the steps and procedures used to design the configurations of the proposed microstrip patch antenna. In addition, in this chapter, the antenna parameters will be described starting from return loss, voltage standing wave ratio, radiation pattern and gain where all simulations are done with Ansys HFSS 15. In addition, two antennas will be presented in this chapter in order to show the total work after many simulations. HFSS, as it was mentioned before, uses FEM method which allows the user to model any arbitrary shaped 3D structure much better than other methods. Moreover, by working on HFSS, it is seen that it is so reliable and flexible software, where it is easy to check the design parameters without interrupting the simulation process. Furthermore, the user can choose material from wide range of material characteristics, where there is no problem to assign an anisotropic material or temperature dependent. Frequency dependent materials can also be chosen.

3.2 Antenna Design

The wide range of applications in the antenna world gives the interested people to do a lot of designs and modifications. The ease of design and fabrication is a good motivation to enter such an area. The idea of this work is to design double T slot microstrip patch antenna dual band for Wimax application; there is still the need for a solution in some areas, and the need to enhance services and applications in development in this process in technology. In this thesis, the proposed antenna is designed using HFSS software. The dimensions are calculated theoretically as they mentioned in chapter 2 equations, as it is known that IEEE 802.16 (Wimax) operates in more than one band and these bands are categorized in two ways: licensed and un-licensed WiMAX. Table 3.1shows the so-called bands:

Table 3.1 Wimax current and future licensed and un-licensed bands

Region or country	Current band	Future
Canada	2.5 , 3.5 and 5 GHz	
USA	2.5 and 5 GHz	
Central and South America	2.5 , 3.5 and 5 GHz	
Europe	3.5 and 5 GHz	2.5 GHz
Middle East	3.5 and 5 GHz	
Russia	3.5 GHz	2.3 and 2.5 GHz
Asia and Pacific	2.3 , 3.3 ,3.5 and 5 GHz	2.5 GHz

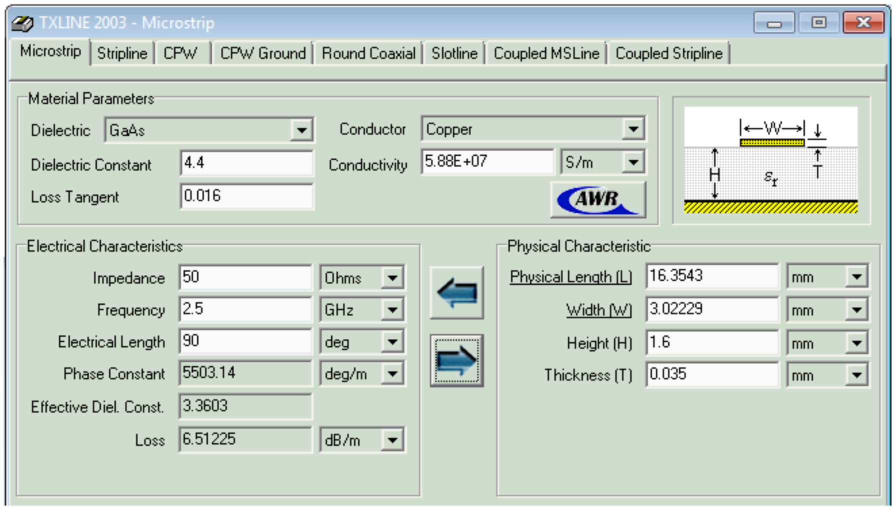


(a) (b)

Figure 3.1.The proposed single slot microstrip patch antenna for Wimax application in HFSS environment, (a) in 3D, (b) in 2D.

3.3 Design Specifications

The proposed single slot microstrip patch antenna dual band is shown in Figure 3.1. The antenna is designed to operate in 2.5 and 5 GHz, the antenna shape was chosen to be a square patch antenna with the dimension W × L and FR4 substrate with the dielectric constant of 4.4 with 0.035 mm in thickness, and its height is equal to 1.6 mm. The slot is modified randomly until a specific return loss values $S_{11} < -10$ dB. The feeding technique is microstrip transmission line, which is an easy technique to be calibrated and fabricated. The dimension of microstrip feed line for matching was calculated with TX-line tool, which is available in AWR software or on AWR corporation web page. This tool is so simple and helpful. Figure 3.2 shows the TX-line tool calculation.



Dielectric: GaAs
Dielectric Constant: 4.4
Loss Tangent: 0.016
Conductor: Copper
Conductivity: 5.88E+07 S/m

Impedance: 50 Ohms
Frequency: 2.5 GHz
Electrical Length: 90 deg
Phase Constant: 5503.14 deg/m
Effective Diel. Const.: 3.3603
Loss: 6.51225 dB/m

Physical Length (L): 16.3543 mm
Width (W): 3.02229 mm
Height (H): 1.6 mm
Thickness (T): 0.035 mm

Figure 3.2. The TX-line tool calculation

The quarter wave transformer general formula is given here in the equation 3.1

$$Z_{in} = Z_1 \frac{R_L + jZ_1 tan\beta_1 l}{Z_1 + jR_L tan\beta_1 l} \qquad 3.1$$

If $\beta_1 l = \frac{2\pi}{\lambda_1} \frac{\lambda_1}{4} = \frac{\pi}{2} \quad rad$. For $\frac{\lambda}{4}$ length of TL, $tan\beta_1 l$ →∞. By substituting this in equation 3.1, which result in:

$$Z_{in} = \frac{{Z_1}^2}{R_L} \quad . \qquad 3.2$$

By putting, $Z_{in}$is equal to Z_0 , so Z_1 could be adjusted in 3.2 and it is led to:

$$Z_1 = \sqrt{Z_0 R_L} \qquad 3.3$$

In other words, a $\frac{\lambda}{4}$ section of TL will present a perfect match (Γ) to the feedline.

3.4 Design Calculations for Single Slot Antenna

The transmission line model described in Chapter 2 will be used to design the antenna. Firstly, the width (w) is calculated by:

$$\mathrm{w} = \frac{c}{2.f_c.\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad 3.4$$

where, f_c is 2.5 GHz and ε_r equal to 4.4

by optimization w=28 mm.

Secondly, because of the fringing problem, normal ε_r cannot be used directly in the calculation, and for this purpose, effective relative permittivity ε_{reff} has been used.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left[1 + 12\ \frac{h}{W}\right]^{-\frac{1}{2}} \qquad 3.5$$

For this, h=1.6 mm.

$\varepsilon_{reff} = 4$

Calculation of the effective length is

$$L_{eff} = \frac{c}{2.f_c.\sqrt{\varepsilon_{reff}}} \qquad 3.6$$

L_{eff} is 30 mm, and L is calculated following equation:

$$\mathrm{L} = L_{eff} - 2.\Delta\mathrm{L}$$

$$\Delta L = 0.412.h.\frac{(\varepsilon_{reff}+0.3).\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258).\left(\frac{W}{h}+0.8\right)} \qquad 3.7$$

$\Delta L = 1.115\ mm$

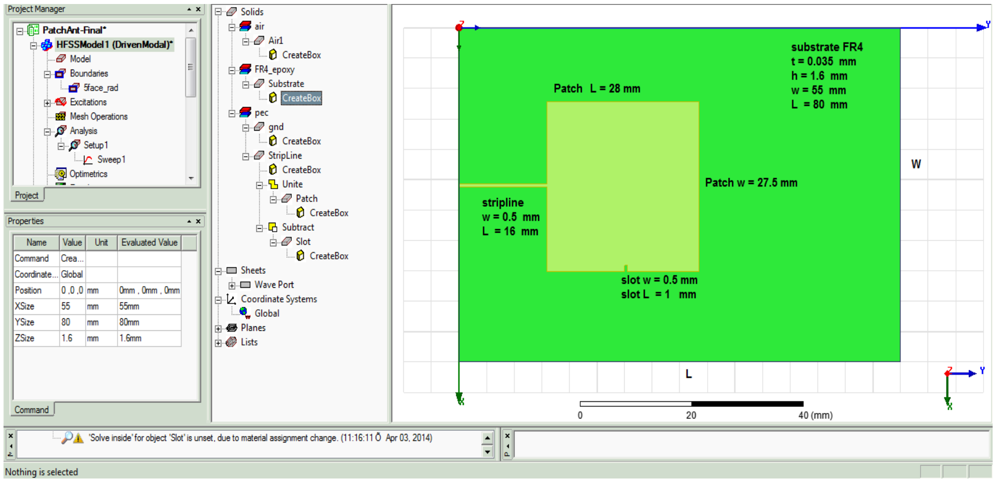
Then after optimization, L is equal to 27.5 mm

In addition, in microstrip feed-line there is a little difference in the dimension, where the length of the line is the same from TX-Line tool. However, the width is different where:

L is 16 mm and in optimization, w is equal to 0.5 mm.

3.5 Measurements and Results

In dual band designation, it is hard to get the bands in just one-step and calculation. Some techniques are used in order to get the needed band. For example, dual feed antenna is a good technique to design dual band antennas, but it has some disadvantages like hard matching because matching for two ports is needed. Here in this work, the proposed antenna was designed in two steps. Firstly, the concentration was to get the first band 2.5 GHz. To achieve this, the antenna dimensions were based on 2.5 GHz as resonance frequency where the last dimension obtained by optimizing the design to specific goals. Secondly, the other band 5 GHz was obtained by adding a small slot in the patch size, as it is already known that adding a slot to microstrip antenna design will lead to additional resonant frequencies. Figure 3.1 shows the antenna shape, and Figure 3.3 shows the dimension for the antenna and slot.



Name	Value	Unit	Evaluated Value
Command	Crea...		
Coordinate...	Global		
Position	0 ,0 ,0	mm	0mm , 0mm , 0mm
XSize	55	mm	55mm
YSize	80	mm	80mm
ZSize	1.6	mm	1.6mm

'Solve inside' for object 'Slot' is unset, due to material assignment change. (11:16:11 Ő Apr 03, 2014)

Figure 3.3 Single slot dual band microstrip antenna dimensions.

In Figure 3.3, the small slot is shown clearly again, and this slot was so useful to control the frequency band. For a specific point, it is used as a shifter for frequency band, and by changing the dimension of this slot; the other resonance frequency 5 GHz is gotten easily.

3.5.1 Return Loss

The frequency where the return loss is minimum is called “center frequency”. The bandwidth of the antenna is calculated from the return loss plot. The acceptable level of return loss is equal or smaller than -10 dB. This is shown in Figure 3.4. Its bandwidth is low at 2.5 GHz with 7% and a little good at 5 GHz with 14% bandwidth efficiency.

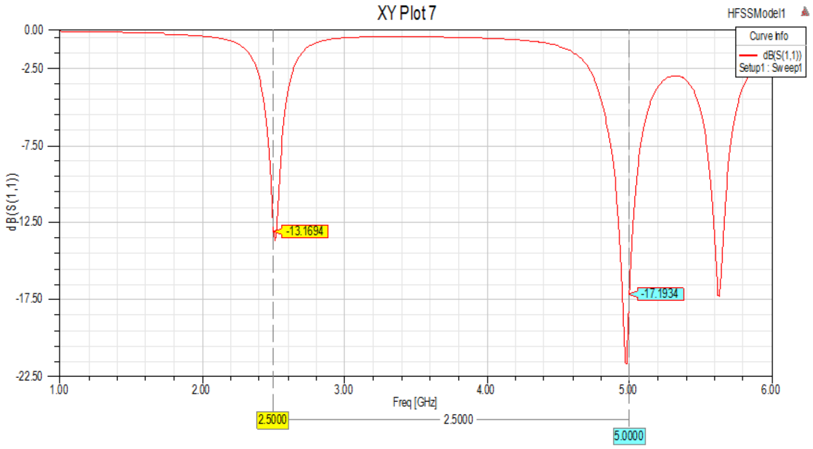


Figure 3.4. S_{11} parameters they are -13and -17db at 2.5 GHz and 5 GHz respectively.

3.5.2 Voltage Standing Wave Ratio (VSWR)

Figure 3.5 shows the VSWR of the single slot antenna, 1.6038 at 2.5 and 1.3421 at 5 GHz.

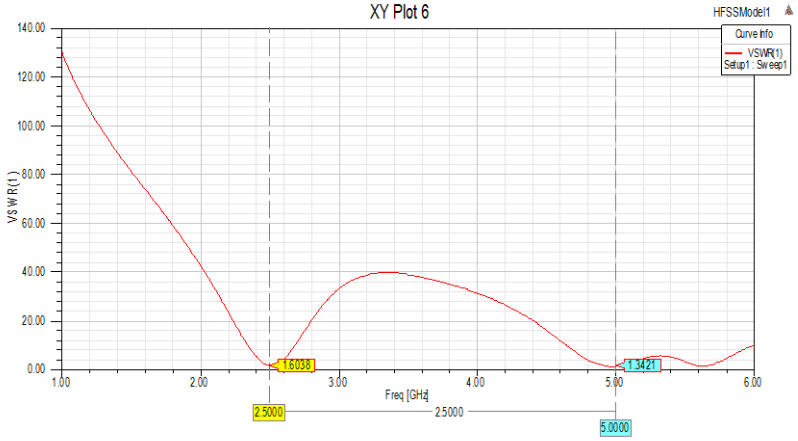
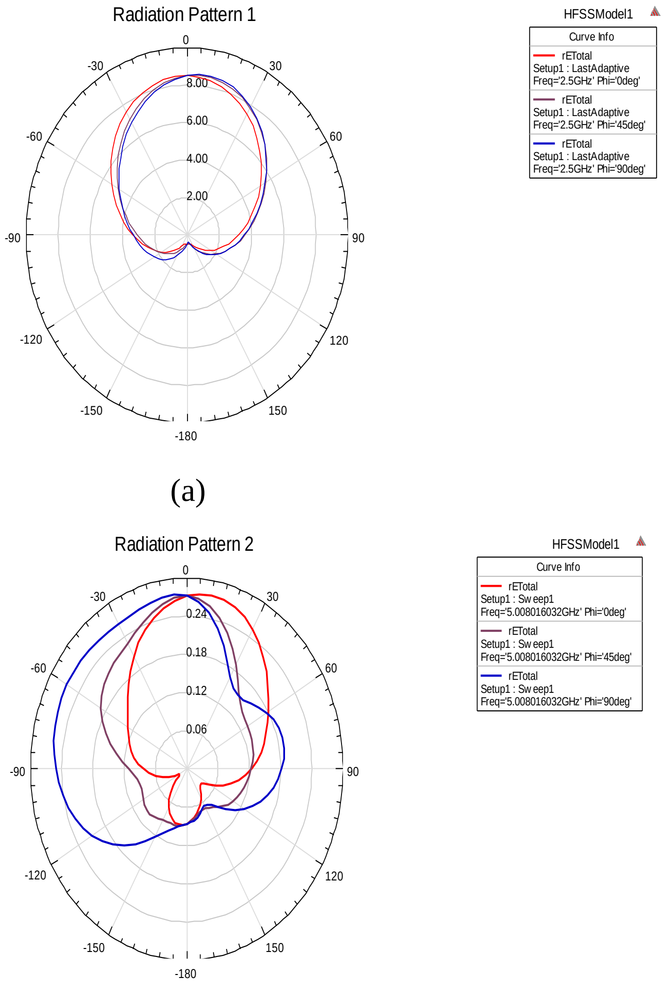


Figure 3.5. VSWR values are 1.6038 at 2.5 GHz and 1.3421 at 5 GHz

3.5.3 Radiation Pattern

(a) 2D plot:

It was known from microstrip antenna basics that patch antenna radiates normally to its patch surface, so the important values of Phi φ in elevation pattern would be φ = 0 , φ = 45 and φ = 90. Figure 3.6 shows the radiation pattern for these elevations.



(a)

(b) Frequency 5 GHz

Figure 3.6. Antenna radiation pattern at (a) 2.5 and (b) 5 GHz at different values of Phi 0,45 and 90 deg.

(b) 3D plot Radiation pattern

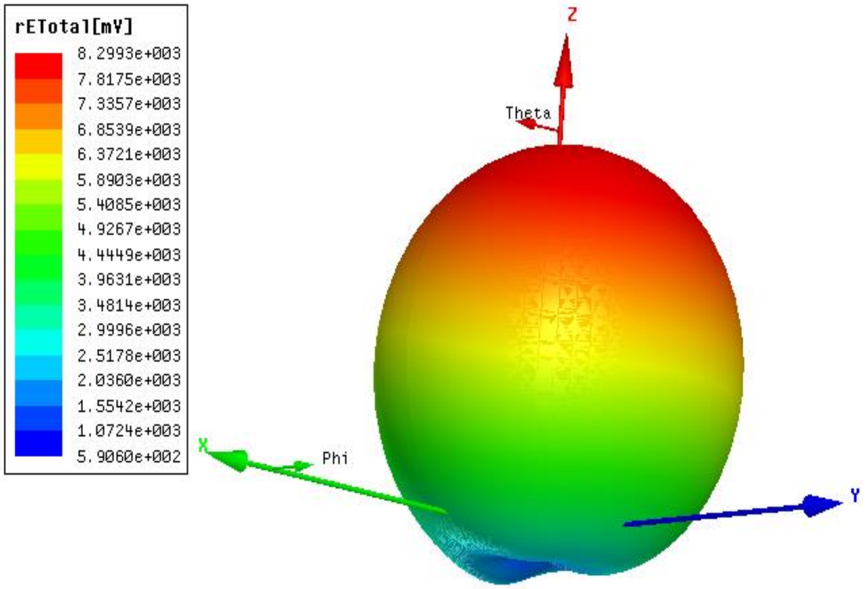


Figure 3.7. Antenna radiation pattern in 3D

3.5.4 Gain

Antenna gain is usually defined as the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. Usually this ratio is expressed in decibels [7]. Microstrip antennas are famous for their poor gain; this is because antenna gain is affected by substrate thickness and relative dielectric constant. Gain is inversely proportional to ε_r and directly proportional to substrate thickness. Many ways are used to enhance antenna gain, like Left Handed Material (LHM), which has negative permittivity and permeability. These negative characteristics will effect electromagnetic waves that would propagate in a direction opposite to that of the flow of energy. In this antenna, the maximum gain is 3.3 dBi, which means that, this antenna still suffers from low gain. Moreover, this problem could be solved by using a material with relative permittivity less than FR 4 epoxy. For example, Duroid 5880 with ε_r 2.2.

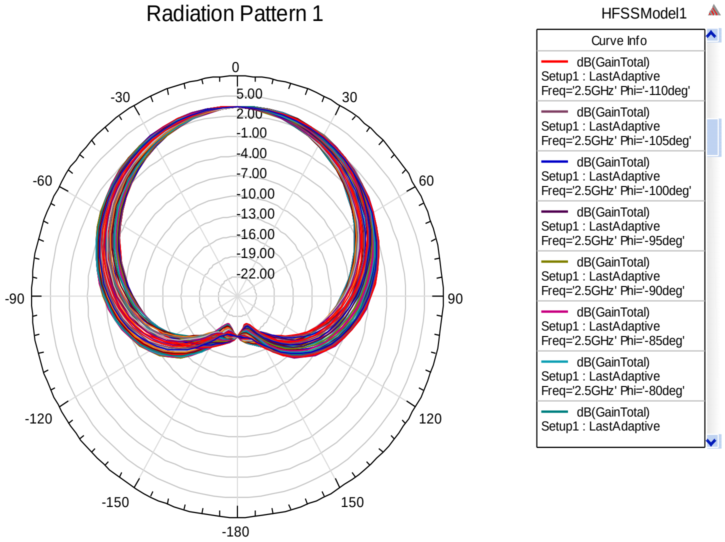
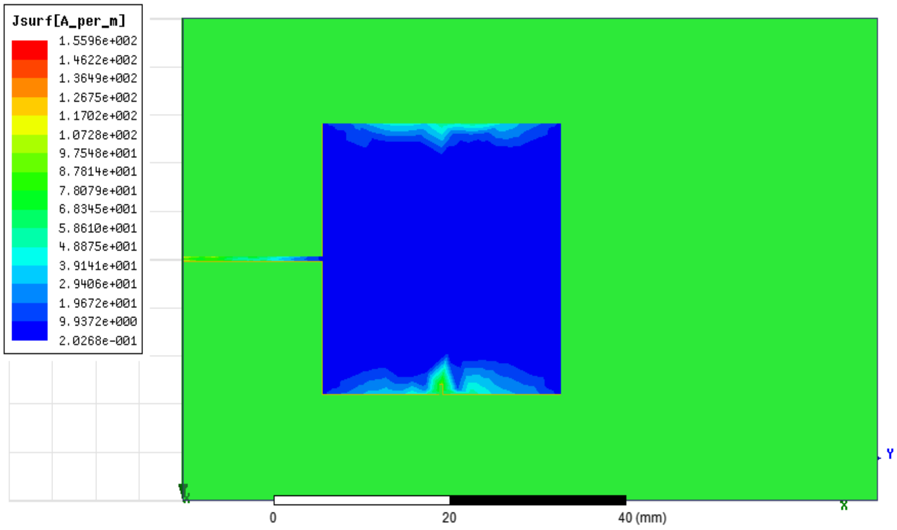


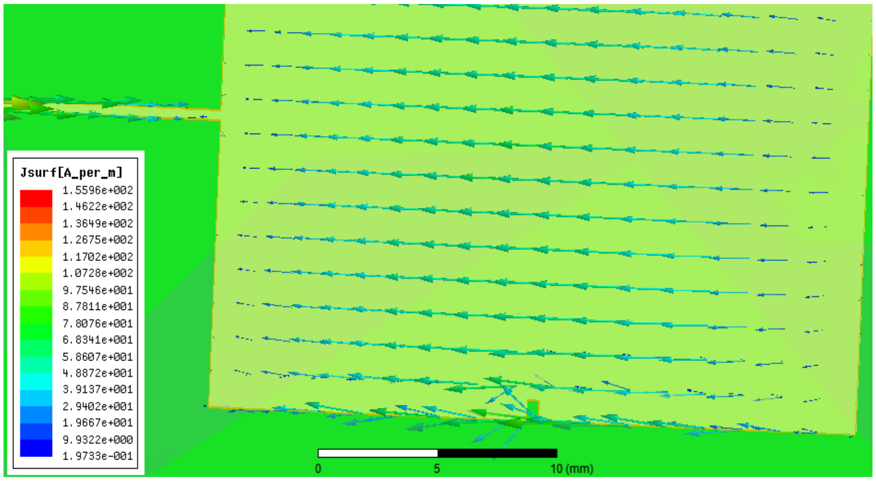
Figure 3.8. Antenna gain 3.3 dBi.

3.5.5 Current Distribution on the Antenna

Current distribution is described as field distribution between the patch and the ground plane, which is used as the indicator of the radiation from microstrip patch. Figure 3.9 shows the current distribution on single slot microstrip antenna.



(a)



(b)

Figure 3.9. Current distribution on the antenna as (a) magnitude and (b) vector

3.6 The Effect of Changing Slot Dimension

Here the dimension of the slot changed gradually in order to investigate the effect of this action on antenna results, especially S_{11}.

Table 3.2 Effect of changing slot dimension

Slot L (mm)	Slot W (mm)	S_{11} (dB) At 2.5 GHz	S_{11} (dB) At 5 GHz
1	0.5	-13.17	-17.20
3	0.5	-13.00	-16.50
5	0.5	-12.40	-15.54
5	1	-6.50	-11.87
3	1	-13.00	-14.77
1	1	-12.43	-13.38

As it is seen from table 3.2, there was a small shift in frequency when the slot size changed also. There is a shift in frequency in the case of changing the slot position.

3.7 The Effect of Changing Slot Position

In table 3.3, we will change the position of the slot along y-axis, but on x-axis, the position will be kept the same in each step, because we need to keep the slot on the antenna side.

Table 3.3 Effect of changing slot position

Position (x, y, z)	S_{11} dB at 2.5 GHz	S_{11} dB at 5 GHz
(38, 29, 1.6)	-13.17	-17.20
(38, 31, 1.6)	-5.81	-8.95
(38, 33, 1.6)	-5.68	-9.26
(38, 35, 1.6)	-5.81	-9.10
(38, 27, 1.6)	-5.69	-9.32
(38, 25, 1.6)	-5.76	-9.28
(38, 23, 1.6)	-14.23	-13.00

Remembering the fact, that microstrip antenna radiates normally to its patch surface, and as it was mentioned in chapter two figure 2.8 about the dominant mode of microstrip antennas for this radiation behavior, the slot will not have big effect on return loss of the antenna.

Table 3.4 Effect of changing feed line width

Feed line w (mm)	S_{11} dB at 2.5 GHz	S_{11} dB at 5 GHz
0.5	-13.17	-17.20
1	-10.30	-15.33
1.5	-8.50	-13.30
2	-6.50	-11.00
2.5	-6.42	-10.5
3	-6.42	-10.5

3.8 Thesis Work Load

In this work, two antennas have been simulated. Because of some changes in antenna design, two antennas were designed. For example, first antenna was designed in order to work in dual band. In the first antenna, it has not been considered that the thickness of the substrate was 0.035mm. During the simulation, we get the two bands 2.5 and 5 GHz. However, when we fabricate the antenna, the band shifted to other band 3.5GHZ. Also in the beginning, the antenna height was 1 mm, but the FR 4 substrate that we have in fabrication is 1.6 in height. This difference leads to different goals. In the following figures, we will describe the other antenna with its errors.

3.9 Dual Band Double T Slot Antenna

The antenna is shown in figure 3.10, whose dimensions were calculated according to the transmission line model equations as mentioned in section 3.4. After simulation and optimization, the final dimensions are shown in the figure 3.10.

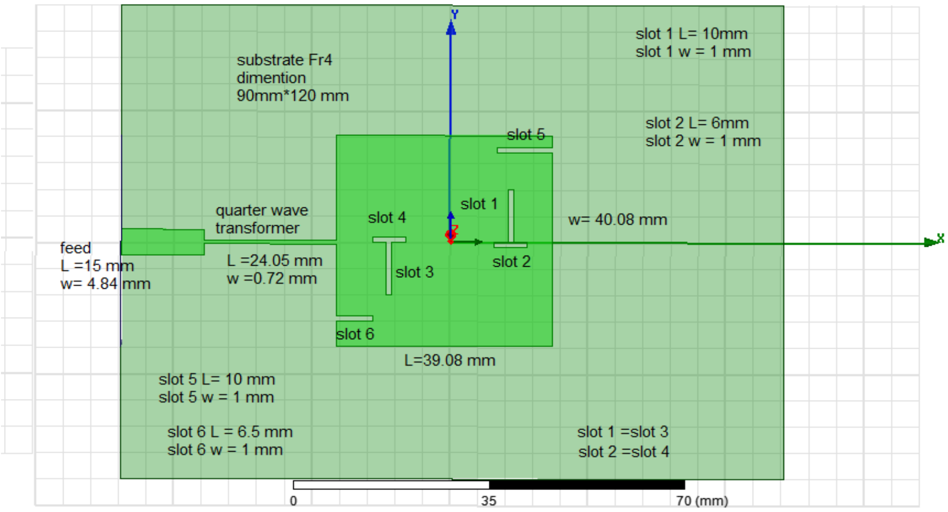


Figure 3.10. Dual T slot antenna dimensions

In Figure 3.10, we can see the final antenna dimensions. The most important part is how to get the dual band antenna. Here the slots are important in getting the dual band. The slots 5 and 6 are used to control resonance frequencies, especially at 5GHz. This antenna is a square antenna. Figure 3.11 shows the proposed antenna in HFSS 15 environment in 3D. In addition, the antenna plots will be shown in the next figures.

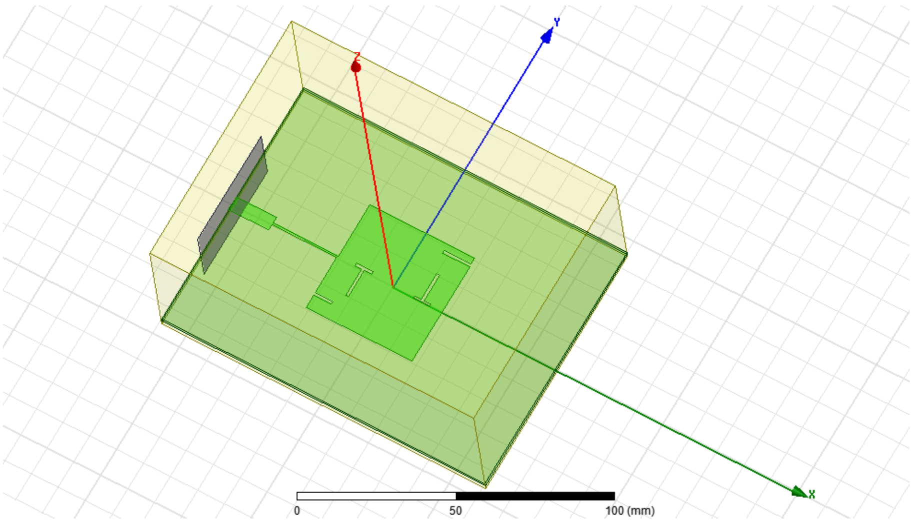


Figure 3.11. Dual T slot antenna in 3D

3.9.1 Antenna Return Loss

In Figure 3.12, the return loss in dB for Double T-slot antenna is shown.

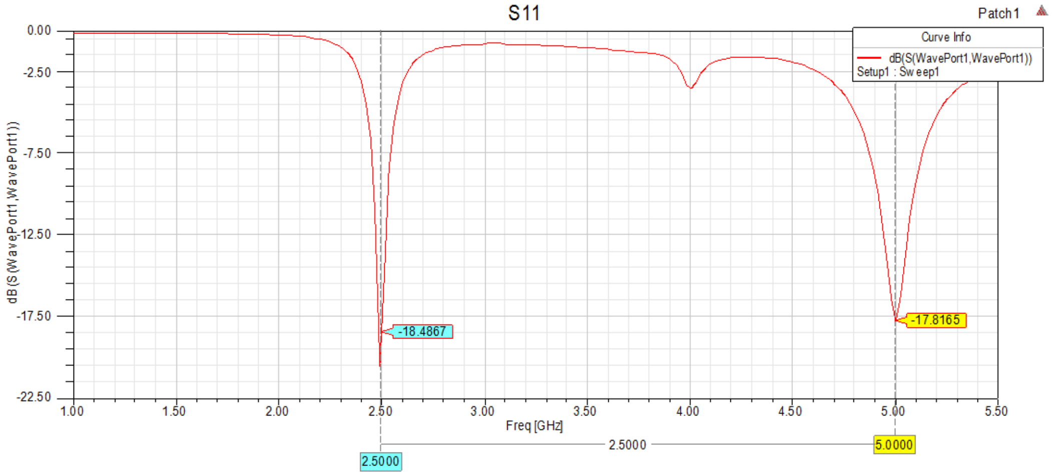


Figure 3.12. Double T slot antenna return loss

3.9.2 Voltage Standing Wave Ratio VSWR:

Figure 3.12 shows the VSWR (dimensionless) for Double T-slot antenna. With good values, we had 1.2977 and 1.3008 at 2.5 and 5 GHz respectively.

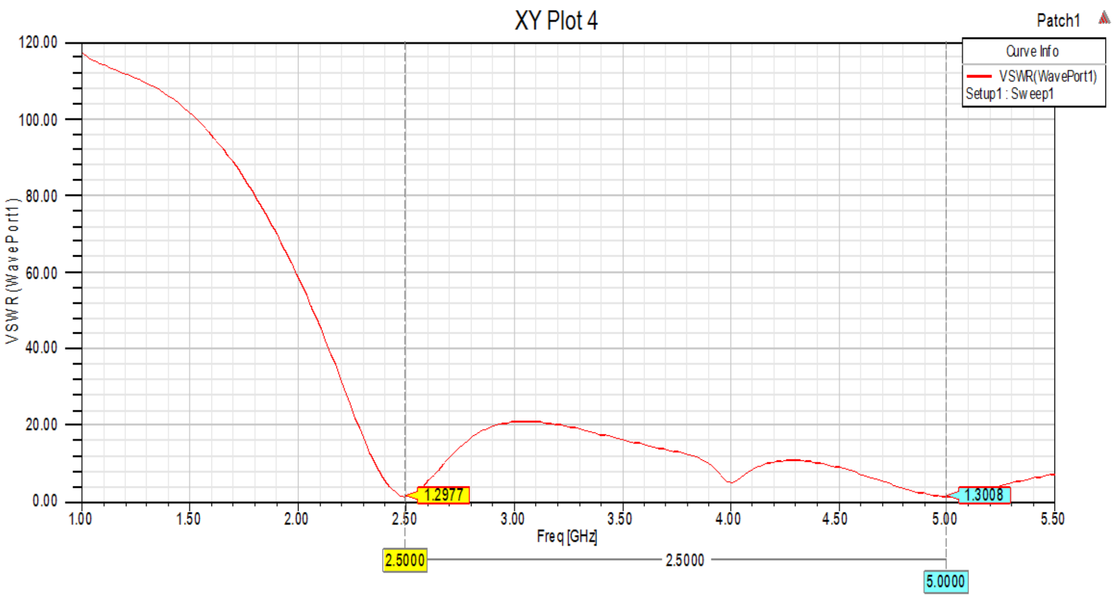
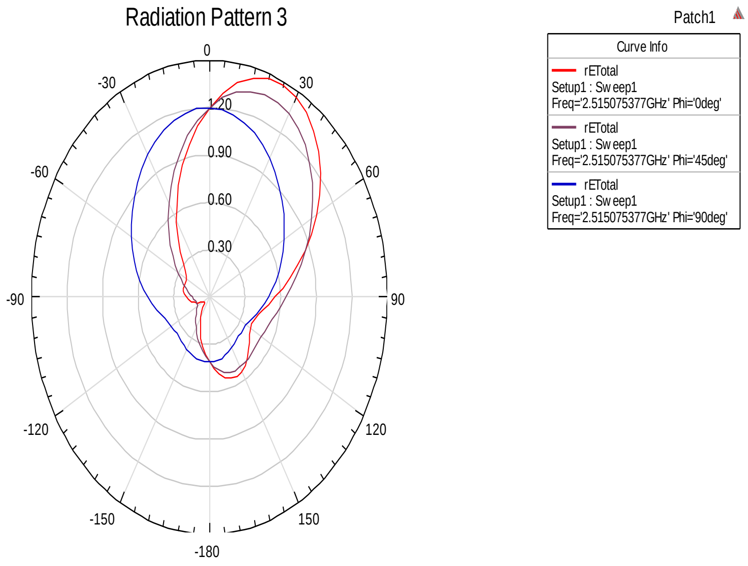
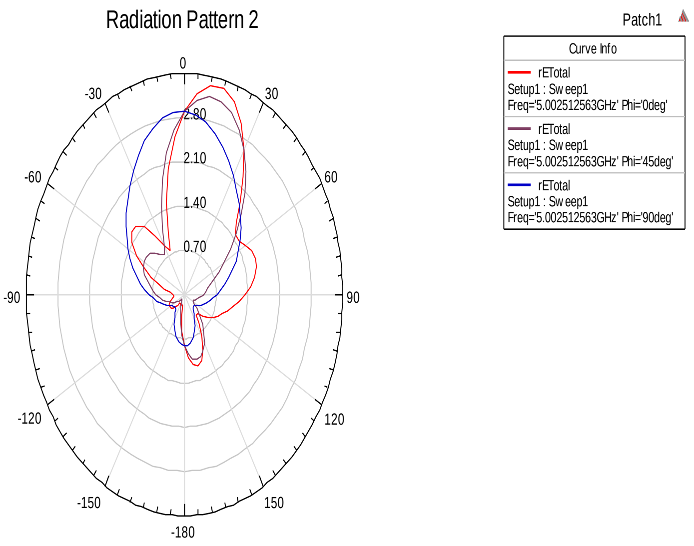


Figure 3.13. Double T slot antenna VSWR

3.9.3 Radiation Pattern in 2D:



(a)



(b)

Figure 3.14. Double T slot antenna radiation pattern in 2D at (a) 2.5 and GHz and (b) 5 GHz

Figure 3.14 (a) and (b) show the radiation pattern in 2-D for 2.5 and 5 GHZ for Double T-slot antenna. By comparing this antenna radiation with single slot antenna radiation, it has less radiation efficiency.

3.9.4 Radiation Pattern in 3D:

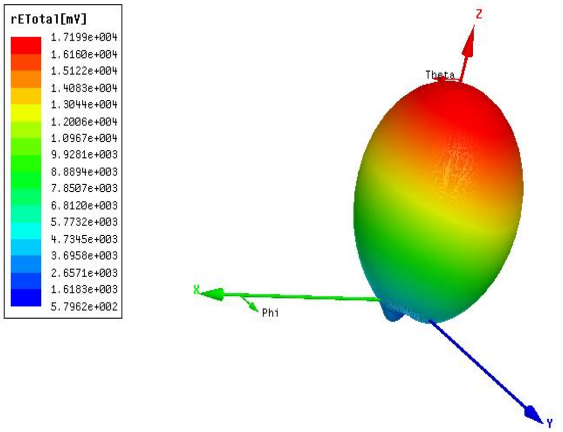


Figure 3.15. Double T slot antenna radiation pattern in 3-D at 2.5 GHz

3.9.5 Antenna Gain:

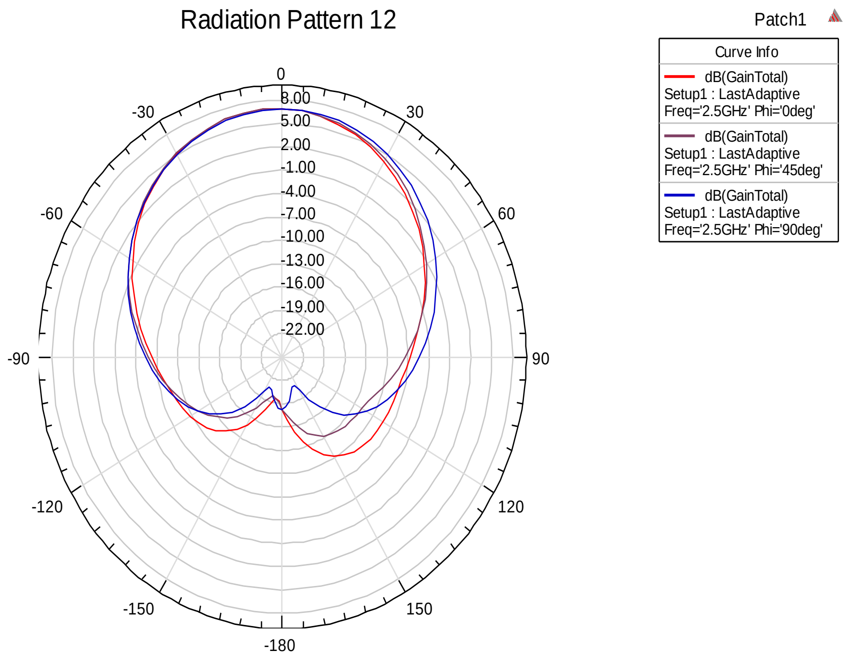


Figure 3.16. Double T slot antenna gain 6.92 dBi.

By comparing gain from both antennas, it is clear, that microstrip antenna with double T slot has a gain measurement higher than the single slot antenna. This happens because the dual T slot antenna has a height less than the other antenna, which has an effect on electromagnetic waves propagation on antenna surface.

CHAPTER FOUR

ANTENNA FABRICATION AND MEASUREMENT

4.1 Introduction

The fabrication of the antennas was done with the substrates and dimensions described in Chapter three in simulation section. The patch antennas were etched on epoxy FR4, which has a dielectric constant of 4.4 and a thickness of 0.035mm. Epoxy FR4 was used because it has a low dielectric constant; it was also a reasonably thin substrate. As it was mentioned in simulation, two antenna have already been simulated. In addition, both of them have been fabricated and shown in this chapter.

4.2 Fabrication Machine

In this section, we will give a brief information about the machine. The its name is LPKF ProtoMat C100/HF (LPKF Laser & Electronics AG); this machine has a resolution (smallest step) equal to 0.0079375mm, which is suitable for our design. In case of material, all base materials supplied by LPKF can be used for machining. Taking in our consideration the fact that the glass fiber reinforced epoxy material (FR 4 or G 10) can be a health hazard due to the milling dust produced (allergies and risk of cancer). This information is given in the machine manual [8].

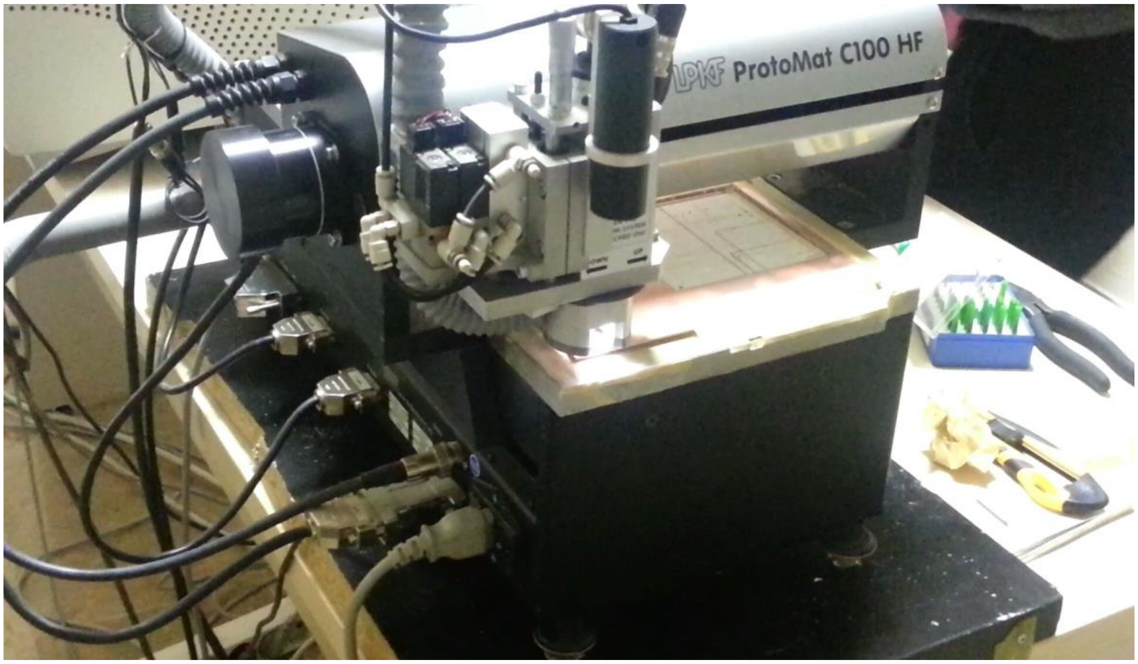


Figure 4.1 LPKF ProtoMat C100/HF PCB Machine

4.3 Antenna Fabrication Process

4.3.1 Double T-Slot Microstrip Antenna

Fabrication means realization of your design and simulation, and it seems to be easy for the designer; however, it is needed to be more carefull and precise between simulation and realization while the software is able to modle and read any design in the range of its library data. But different errors may occure during this thesis fabrication process, where the error of substrate thickness has not been considered as 0.035mm. This leads to perfect simulation result, but the real antenna performance was different from the simulated one. In this section, two antennas will be described: antenna with different simulation and fabrication result, and the perfect one, which have the same measurement in simulation and fabrication. In Figure 4.2, this antenna with double T slots is shown which is described in the previous chapter. This figure is about applying the command of PCB machine to start fabrication. Figure 4.1 shows PCB machine and antenna , and in the next figures antenna with feed connector will be shown, as well vector analyzer return loss plot.

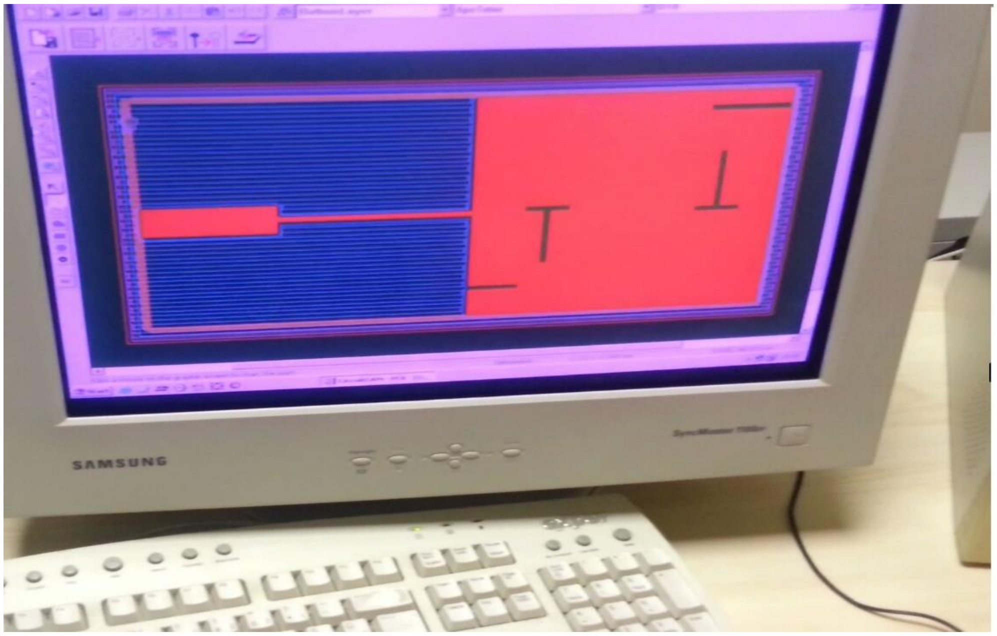


Figure 4.2 Antenna during fabrication

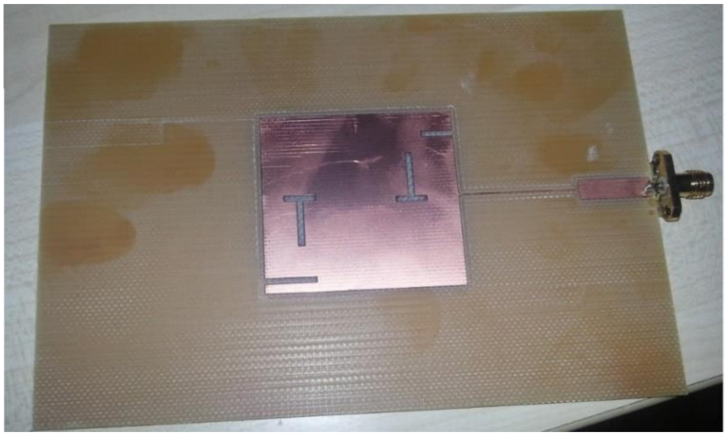
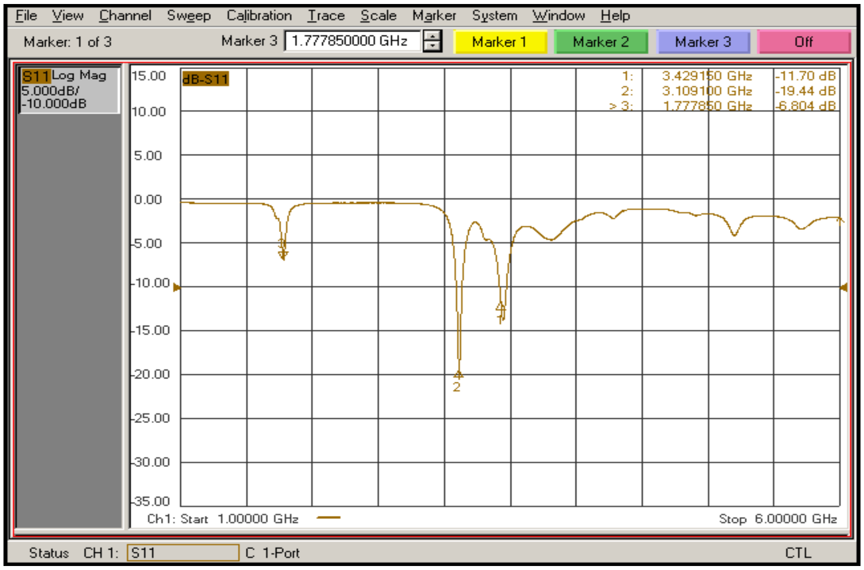


Figure 4.3 Antenna after fabrication

Figure 4.3 shows the fabricated antenna, which is ready to be measured by vector analyzer, which is, an instrument that measures the network parameters of electrical networks. Today, network analyzers commonly measure S–parameters because reflection and transmission of electrical networks are easy to measure at high frequencies [9]. In Figure 4.4, the return loss measurement of vector analyzer is shown. If we compare the simulation result from Chapter three, which is mentioned in Figure 3.12, it can be seen that, the resonance frequency is shifted from 2.5 to 3.1GHz with -19.44 dB and the other frequency is 3.4 rather than 5 GHz with -11.7 dB.



```
Marker: 1 of 3    Marker 3 1.777850000 GHz
S11 Log Mag
5.000dB/
-10.000dB
   1:  3.429150 GHz  -11.70 dB
   2:  3.109100 GHz  -19.44 dB
 > 3:  1.777850 GHz  -6.804 dB
Ch1: Start 1.00000 GHz                 Stop 6.00000 GHz
CH 1: S11    C 1-Port
```

Figure 4.4 Vector analyzer S_{11} plot for Dual T slot antenna

4.3.2 Single Slot Microstrip Antenna

Figure 4.5 shows a single slotted microstrip antenna, which is the last design. After evaluating and correcting the mistake in the previous design double T slot antenna, the substrate thickness is considered, and the antenna is re-designed. The simulation has already been performed, and S_{11} plot is shown in Chapter three in Figure 3.4.

The return loss graphs show that the resonant frequencies have shifted in the magnitude from the designed frequency for all the designs. The main cause of the shift could be due to the FR-4 board, which varies from 4.0 to 4.9. In practical world, a material that varies along length, width, and height will affect resonant frequency for shifting, and during the simulation, it is assumed as a constant. The other factors affecting etching accuracy such as the chemical used, surface finish and metallization thickness also could be the reasons for shifting the resonant frequency [10].

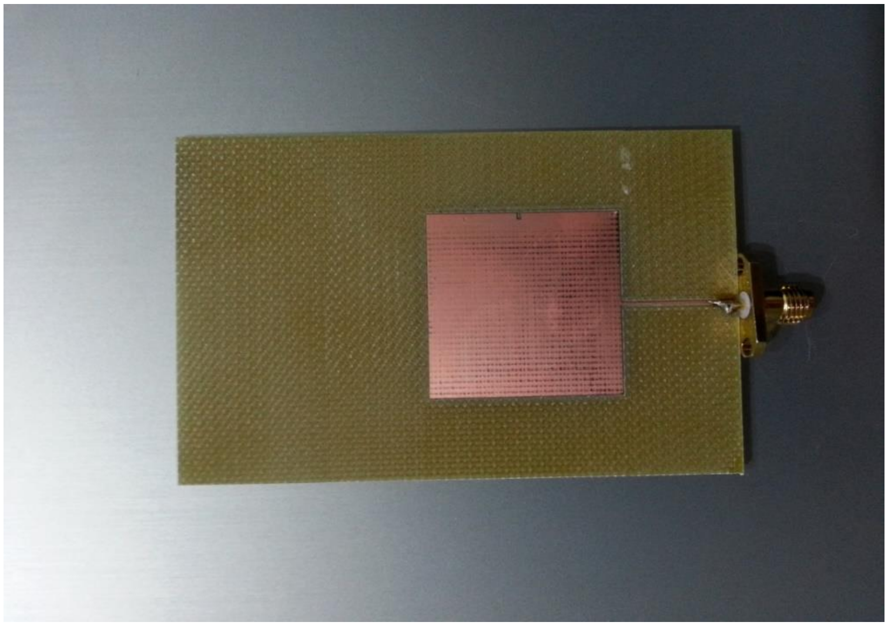


Figure 4.5 Fabricated single slot microstrip antenna

Figure 4.6 shows the single slot microstrip antenna connected to spectrum analyzer, during measurement in Antenna laboratory at Atilim University. Moreover, Figure 4.7 is the vector analyzer S_{11} reading at 2.5 and 5 GHz

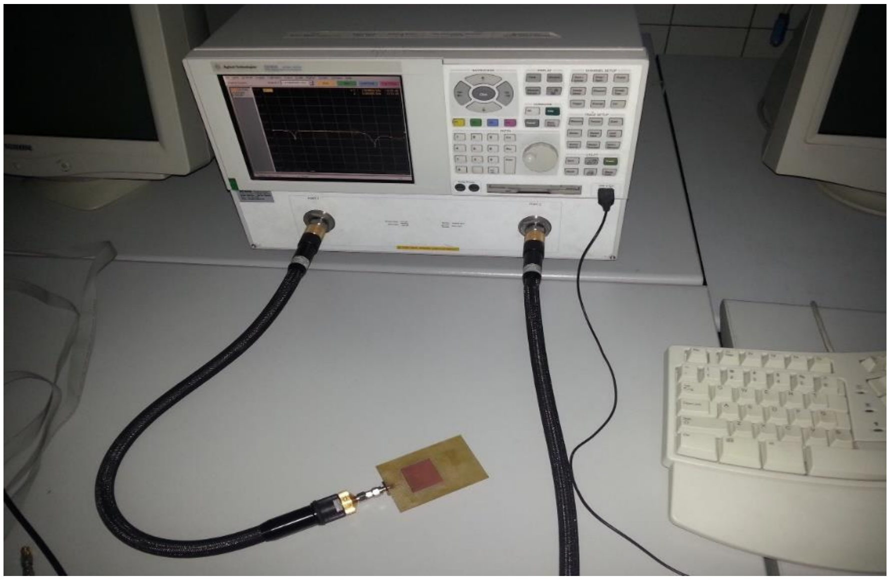
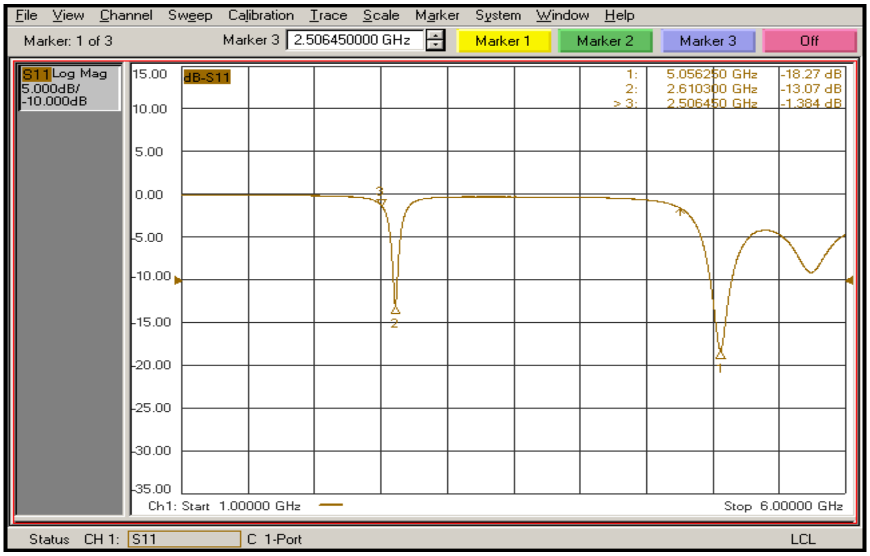


Figure 4.6 Antenna connected to Vector analyzer for measurement in laboratory



```
Marker 3 2.506450000 GHz

1:    5.056250 GHz   -18.27 dB
2:    2.610300 GHz   -13.07 dB
> 3:  2.506450 GHz   -1.384 dB
```

Figure 4.7 Vector analyzer S_{11} plot for Single slot antenna

4.4 Comparison between Simulated Results and Fabricated Results

Table 4.1 Comparison between Simulated results and fabricated results

Parameters	Simulated Results	Fabricated Results
Frequencies Covered in double T slot antenna	2.5 and 5 GHz	3.1 and 3.4 GHz
Frequencies Covered in single slot antenna	2.5 and 5 GHz	2.61 and 5.05 GHz
Return Loss in double T slot antenna	-18.486 dB at 2.5 GHz -17.8165 dB at 5 GHz	-19.44 dB at 3.1 GHz -11.7 dB at 3.4 GHz
Return Loss in single slot antenna	-13.1694 dB at 2.5 GHz -17.1934 dB at 5 GHz	-13.07 dB at 2.61 GHz -18.27 dB at 5.05 GHz
Applications covered by double T slot antenna	Wimax application	Wimax application
Applications covered by single slot antenna	Wimax application	Wimax application

In Table 4.1. The comparison was done in order to investigate the antenna validity to work in the desired band of WiMAX. Although, both antenna have different bands. 2.5, 5, 3.1 and 3.4 GHz. Both antennas were able to work in Wimax band. One of them with sufficient gain, and the other with low gain.

CHAPTER 5

CONCLUSION

The goal of this thesis was to design a dual band microstrip patch antenna for Wimax applications. Wimax has different types: 802.16, 802.16 2004 and 802.16e 2005, which are operating at different bandwidths. the concentration was on the last type 802.16e 2005,where there are two types: fixed and mobile Wimax, which operate in two frequency bands, the fixed one operates in the band 2-11 GHz, and the other mobile type in 2-6 GHz. The thesis is based on the mobile Wimax and its band. Hence, the antenna designed must be able to fit in Wimax devices. As we discussed in Chapters three and four, a dual band microstrip patch antenna has been successfully designed having a center frequency of 2.5 GHz. The ground plane dimensions for the patch is 50 mm by 80 mm and it could be smaller than these dimensions. In addition, the patch dimension is 28 mm by 27.5 mm. so the designed antenna is suitable for wimax devices. After that, the other resonance frequency at 5 GHz is gotten by slot etched on the patch.

During antenna simulation and fabrication, many problems appears. One of the problems in this thesis is related with the substrate thickness t, where the substrate height was considered in the simulation as 1.6 mm, but the thicknesses of patch, strip line and ground were not considered, and they were all 0.035 mm. Then, in simulation result for return loss S_{11}, the resonant frequency has been shifted from 2.5 to 3.4 GHz. After many steps in simulation and fabricating more than three antennas, the trouble was solved, being about the thickness of patch and ground. Most of these steps have been described in chapters three and four.

The dual band microstrip antenna was simulated and fabricated in this thesis, and the most important summary was about how to control or get dual band antenna. The method of etching slots on such antenna is useful to get the other frequency band. Also by changing the slot position and dimension W or L, reasonable return loss S_{11} values will be obtained, however. S_{11} values are acceptable and they are less than -10 dB, but the microstrip antenna still suffers from low gain and small bandwidth, because there is a tradeoff between antenna dimension and bandwidth.

By antenna optimization, the last design does not exactly follow microstrip antenna dimension and formulas, for example, here the dimensions of this antenna calculated by microstrip equations are 36.5 mm for L and W equals to 28.25 mm. Also from TX-line tool from AWR, the stripline length is 16 mm and its width is 3 mm. But in the final optimization, the dimension of L, W for patch are 28 by 27.5 mm.

The drawback in such antenna design is that the relative permittivity value of the substrate, if high ε_r material is assigned, the antenna will suffer from poor S_{11} but will have a nice gain, and just the opposite will happen when you assign low ε_r. Because of this, the FR4 epoxy substrate has low gain in this thesis. However, there are many steps to solve this issue. This could be done by changing in the shape of the antenna or assigning different material properties like Left-handed meta-material (LHM), which is a material whose permeability and permittivity are simultaneously negative.

In Future Work, one may modify any antenna shape to a specific application. Future work will concentrate on how to tackle with size and performance of this type of antennas. Triple band with high gain will be a good idea to continue studies in this field.

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