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DESIGN OF SMALL DUAL BAND SLOT ANTENNA

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Abstract

This paper aims to design a slot antenna having small dimensions with dual bands, dual-band antennas allow you to connect wirelessly for tighter access to locations and are often used for devices such as cellular or dual-band wireless access points, the antenna works at 3.1 and 5.4 GHz and their geometry consists of a rectangular slit associated with the broad part of the L -shaped slot fed by a 50-ohm micro-strip line and another rectangular slit scratched at the base of the ground plane connected, the length of the first rectangular slit is set to be around 1/4λ at the lower frequency $f_1 = 3.1$GHz, while the length of the second slit is set to be around 1/4λ at the upper-frequency $f_2 = 5.4$GHz, the antenna printed on a 0.8 mm of FR4 substrate thickness with relative permittivity 4.4. In this paper, we simulated and designed a small dual-band slot antenna with a small size and good outcomes (the return losses s11 were -22 dB and -15 dB at frequencies 3.9 and 5.5 GHz, respectively,). The design parameters of the antenna used the transmission line model, and HFSS electromagnetic software was used for the simulation process.

Keywords: Antenna, Microstrip antenna, slotted antenna, dual-band antenna, small antenna.

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1. Introduction

Rapid advancements in wireless technology have led to its increasing integration into people's daily lives worldwide. More and more people rely on innovation, either directly or indirectly. Media communications that use electromagnetic waves to transmit the flag over a portion or the majority of the correspondence channel are referred to as wireless. The rapid improvement of wireless communication technology has led to a significant growth in the use of small-size antennae. The usage of microstrip patch antennas in contemporary wireless communications systems is highly beneficial

The need for compact antennas, particularly for mobile communication, has made antenna miniaturization more significant in recent years. Small serial connections should once again be produced with integrated antennae. Other crucial features include affordability and lightweight. In the literature, numerous formation quotations are suggested. Many of these are well-known geometries that result in the antenna's physical size being reduced. [1] - [2]. That is, by using high permittivity substrates, the technique raises the effective dielectric constant. [3]. A slot is another method to make a patch smaller [4]. Another option is to short the antenna's pins or load it with

capacitive or resistive loads [5]–[6]. Compact antennas with integrated active devices have been proposed recently, as shown in [7], and [8]. However, all of the structures are currently understood to be based on radiation mechanisms and intuitive designs that should function.
The goal of this paper was to design a small dual-band microstrip patch antenna that could operate at two frequencies, 3.1GHz and 5.6GHz. The proposed antenna was designed as L-shape slots using a quarter wavelength matching technique, and HFSS software was used to simulate the antenna. This paper is divided into five sections: Section One covers the fundamentals of wireless technology; Section Two discusses the structure and design of the microstrip patch antenna; Section Three introduces a simulation of the proposed antenna; and Section Four explains how the project led to this design.

2. CONSTRUCTION AND GEOMETRY OF MICROSTRIP ANTENNA

2.1-GEOMETRY OF MICROSTRIP ANTENNA

Figure 2.1 illustrates how a microstrip antenna typically uses a thin metallic patch on a height-h dielectric substrate. The metallic patch has a tiny wavelength portion over a ground plane.[2]

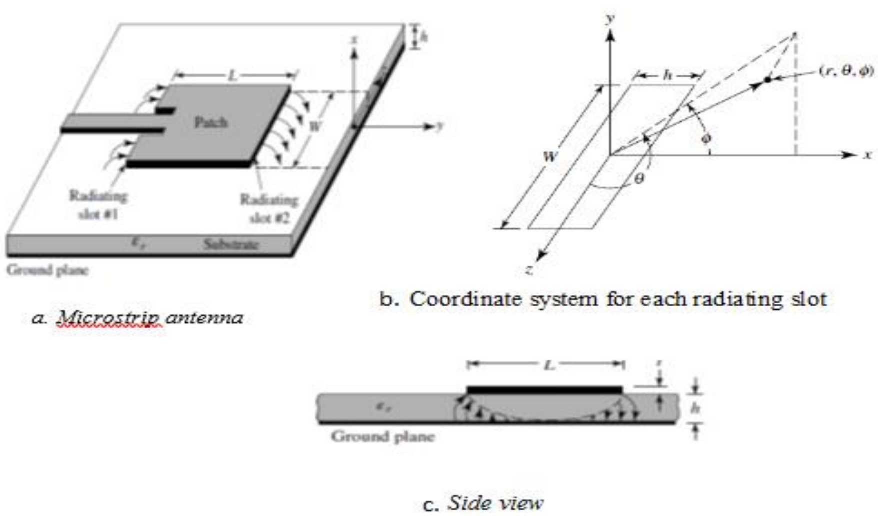

Figure 2-1. microstrip antenna and coordinate system [9]

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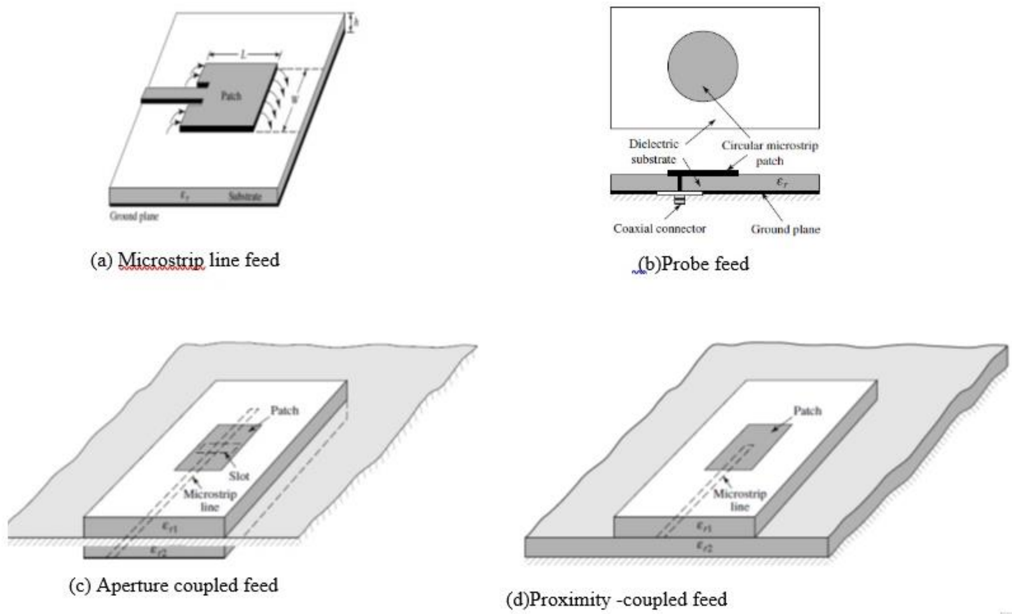

Figure 2-2. Typical feed for microstrip antenna [9]

2.2-Transmission Line Model

A rectangular microstrip antenna can be represented as an array of two radiation-narrow apertures (slots), each with a width of W and height of h, separated by distance L. The transmission line model represents the micro-strip antenna by two slots, separated by a low impedance Zc transmission line of length L.

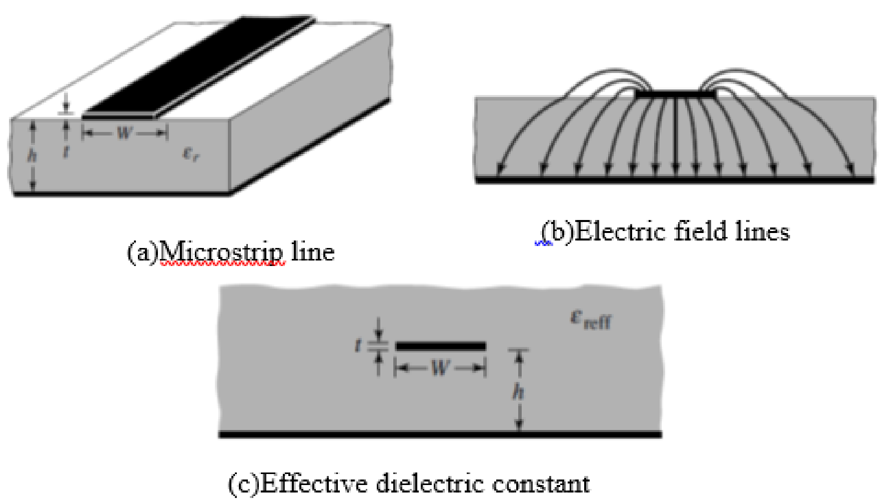

Figure 2-3Microstrip line and its electric field lines, and effective dielectric constant geometry[9].

The propagation mode of any antenna is TM, and to operate in TM mode, the patch length needs to be shorter than λ/2, were:

$$\lambda = \frac{\lambda_o}{\varepsilon reff} \qquad (2.1)$$

Where λ is a wavelength, $\varepsilon reff$ is the effective dielectric constant.

Since some of the electric field lines enter the air before reaching the dielectric substrate, this cannot be confirmed. In transmission line mode, the circulation of electric field lines, as shown in Figure 2.4.b, has a thickness of t. As a result, the transmission line cannot support exchange-electric-attractive TEM, where TEM refers to direct exchange of electric field lines to the dielectric. Figure 2.4 shows the overwhelm mode TM a, b.

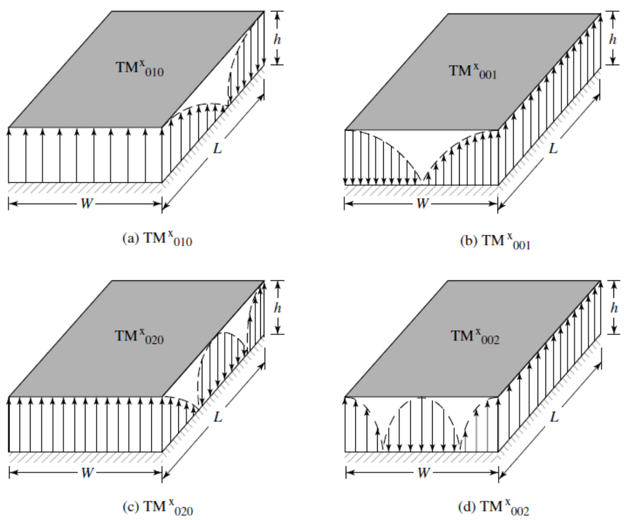

Figure 2-4Field configuration (modes) for rectangular microstrip patch.[9]

For this problem, relative permittivity ε_r will be replaced with ε_{reff} it is given as:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r+1}{2}\left[1 + 12\frac{h}{w}\right]^{-0.5}, \frac{w}{h} > 1 \qquad (2.2)$$

Where h is the dielectric substrate height, ε_r is the substrate dielectric constant and w is the patch width.

As seen in Figure 2.5, the movement of the electric field lines in the air will cause the patch's length to be extended out on both sides of the design.

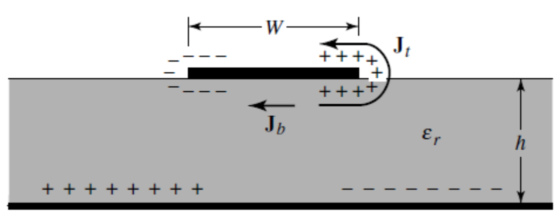

Figure 2-5. The electric field lines on both edges of the microstrip antenna.[9]

ΔL is calculated by the following formula:

$$\Delta L=\frac{0.412*h*(\varepsilon reff+0.3)*(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)*(\frac{w}{h}+0.8)} \quad (2.3)$$

Presently, we will portray the antenna width, length, and ground plane.

The following equation is used to calculate the width:

$$w=\frac{c}{2*fc*\sqrt{\frac{\varepsilon r+1}{2}}} \quad (2.4)$$

Where f_c is the resonance frequency, c is the speed of light and ε_r is the dielectric constant of the substrate. The effective length L_{eff} can be found from the following equation:

$$L_{eff}=\frac{c}{2*fc*\sqrt{\varepsilon reff}} \quad (2.5)$$

The actual length can be calculated by the following equation:

$$L = Leff - 2 * \Delta L \quad (2.6)$$

An infinite ground plane is utilized only as a part of the transmission line model. On the off chance that the ground plane is six times bigger than the height of the dielectric substrate, in addition to the utilized length or width, it can utilize a finite ground planePresently, we can compute the ground width and length as the accompanying conditions:

$$wg = 6 * h + w \quad (2.7)$$

$$Lg = 6 * h + L \quad (2.8)$$

Where wg is the ground width and Lg is the ground length.

2.3-ANTENNA DESIGN

The proposed antenna is printed on a 0.8 mm-thick FR4 substrate with a relative permittivity of 4.4. The antenna is composed of an L-shaped slot fed by a 50-ohm micro-strip line and is embedded at the center of the ground plane rectangular slit which is shortened with the L-shaped slot and another rectangular slit at the bottom of the ground plane. The total dimension of the antenna is 28*16*0.8 mm^3 and is shown in Figure 2.6. We have used the same geometry and simulated it.

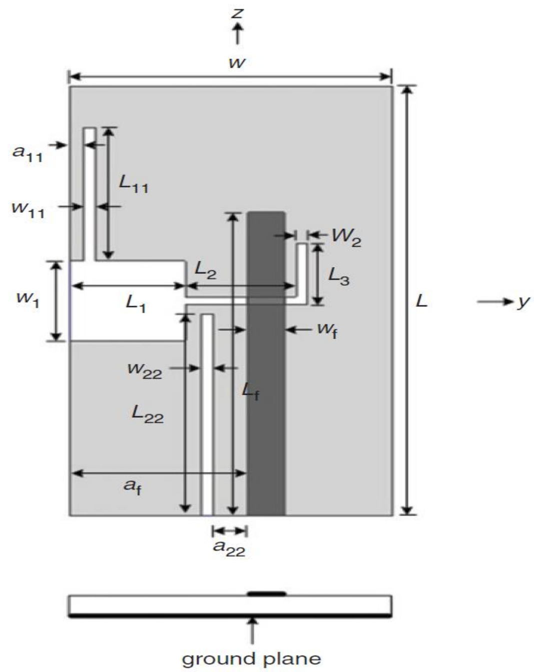

Figure 2.6 .Structure of the antenna [10]

3. SIMULATION

To focus on electromagnetic and related issues, a variety of software applications are available. We used the commercial electromagnetic structure solver HFSS (High-Frequency Structural Simulator), which is based on the finite element approach, in this paper.

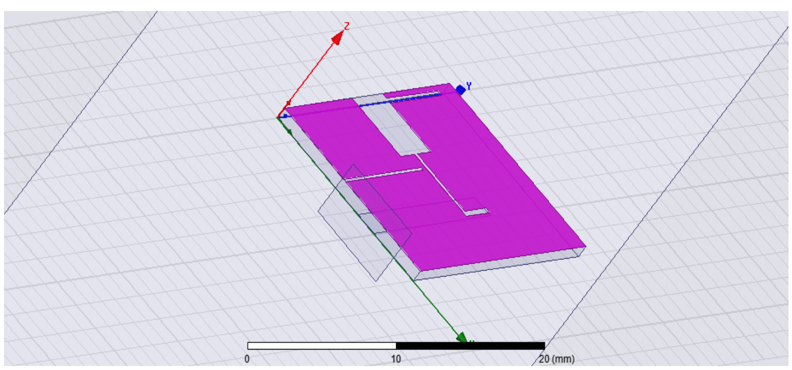

Figure 3.1. The proposed Antenna by HFSS

In this paper, we simulated the same geometry in Figure 3.1 with the same dimensions.

For this design, the dimensions are as follows:

Table 3-1.The dimension of the proposed antenna in mm

Symbol	W	L	af	wf	Lf	W_1	L_3	L_1	L_2
dimension	16	28	8.3	1.6	18.4	4.8	3.7	5	4.9
Symbol	w_{11}	L_{11}	a_{22}	W_{22}	L_{22}	h	a_{11}	W_2	
dimension	0.4	8.1	2	0.22	12.2	0.8	0.4	0.4	

A rectangular slit that is connected to the broad portion of the L-shaped slot and another rectangular slit that is scratched at the base of the ground plane is used to achieve the dual band. At the lower frequency f1 = 3.1GHz, the length of the first rectangular slit is set to approximately 1/4λ, and at the higher frequency f2 = 5.4GHz, the length of the second slit is set to approximately 1/4λ

1- Return Loss

The frequency, where the return loss is the least, is called center frequency. The bandwidth of the antenna is calculated from the return loss plot. The worthy level of return loss is equivalent to or smaller than -10 dB, which can be seen in Figures 3.2 and 3.3.

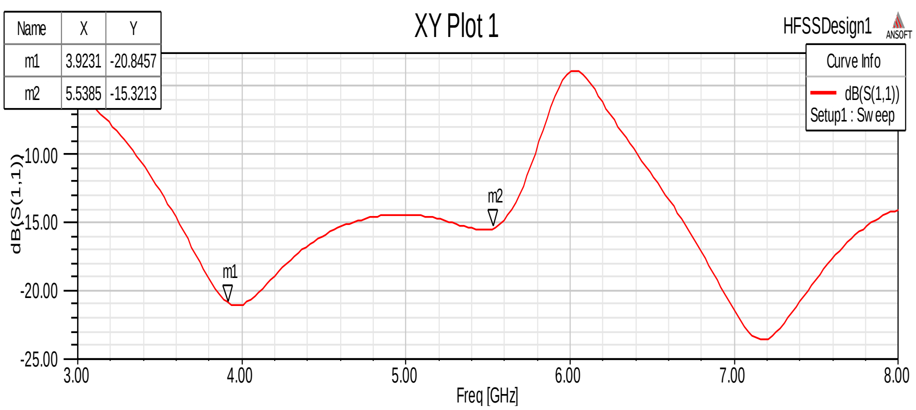

Figure 3-2. The return loss at 0.8mm of height

After this, we changed the thickness of the substrate to 1.6 mm and optimized it. The optimization gave the same dimensions as in the previous case except l_{11} was 7mm. After that, we showed the effect of slots with this dimension, which will be discussed in the next section. The next figure demonstrates the return loss at 1.6mm of height...

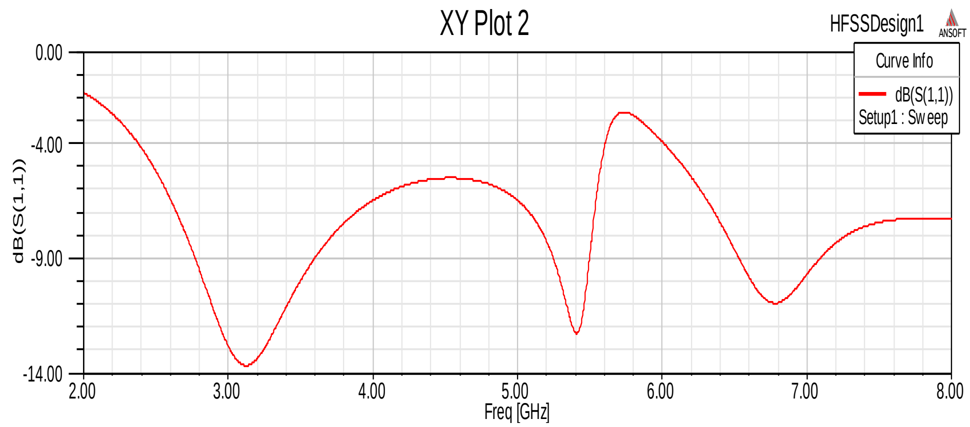

Figure 3-3The return loss at 1.6mm of height

A comparison can be made from these results and we can say that the thickness of the substrate is a critical parameter for antenna design. It is understood from this comparison that when the height was increased, the frequency shifted to the left.

Table 3-2.The difference between the two heights of the substrate.

Substrate height	0.8mm	1.6mm
Dielectric constant	4.4	4.4
Lower frequency	3.9GHz	3.1GHz
Return loss	-22dB	-12dB
Upper frequency	5.5GHz	5.4GHz
Return loss	-15dB	-12dB

2- Gain

Antenna gain is generally characterized as the proportion of the power created by the antenna from a far-field source on the antenna's beam axis to the power delivered by an ideal lossless isotropic antenna, which is a similar response to signals from all directions. [10]. Microstrip antennas are famous for their poor gain since antenna gain is affected by substrate thickness and relative dielectric constant, as shown in Figures 3.4 and 3.5.

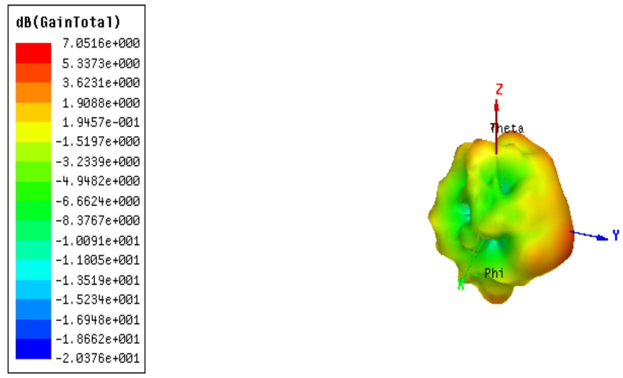

Figure 3-4.The gain of the proposed antenna at 0.8mm of height

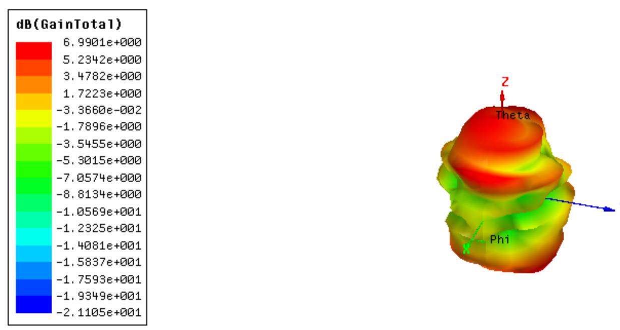

Figure 3-5.The gain of the proposed antenna at 1.6mm of height.

Figure 3-6 will show gain vs frequency for simulation results by using an Excel program in two dimensions (2D)

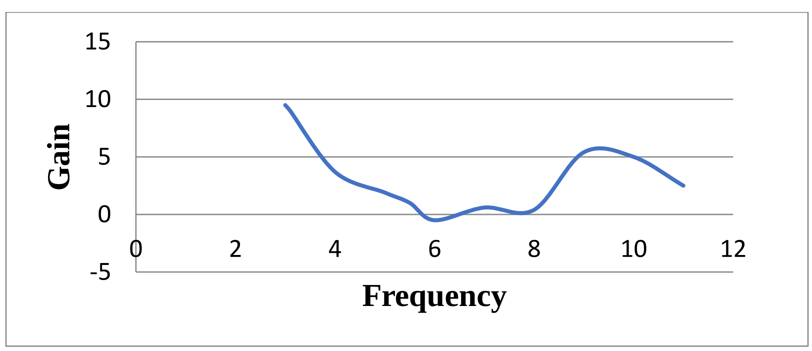

Figure 3-6. Gain vs frequency at 1.6mm of height

3-Voltage standing wave ratio

VSWR is resolved from the voltage measured along a transmission line prompting to an antenna, VSWR is the proportion of a standing wave's peak amplitude to the minimum amplitude value of the standing wave. Figure 3-7 and figure 3-9 shows VSWR

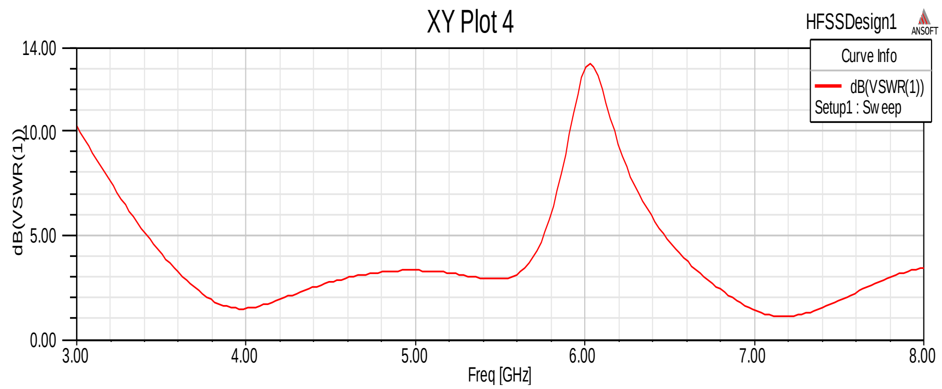

Figure 3-7. VSWR of proposed antenna at 0.8mm of height

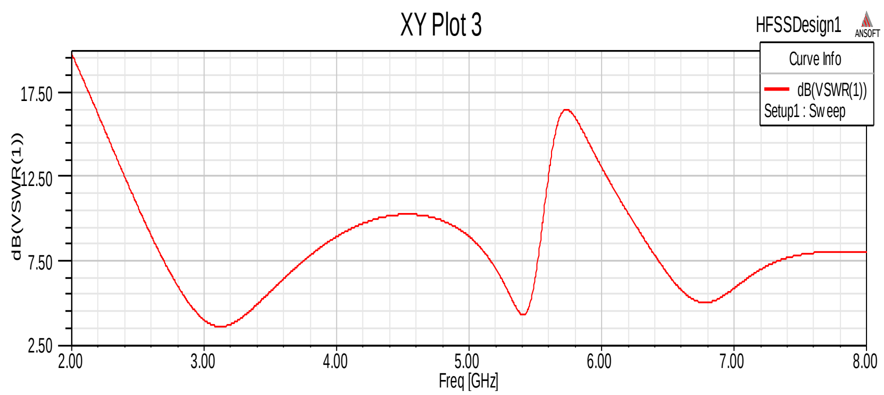

Figure 3-8 VSWR of proposed antenna at height 1.6mm

Since the voltage does not vary in an ideal system, its VSWR is 1. From figures 3-8 and 3-9, When the thickness of the substrate was 1.6mm the VSWR was close to 3.5 dB at the frequency of 3.1 GHz this is the best compared with a thickness of 0.8, Which was 7 dB. The same compared with high frequency (5.4GHz) in the higher thickness was better than lower thickness.
As mentioned before, there are two slots, one affecting lower frequency (near 3.5GHz) and the other affecting upper frequency (near 5.5). Their effect is shown thereafter.

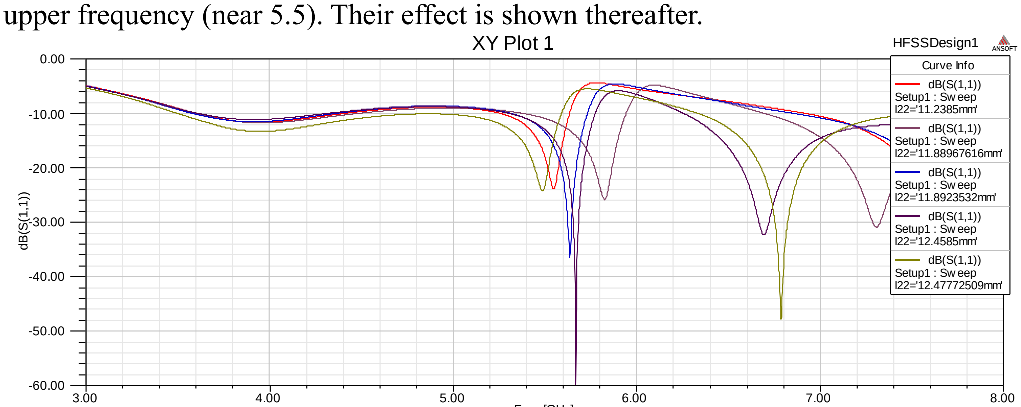

Figure 3-9. The effect of length slot22 at 3.5 GHz

It was understood from Figure 3-9 that the effect of length slot22, which is the length of slot affecting lower frequency with width, was constant only on return loss but the frequency was better from 3.5GHz to 3.9GHz when length slot22 was 11.2385mm.

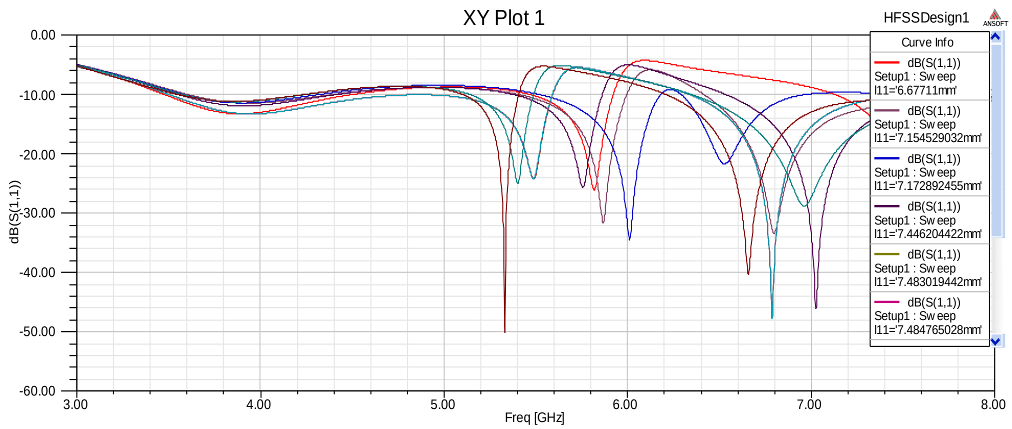

Figure 3-10. The effect of length slot11 at 5.5GHz.

slot width w11=0.4mm

Table 3-3. The effect of length slot11 on resonant frequency and return loss

length of slot11 (mm)	Frequency resonant fr (GHz)	Retur n loss
6.6	6	-37.50
7.2	5.9	-19
8.28	5.7	-20
7.69	5.6	-22
7.4	5.5	-21
8.1	5	-31

From previous Table 3-3 and Figure 3-10 we can see how the length of slot11 can affect frequency and return loss (best result at 7.6mm).

4-ANTENNA FABRICATION AND MEASUREMENTS

The patch antenna was etched on epoxy FR4, which has a dielectric constant of 4.4 and a thickness of 1.6mm. It should have been more careful and precise between simulation and acknowledgment while the software can model and read any design in the range of its library data. However, different errors may occur during the fabrication process in this thesis.

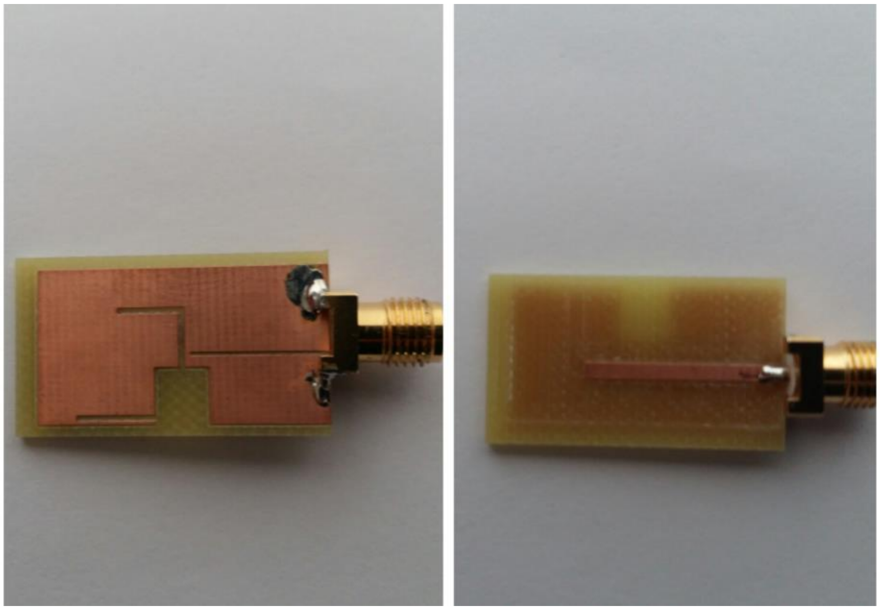

Figure 4-1. Top and bottom side of antenna fabrication.

Figure 4.1. shows the fabricated antenna, which is ready to be measured by the vector analyzer, an instrument that measures the network parameters of electrical networks. Today, network analyzers commonly measure S-parameters because the reflection and transmission of electrical networks are easy to measure at high frequencies [10].In Figure 4.2., the return loss measurement of the vector analyzer is shown.

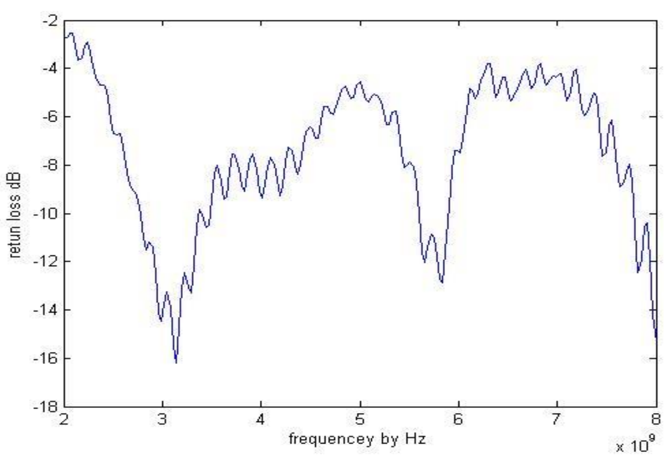

Figure 4-2. Return loss measurement

Table 4-1. Comparison between simulated results and fabricated results

Symbol	Simulation	Measure	Simulation	Measure
Frequency GHz	3.1	3.1	5.4	5.6
S_{11} dB	-13	-17	-12	-12.29
BW	3.4-2.8=0.6	3.3-2.8=0.5	5.47-5.3=0.17	5.8-5.59=0.21
Error	0		(5.65.59)/5.6 =0.001	

If the simulation results, which are mentioned in part 3., are compared, the comparison will be clear in Table 4-1, we can see that the resonance frequency is shifted from 5.4 to 5.6GHz with an error of 0.001.

1-Measurement of Gain

For the measurement of the gain of the antenna, first, we used two horn antennas (WR284 to WR28) to create a communication system. Secondly, we measured all the losses of the system and we used some information from the data sheet. All of these steps will be shown in the next equations:

$$Pr = Pt - L_1 - Lc_1 + Ga_1 - Plf + Ga_2 - L_2 - Lc_2 \tag{4.1}$$

Pr is the receiver power, Pt is the transmitter power, L_1 and L_2 are losses from two cables, Lc_1 and Lc_2 are losses from two connectors, and Plf is path loss.
We defined free space loss as the ratio of the received power to the transmitted power.
We can calculate Plf from the next equation:

$$Plf = 32.45 + 20log(d) + 20log(fr) \tag{4.2}$$

d is the distance between two antennas by Km and fr is operation frequency.[11]
We can calculate the distance by the next equation[12]:

$$d > \frac{2\,D^2}{\lambda} \tag{4.3}$$

In this case, the distance must be greater than 1m.
All losses did not change between the two measures because we used the same cables (SMA cable) and two connectors, Ga1 and Ga2, which are 15 dB, from the datasheet we applied 0dBm for transmitter power. This calculation was the reference. We used a generator and spectrum analyzer to calculate the transmitter power and receiver power. All these measurements were performed in a laboratory setting. Figure 4-3 shows the system.

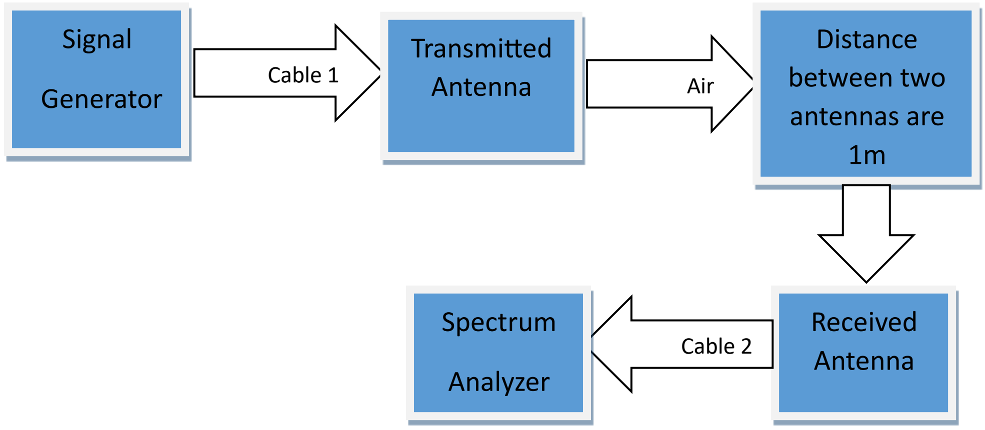

Figure 4-3 Block diagram of gain measurement system

After that, we measured the receiver power for the horn antenna which was -31dBm. As the next step, we changed the receiver horn antenna with the proposed antenna with the same material. By changing the receiver antenna, the measure was found as -40dBm.
From the equation (4.1), we calculated the gain at 3.1 GHz

$$-31 = 0 + Ga_1 + 15 - loss \quad \text{reference antenna} \quad (4.4)$$

$$-40 = 0 + Ga_1 + Ga_2 - loss \quad \text{proposed antenna} \quad (4.5)$$

When (4.4) was subtracted from (4.5), we got the gain of the proposed antenna.
The same procedure has been applied to another frequency (5.6 GHz)
Table 4-2 shows:

Table 4-2.The comparison between the simulated gain and measured gain.

Parameter	Frequency at 3.1	Frequency at 5.6
The reference antenna (measured of received power)	-31dBm	-17dBm
Proposed antenna (measured of received power)	-40dBm	-30dBm
The gain (measured)	6dB	2dB
The gain (simulation)	8dB	1.17dB

From this table, we can say that there is a broad consensus in gain between simulation and measurement.

4-CONCLUSION

This paper aimed to design a small dual-band microstrip patch antenna, which allows you to connect wirelessly for tighter access to locations and is often used for devices such as cellular or dual-band wireless access points. The dual band antenna was simulated with 0.8 substrate thickness, the simulation result of s11 was -22 dB and -15 dB at frequencies 3.9 and 5.5 GHz,

respectively., and a gain of around 7 dB. Considering these performance results, for many devices, dual-band antennas are a stable and easy way to connect to the things you need.
Two rectangular slits are joined to achieve the dual-band: one at the base of the ground plane and the other at the broad portion of the L-shaped slot. Roughly 1/4λ is the length of the first rectangular slit at the lower frequency f1 = 3.1GHz, and roughly 1/4λ is the length of the second slit at the higher frequency f2 = 5.4GHz. A small-sized, dual-band slot antenna design was suggested. The L-shaped slot and the micro-strip-fed line may be simply adjusted to achieve good impedance matching, and two parasitic slits can be embedded to quickly create rejected bands at 3.5 GHz and 5.5 GHz. In the future, it would be wise to concentrate on how to design small antennas below 1GHz with the same advantages as the small size and good gain.

5-ACKNOWLEDGE

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