A CIRCULARLY POLARZIED TRIANGULAR SLOT RECONFIGURABLE ANTENNA FOR WIRELESS APPLICATIONS

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ABSTRACT

Today's remote shopper gadgets, intended for indoor correspondence needs high information rate. In addition, therefore correspondence like Bluetooth, WLAN, WiMAX, and HIPERLAN-2 needs compact antenna with wide bandwidth. The channel capacity having higher bandwidth improves the date rate of compact antennas. Slot antenna has attractive features such as wider bandwidth, low profile, lightweight, easy integration with microwave monolithic integrated circuits, low cost and eases fabrication. A circularly polarized antenna gives a flexible orientation of the transceiver and it also helps to combat multi-path fading effects in a diverse environment.

In this project, a coplanar waveguide feed (CPW) slot antenna for wide band application with circular polarization is designed and experimentally validated. The triangular slot is excited using a CPW microstrip feed line which is terminated on a rectangular shaped tuning stub. To achieve circular polarization, inverted L shape strip are attached to the ground plane and to achieve the wide band the two arcs are also attached in the ground plane. The proposed antenna provides a wider bandwidth 10GHz (3GHz - 13GHz). The gain of the antenna is enhanced by using a double layered square loop frequency selective surface (FSS). The FSS is used as a reflector that is placed beneath the antenna at on optimum distance of 9mm.

The gain improvement is about 3.36dB at most of the operating band. Antenna parameters like radiation efficiency, radiation pattern for different operating frequency, return loss characteristics and directivity have been evaluated. After getting maximum gain the frequency reconfigurable technique is included. The frequency reconfigurable technique can be achieved by using switches. The complexity of the DC bias is decreased by using minimum number of switches. Hence the proposed antenna has one switch and it is attached to the rectangular slot. When the switch is in ON state, the antenna covers the frequency range from 3.6GHz-13GHz. When the switch is in OFF state, the antenna covers 3.5GHz-3.7GHz, 5.3GHz-6.6GHz & 9GHz-13GHz. The proposed CPW triangular slot antenna is designed and simulated using HFSS (High frequency structural simulator) software, fabricated and tested using network analyzer. This antenna is applicable to the wireless services like WLAN, GPS, PCS, CDMA, WIFI, WIMAX and satellite services like Fixed Satellite Service (FSS), FSS military, terrestrial earth exploration, meteorological satellites.

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LIST OF ABBREVIATIONS

ABBREVATIONS	NOMENCLATURE
WLAN	Wireless Local Area Network
WiMAX	World Wide Interoperability For Microwave Access
HIPERLAN	High performance Radio Local Area Network
CPW	Coplanar Waveguide Feed
FSS	Frequency Selective Surface
HFSS	High Frequency Structural Simulator
WPAN	Wireless Personal Area Network
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
EDGE	Enhanced Data GSM Environment
UMTS	Universal Mobile Telecommunications System
WAP	Wireless Application Protocol
PCS	Personal Communication System
PIFA	Planar Inverted-F Antenna
CP	Circular Polarization
RHCP	Right Hand Circular Polarization
VSWR	Voltage Standing Wave Ratio
RFID	Radio Frequency Identification
FR4	Flame Retardant
FEM	Finite Element Method
EM	Electromagnetic Field

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Wireless is a term used to describe telecommunication in which electromagnetic waves carry the signal over part or the entire communication path. Common examples of wireless equipment in use today include: cell phones, pagers, GPS, cordless computer peripherals such as wireless keyboards, cordless telephone sets, remote garage-door openers, two-way radios, satellite televisions, wireless local area network (WLAN) and wireless personal area network (WPAN). Wireless technology is rapidly evolving, and is playing an increasing role in the lives of people throughout the world. In addition, ever larger numbers of people are relying on wireless technology, either directly or indirectly. More recent examples of wireless communications include the following technologies:

- **Global System for Mobile Communication (GSM):** a digital mobile telephone system used in Europe and other parts of the world;

- **General Packet Radio Service (GPRS):** a packet-based wireless communication service that provides continuous connection to the internet for mobile phone and computer users;

- **Enhanced Data GSM Environment (EDGE)**: a faster version of the Global System for Mobile (GSM) wireless service designed to deliver data at rates up to 384 Kbps and enable the delivery of multimedia and other broadband applications to mobile phone and computer users;

- **Universal Mobile Telecommunications System (UMTS):** a broadband packet based system offering a integrated set of services to mobile computer and phone users no matter where they are located in the world;

- **Wireless Application Protocol (WAP):** a set of communication protocols to standardize the way that wireless devices, such as cellular telephones and radio transceivers, can be used for internet access.

Wireless can be divided into three categories: fixed, mobile, and portable. Fixed wireless refers to the operation of wireless devices or systems in fixed locations such as homes and offices. Mobile wireless applications refer to devices or systems aboard moving vehicles. Examples include the automotive cell phone and onboard GPS system. Portable wireless applies to the operation of autonomous, battery-powered wireless devices or systems outside the office, home, or vehicle; examples include handheld cell phones and personal communication system (PCS) units. Recent technologies enable wireless communication devices to become physically smaller in size. Antenna size is obviously a major factor that limits miniaturization. Antenna physical size is inversely proportional to its operating frequency. However, reducing the antenna physical size also means reducing its electrical size since the operating frequency of these devices does not change. Electrical size is expressed as a fraction of wavelength, λ. For example, the electrical size of a half-wave dipole antenna operating at 1800 MHz ($\lambda = c/f = 16.6$ cm) is 8.3 cm long because its electrical size is 0.5 λ. If a wireless device is required to have a physically small antenna, say half the size or 4.15 cm, and still operate at 1800 MHz, then it requires an antenna with a physical size of 4.15 cm, corresponding to an electrical size of 0.25 λ. Many applications at around 1800 MHz require antennas in the order of 0.25 λ or less. Examples of antennas of quarter-wavelength electrical size that are used include monopole antennas, slot antennas, helical antennas, and PIFAs (planar inverted-F antenna).

In the past few years, new designs of low-profile antennas for handheld wireless devices have been developed. The major drawback of many low-profile antenna designs is their narrow impedance bandwidth. Some designs can barely cover the bandwidth requirement and hence, may not be used because there is no margin in the bandwidth for potential detuning effects due, for example, to the presence of a human operator. Furthermore, the market trend of personal wireless devices is moving toward a universal system that can be used anywhere. Rapid expansion of the wireless communication industry has created a need for connectivity among various wireless devices using short-range wireless links in the Bluetooth operating band to get rid of the cable connections.

This requires therefore multiple frequency band operation. A list of a few useful wireless applications and their operating frequencies is shown Table 1.1. Dual-band and tri-band compact antennas have been realized to help the transition of new wireless system generations go smoothly but the current market demand needs wireless systems to operate in more than three bands especially wide band. In summary, physically small size, wide bandwidth, and high efficiency are the desired characteristics of antennas in wireless communication systems.

Table 1.1: Frequency Bands for a Few Popular Wireless Applications

Wireless Applications	Frequency Band (GHz)	Bandwidth (GHz)
Bluetooth	2.4-2.5	1
WLAN	5-5.8	0.8
WiMAX	3.3-11	7.7
Satellite service	8-8.4	0.4

In this project, the design flow of a triangular-slot microstrip patch antenna for wireless application such us WLAN, WiMAX, using HFSS software will be described. This antenna design can produce the multiple resonant modes and a much wider bandwidth. It can also provide a circular polarization where the polarization of the antenna will be following the direction of the maximum gain. A circularly polarized antenna gives a flexible orientation of the transceiver and it also helps to combat multi-path fading effects in a diverse environment. For achieving the bandwidth enhancement various slots are cut in the main patch. Various slots are shaped in the radiating patch to manage the current flow on the antenna surface. Slot dimensions are varied to improve various parameters like gain, return loss. The gain of the antenna is enhanced by using a double layered square loop frequency selective surface (FSS).

After getting maximum gain, the frequency reconfigurable technique is included in the proposed antenna. The proposed antenna can be reconfigured using switch S. The switch acts as a perfect conductor when its is ON. Some advantages of WiMAX application is single station can serve hundreds of users, much faster deployment of new

users comparing to wired networks, speed of 10 Mbps at 10 kilometers with line-of-sight, it is standardized, and same frequency equipment should work together and the advantages of WLAN are listed as below

➢ Flexibility: within radio coverage, nodes can communicate without further restriction. Radio waves can penetrate walls.

➢ Planning: wireless ad hoc networks allow for communication without planning. Wired networks need wiring plans,.

➢ Robustness: wireless networks can survive disasters, if the wireless devices survive people can still communicate.

Circular polarization (CP) is commonly used and more suited to antennas used in mobile communication, due to their insensitivity to the transmitter and receiver orientation process. The detailed explanation of this project is described in the following chapter.

1.2 PROJECT OBJECTIVE

➢ Design, simulate and fabricate a circularly polarized triangular slot reconfigurable antenna for wireless applications and also analyse the antenna parameters such as Gain, VSWR, Radiation pattern.

➢ Improve the antenna performance by adjusting the antenna dimensions and its shape.

Basic design specifications for a triangular slot antenna are listed in Table 1.2,

Table 1.2: Antenna Specifications

FEATURE	VALUE OR TYPE
Bandwidth	10GHz(3GHz-13GHz)
Return Loss	<-10dB
Circuit Board Material	FR4
Substrate thickness	1.6mm
Relative permittivity	4.4
Characteristic Impedance	50Ω

CHAPTER 2
LITERATURE REVIEW

1) R.V.S Ram Krishnaa, Raj Kumarb, Nagendra Kushwahaa**, "A circularly polarized slot antenna for high gain applications,"** Int. J. Electron. Commun.(AEÜ) 68 (2014) 1119–1128.

A coplanar waveguide feed slot antenna for wideband circular polarization is designed and experimentally validated. The rectangular slot is excited using a stepped feed line terminated on a circular disc shaped tuning stub. To obtain circular polarization, inverted L-shaped strips are attached to the ground plane at the opposite corners while a rectangular slit is cut in the circular disc. The combined bandwidth (3-dB axial ratio and 10 dB impedance matching) achieved is 48% (4.35–7.1 GHz) under simulation and 40% (4.75–7.1 GHz) in measurement. The CP bandwidth realized is 40% centered at 6 GHz while the impedance bandwidth attained is 121% (from 2.5 to 10.2 GHz). The CPW feed is used in this paper. In particular, the coplanar waveguide (CPW) fed slot antenna is preferred for its cost efficient uniplanar structure and wider bandwidth. The uniplanar structure also reduces misalignment errors to a large extent. In addition, the CPW feed is characterized by less dispersion, low radiation loss and ease of integration with monolithic microwave integrated circuitry. The gain of the antenna is next enhanced by the application of a double layered square loop frequency selective surface. The frequency selective surface is used as a reflector placed beneath the antenna at an optimum distance. An improvement of about 4 dB is seen in the measured peak gain over most of the operating band. To improve the gain of the antenna, two frequency selective surface designs are presented. The first is a square loop designed at the center frequency of 7.33 GHz which improves the antenna gain by about 4 dB. The second is a patch type frequency selective surface which, besides enhancing the gain, retains the axial ratio bandwidth achieved without the frequency selective surface.

2) Sze J-Y, Hsu C-IG, Chen Z-W, Chang C-C, **"Broadband CPW-fed circularly polarized square slot antenna with lightening-shaped feed line and inverted-L grounded strips,"** IEEE Trans Antennas Propagation 2010;58(3):973–7.

A new broadband circularly polarized (CP) square slot antenna is evaluated numerically and verified experimentally. The proposed antenna used a lightening-shaped feed line protruded from the signal line of the feeding coplanar waveguide (CPW). The antenna is etched on a square 0.8 mm FR4 substrate, relative permittivity $\varepsilon r = 4.4$ and loss tangent of $\tan \delta = 0.02$. The overall dimensions of the antenna are $60 \times 60 \times 0.8$ mm^3. The characteristics of the proposed CP antenna have been simulated by Ansoft High Frequency Structure Simulator (HFSS) software and measured by Agilent N5230A network analyzer. Two symmetrical F-shaped slits embedded in opposite corners of ground plane are designed to obtain an excellent CP bandwidth. The radiation efficiency of the antenna is about 50% to 60%. It can be seen that although the efficiency shows some level of decrease with the improvement of impedance bandwidth, it is acceptable for the circularly polarized antenna. By adjusting the dimensions of the lightening-shaped feed line, the CP bandwidth can be further enhanced. The lightening-shaped feed line is used for enhancing the AR bandwidth. The antenna performs a wide bandwidth due to the two resonant modes which are excited by the lightening-shaped feed line and F-shaped slits. Measured results show that the 3 dB axial ratio bandwidth of the proposed antenna can reach 51.7% (2150 MHz– 3650 MHz), and the impedance bandwidth is as large as 60.2% (2150 MHz–4000 MHz) with VSWR ≤ 2. Measured results are in good agreement with the simulation.

3) Mudar Al-Joumayly, and Nader Behdad, **"A New Technique for Design of Low-Profile, Second-Order, Band pass Frequency Selective Surfaces,"** IEEE transactions on antennas and propagation, vol. 57, no. 2, February 2009.

In this paper, a new method for designing low profile frequency selective surfaces (FSS) with second-order band pass responses is presented. The FSSs designed using this technique utilized non-resonant sub-wavelength constituting unit cells with unit cell dimensions and periodicities in the order of 0.15λo. It is demonstrated that using the proposed technique, second-order FSSs with an overall thickness λo/30 of can be designed. This is considerably smaller than the thickness of second-order FSSs designed using traditional techniques and could be particularly useful at lower frequencies with long wavelengths. The FSS structure is composed of three different metal layers separated from one another by two very thin dielectric substrates. The top and bottom metal layers consist of two, two-dimensional (2-D) periodic arrangements of sub wavelength capacitive patches. The center metal layer consists of a 2-D periodic arrangement of metallic strips in the form of a wire grid. A FSS is a periodic structure usually composed of an assembly of identical elements arranged in a one or two-dimensional lattice. In their simplest form, these elements can be in the form of metallic patches with a specific pattern or the complementary of the metal patches having apertures similar to the metallic patches etched in a ground plane. Similar to microwave filters, frequency selective surfaces can have low-pass, high-pass, band pass, or band-stop frequency responses. However, unlike microwave filters, these responses depend not only on frequency but also on the polarization and angle of arrival of the incident electromagnetic wave. Traditional FSS design techniques often use periodic arrays of resonant elements to achieve band pass. To facilitate the design of this structure, an equivalent circuit based synthesis method is also presented in this paper. Two band pass FSS prototypes operating at X-band are designed, fabricated, and tested. A free space measurement setup is used to thoroughly characterize the frequency responses of these prototypes for both the TE and TM polarizations and various angles of incidence. The frequency responses of these structures are shown to have a relatively low sensitivity to the angle of incidence.

4) Lin Dang, Zhen Ya Lei, Yong Jun Xie, Gao Li Ning, and Jun Fan , **"A Compact Microstrip Slot Triple-Band Antenna for WLAN/WiMAX Applications,"** IEEE antennas and wireless propagation letters, vol. 9, 2010.

A compact triple-band microstrip slot antenna applied to WLAN/WiMAX applications is proposed in this paper. This antenna has a simpler structure than other antennas designed for realizing triple-band characteristics. It is just composed of a microstrip feed line, a substrate, and a ground plane on which some simple slots are etched. The configuration of the triple-band slot antenna is designed and fabricated on a substrate with FR4, relative permittivity of 4.4, and a loss tangent of 0.02. The entire size of the antenna is only 35x30x1.6 mm^3 . Without loss of generality, a 50-Ω microstrip feed line with a width of 3 mm is adopted for centrally feeding the antenna at one side of the substrate. Some simple slots are etched on the ground plane to provide all the work bands. The rectangular slot can achieve the lowest resonant frequency. The trapezoid slot, which is a resistance gradual changing structure, provides the highest resonance and makes impedance matching in a wideband range. The strips embedded in the rectangular slot are used for feeding and providing the middle work band. Then, to prove the validation of the design, a prototype is fabricated and measured. The experimental data show that the antenna can provide three impedance bandwidths of 600 MHz centered at 2.7 GHz, 430 MHz centered at 3.5 GHz, and 1300 MHz centered at 5.6 GHz. Nearly Omni directional radiation patterns in the yz plane and dipole-like radiation patterns in the xz plane are obtained at these frequencies. . The antenna gain had a peak value of 3.86 dBi at 2.5 GHz, 3.52 dBi at 3.5 GHz, and 4.32 dBi at 5.5 GHz, respectively. The measured results show that the obtained impedance bandwidths are 22.2% (2.4–3.0 GHz), 12.3% (3.25–3.68 GHz), and about 23.2% (4.9–6.2 GHz), respectively, good enough for WLAN and WiMAX applications. In addition, the proposed antenna has good radiation characteristics and gains in the three operating bands, so it can emerge as an excellent candidate for multiband generation of wireless.

5) Wang C-J, Chen C-H, **"CPW-fed stair-shaped slot antennas with circular polarization,"** IEEE Trans Antennas Propagation 2009;57(8):2483-6.

The design is described of a coplanar-waveguide (CPW)-fed circularly polarized slot antenna. The slot antenna and the feeding structure are fabricated on the same plane of the substrate so that circuit process and position alignment could be simplified. The schematic configurations of the proposed CP slot antenna dimension with $60 \times 40 \times 1.6 mm^3$. FR-4 is used as a substrate in the proposed antenna with the dielectric constant of 4.4 and the thickness of 0.8 mm, respectively. The performance of the antennas was simulated using Ansoft High Frequency Structure Simulator (HFSS) and the scattering parameters were measured with an Agilent N5230A network analyzer. A stair-shaped slot is etched on the ground plane of the substrate. A protruded strip of width 3mm is connected to a 50-Ω CPW transmission line. By etching a longitudinal slot at a middle point of a stair-shaped slot and tuning geometrical parameters, two orthogonal electric fields with quadrature phase difference excite a circularly-polarized wave. A bandwidth of 31.2% (2.30–3.15 GHz) is achieved with an axial ratio <3 dB and reflection coefficient <-10 dB. The circular polarization of the proposed stair-shaped slot antenna is right-hand (RH). For the no-cavity antenna, the CP of the antenna in the bore sight direction is the opposite polarization. The reason is that the vertical component of the electric field on the top and bottom surface of the substrate remains the same phase; however, the horizontal component of the electric field on the top and bottom surface of the substrate is 180 out of phase. By adding a cavity and filling absorbing material, a unidirectional radiation pattern is obtained. The gain of the no-cavity antenna at 2.4 GHz is 3.7 dBi. The proposed antenna is very simple and may be a candidate of a radiating element for multifunctional devices of wireless communication systems, such as Wi-Fi (at 2.45 GHz), the satellite digital audio radio system (RHCP at 2.6 GHz) and WiMAX (at 3.5 GHz).

6) Abdelheq Boukarkar, Xian Qi Lin, Yuan Jiang, **"A New Reconfigurable Multi-band Monopole Antenna for Different Wireless Applications,"** IEEE International Conference on Communication Software and Networks, 2015;978-1-4799-1984-0.

In this paper, a compact reconfigurable multi-band antenna is proposed. The substrate used for this antenna is F4B with a dielectric permittivity of 2.55 and loss tangent of 0.002. The thickness of the substrate is 0.764 mm. The ground plane is printed on the bottom side of the substrate. The total size of the antenna is 30 x 30 x 0.764 mm^3. The inverted U shape geometry was used to increase the electrical size of the antenna without increasing its physical size. The antenna can be reconfigurable using two switches S1 and S2. These two switches acts as a perfect conductors when their states are on. Depending on their states, different frequency bands are selected. Resonant frequencies are obtained by adjusting the lengths L1, L2, and L3. If two switches are on state it cover 2.2GHz & 5.5 GHz and both switches are off state it covers 4.5GHz. If S1 is on S2 is off it covers 2.45GHz & 5.8GHz and S1 is off S2 is on it covers 4.5GHZ & 6GHz. The. antenna has the particularity of using only two switches to achieve more than three frequency bands. The complexity of the DC biasing circuit is decreased by using a reduced number of switches. The antenna can be used practically to cover the following frequency bands: UMTS/IMT-2000, ISM, some wireless communications using the frequency 4.5GHz like INSAT, and WLAN bands.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 INTRODUCTION TO ANTENNA

An antenna is a device that provides a transition between electric currents on a conductor and electromagnetic waves in space. A transmitting antenna transforms electric currents into radio waves and a receiving antenna transforms an electromagnetic field back into electric current. The main property of the antenna is Reciprocity. Reciprocity means that the antenna's electrical characteristics are the same whether it is used for transmitting or receiving. Because this is always true, the antenna is a transitional structure between free-space and a guiding device and the guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. In the former case, they have a transmitting antenna and in the latter a receiving antenna.

A Thevenin equivalent of the antenna system in the transmitting mode is shown in Figure 3.1 where the source is represented by an ideal generator, the transmission line is represented by a line with characteristic impedance Zc, and the antenna is represented by a load Z_A [$Z_A = (R_L + R_r) + jX_A$] connected to the transmission line.

$$Z_A = (R_L + R_r) + jX_A$$
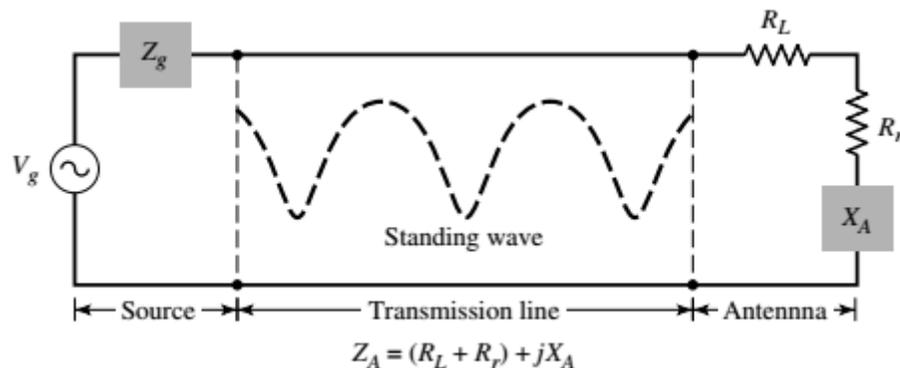
Figure 3.1: Thevenin equivalent of antenna in transmitting mode

The antenna used in systems such as radio broadcasting, broadcast television, two-way

radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones Bluetooth-enabled devices, wireless computer networks, baby monitors, RFID tags on merchandise, etc.

3.1.1 Basic Concept of Microstrip Patch Antenna

A microstrip patch antenna has been one of the most innovative topics in antenna theory and design. Microstrip antennas are designed to have many geometrical shapes and dimensions but rectangular and circular microstrip patches have been used in many applications. They are used in wide range of modern microwave applications because of their simplicity and compatibility with printed-circuit technology.

A microstrip patch antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in Figure 3.2. The bottom surface of a thin dielectric substrate is completely covered with metallization that serves as a ground plane. The rectangular microstrip patch antenna is made of a rectangular patch with dimensions width (W) and length (L) over a ground plane with a substrate thickness (h) and permittivity (ε_r). The length (L) of the patch is usually $\lambda_O/3 < L < \lambda_O/2$ and the thick of the patch is very thin (t $<<\lambda_O$).
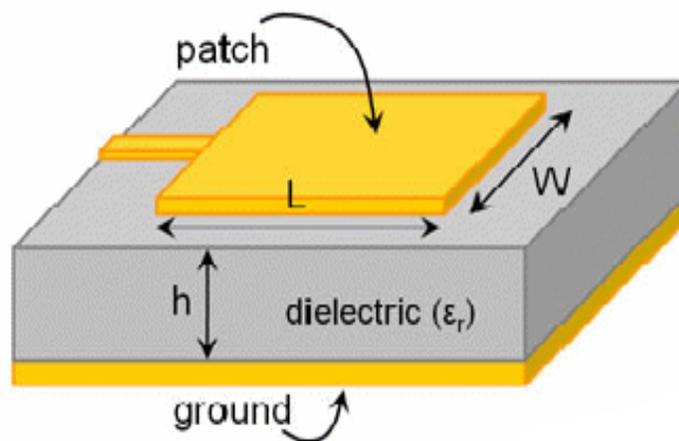
Figure 3.2: The simplest microstrip patch antenna

The patch is generally made of a conducting material like gold or copper. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edges by variety of methods. The patch is in fact electrically a bit larger than its physical dimensions due to its fringing fields.

3.1.2 Types of Microstrip Patch Antenna

There are different types of microstrip patch antennas which can be classified based on their physical parameters. The patch may be square, rectangular, dipole, circular, triangular, circular ring, elliptical or any other configuration. These are illustrated in Figure 3.3. The rectangular microstrip patch antenna is the widely used because of ease of fabrication and analysis. This type is also robust and very eases to handle.
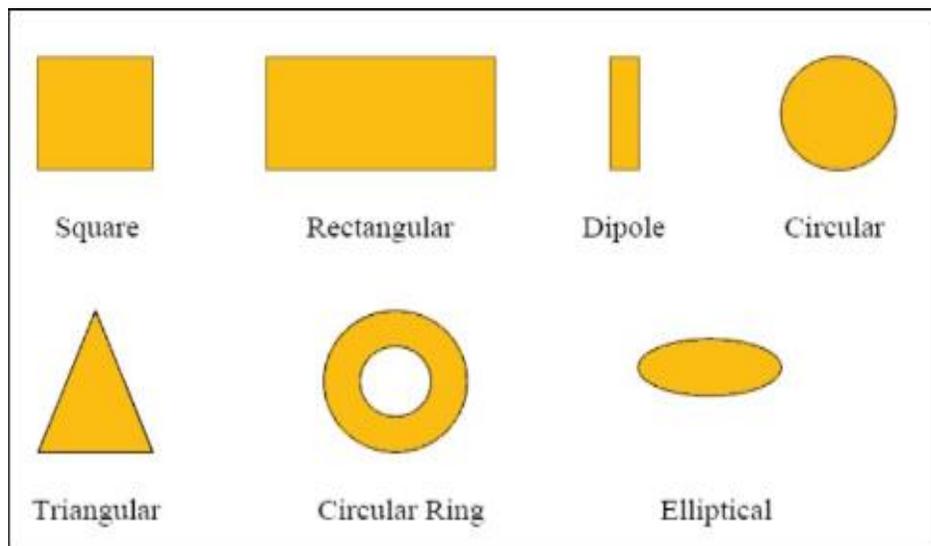
Figure 3.3: Common shapes of microstrip patch antenna

3.1.3 Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories, contacting and non-contacting. In the contacting

method, the RF power is fed directly to the radiating patch using a connecting element such as microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe, aperture coupling and proximity coupling.

3.1.4 Return Loss

Return loss is an important parameter when connecting an antenna. It is a way to characterize the input and output of signal sources. The return loss is related to impedance matching and the maximum transfer of power theory. When the load is mismatched, not all the available power from generator is delivered to the load. This return loss is also a measure of the effectiveness of an antenna to deliver power from the source to the antenna. The return loss, R_L shows the level of the reflected signal with respect to the incident signal in dB. It is defined by the ratio of the incident power of the antenna P_{in} to the power reflected back from the antenna of the source P_{ref}. The mathematical expression is:

$$R_L = -20 \log_{10}|\Gamma| (dB) \tag{1}$$

Where $|\Gamma|$ is determined by:

$$|\Gamma| = \frac{P_{in}}{P_{ref}} = \frac{Z_L - Z_O}{Z_L + Z_O} \tag{2}$$

The Z_L and Z_O are the load and characteristic impedance.

For good power transfer, the ratio P_{in}/P_{ref} shall be high. If the return loss is low, the standing wave phenomena's or resonances might occur, and it will end up in the frequency ripple or gain. During the process of the design of microstrip patch antenna there is a response taken from the magnitude of S_{11} versus the frequency which known as the return loss. In most practical circuits a return loss value of -10 dB is good enough.

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3.1.5 Gain

Gain is a useful measurement describing the antenna performance. Although the gain of the antenna is closely related to directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Antenna gain is usually expressed in dB,

Mathematically the maximum gain, G is obtained by

$$G = \eta D \qquad\qquad (3)$$

Where, η = efficiency and D = directivity

3.1.6 Directivity

It is desirable to maximize the radiation pattern of the antenna response in a fixed direction to transmit or receive power. Likewise, the directivity is dependent only on the shape of radiation pattern. It is always referenced to an isotropic point source as in Figure 3.4. A quantitative measure of this response is the directive gain of the antenna for a given direction.
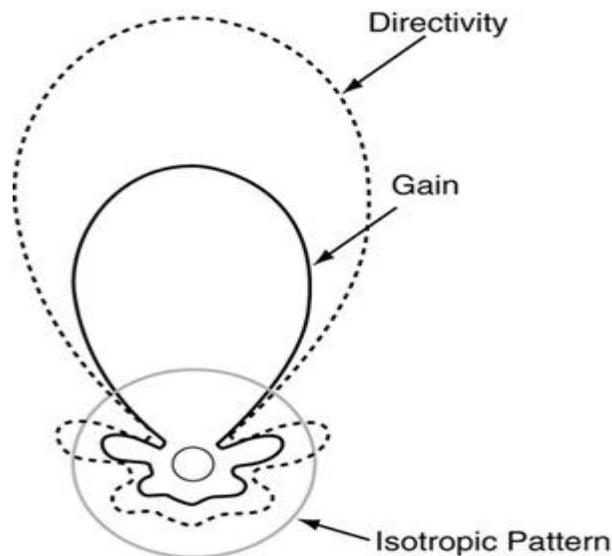
Figure 3.4: Directivity of an antenna

3.1.7 Radiation Pattern

The power radiated or received by an antenna is a function of the angular position and radial distance from the antenna. The radiation pattern is represented in the form of a three dimensional graph of power versus elevation and azimuth angles but more commonly represented by E-plane or H-plane where one angle is held fixed while the other is varied.

3.1.8 Bandwidth

The bandwidth of an antenna is defined as the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency. The bandwidth is given by the expression:

$$\text{Bandwidth}_{\text{ narrow band}} (\%) = [\frac{f_H - f_L}{f_c}] \text{ x } 100\% \tag{4}$$

Where,

$$f_H = \text{upper frequency}$$
$$f_L = \text{lower frequency}$$
$$f_C = \text{center frequency}$$

3.1.9 Antenna Efficiency

The antenna efficiency is defined as the ratio of total power radiated by the antenna to the input of the antenna. The total antenna efficiency is used to take into account losses at the input terminals and within the structure of the antenna. An antenna may dissipate power due to conductor loss or dielectric loss. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency

antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

3.1.10 Polarization

The polarization of an antenna is defined as the polarization of the wave transmitted or radiated by the antenna. Whenever, the direction is not stated, the polarization of the antenna will be following the direction of the maximum gain. It is known that a rectangular patch with a conventional feeding will radiate linearly. However, with some modifications on the feeding techniques or the patch itself can turns to a circular polarization. The main advantage of using circular polarization is because of it as a receiver orientation so that it can always receive a signal even from different axis of transmission.

3.1.11 Substrate

There are numerous substrates that can be used for the design of microstrip patch antenna. Their dielectric constants are usually in the range of $2.2 < \varepsilon_r < 12$. The microstrip patch antenna radiates primarily because of the fringing fields between the patch edge and the ground plane. Therefore, the effective dielectric constant (ε_{reff}) must be obtained. The dielectric constants play a major role in the overall performance of the antenna. When a dielectric substrate is selected, the material with the lowest tangent (tan δ) is preferred. The loss tangent is a metric of the quantity of electrical energy, which is converted to heat by a dielectric. The lowest possible loss tangent maximizes the antenna efficiency.

The relative dielectric constant, ε_r of the substrate determines the physical size of a patch antenna. The larger the dielectric constant, the smaller the element size, but also the smaller the impedance, bandwidth and directivity and the surface wave loss increases. If the material has high dielectric constant, it reflects more RF energy and detunes the antenna more, which makes it harder to tag. The materials that are most desirable for antenna performance are thick substrates whose dielectric constant is in the lower end of

the range because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element sizes.

However, they are less efficient and have relatively smaller bandwidth because of their greater losses. Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design. Table 3.1 shows types of dielectric constant for different materials.

Table 3.1: Dielectric and Loss tangent for different materials

Material	ε_r	tan δ
Teflon (PTFE)	2.1	0.0005
Rexolite 1422	2.55	0.0007
Noryl	2.6	0.0011
FR4	4.4	0.02
Alumina	9.8	0.0003

3.1.12 Fringing Effects

Fringing fields have a great effect on the performance of a microstrip antenna. In microstrip patch antennas, the electric field in the center of the patch is zero. The radiation is due to the fringing field between the periphery of the patch and the ground plane. Higher the substrate, the greater is the fringing field. Due to the fringing effect, the microstrip patch antenna looks greater than its physical dimension. Thus, an effective dielectric constant is to be introduced. The effective dielectric constant takes in account both the fringing and the propagation in the line. Hence, when designing a patch antenna it is typically trimmed by 2-4% to achieve at the desired resonance frequency.

3.2 RECONFIGURABLE ANTENNA

Reconfigurable antennas should be able to alter their operating frequencies, impedance bandwidths, polarizations, and radiation patterns independently to accommodate changing operating requirements. Reconfigurable antennas are used in portable wireless devices, such as a cellular telephone, a personal digital assistant, or a laptop computer.

In modern day wireless devices multiple antennas are required to make sure that it can be used for multiple communication services, this not only make the system bulky but power loss is also more. In frequency reconfigurable antenna a single antenna can replace them and making the system low profile and handheld devices, more light weight and energy efficient. Combining wideband and narrowband functionality makes the antenna more useful in multimode operation and reduce size and increases flexibility of operation for users.

The advantages of reconfigurable antenna are such that,

- operating in various bands
- less power, small size
- portability.
- cost restrictions

3.2.1 Classifications and Categories of Reconfigurable Antennas

Antenna with reconfigurable feature can be of large variety and different shapes and sizes, but these can be mainly grouped in four categories based on their functionality as:

- A frequency reconfigurable antenna
- A pattern reconfigurable antenna
- A polarization reconfigurable antenna
- A hybrid antenna(combination of above stated categories)

In frequency reconfigurable antenna, the frequency tuning can be done by controlling switching circuits or manually changing the configuration of the antenna. The return loss curve shows the shifting of resonating frequency. These kind of antenna can be used in wireless devices working at different wireless services with different frequency of operation, it can also be used in advanced technology like cognitive radio. Cognitive radio is a software controlled dynamic band sharing technology to accommodate large traffic and demand of higher data rate. In case of pattern reconfigurable, antenna the radiation parameters changes in terms of shape, direction or gain. In third case polarization of the antenna can be reconfigured using diodes, the antenna can show circular, linear or elliptical polarization. These kind of antenna is necessary to reduce multipath contributions and hence employing high gain antennas. The last kind employ combination of above mentioned types, called hybrid antennas for example frequency reconfigurable antenna with pattern diversity.

3.2.2 Functional Mechanism of Reconfigurable Antennas
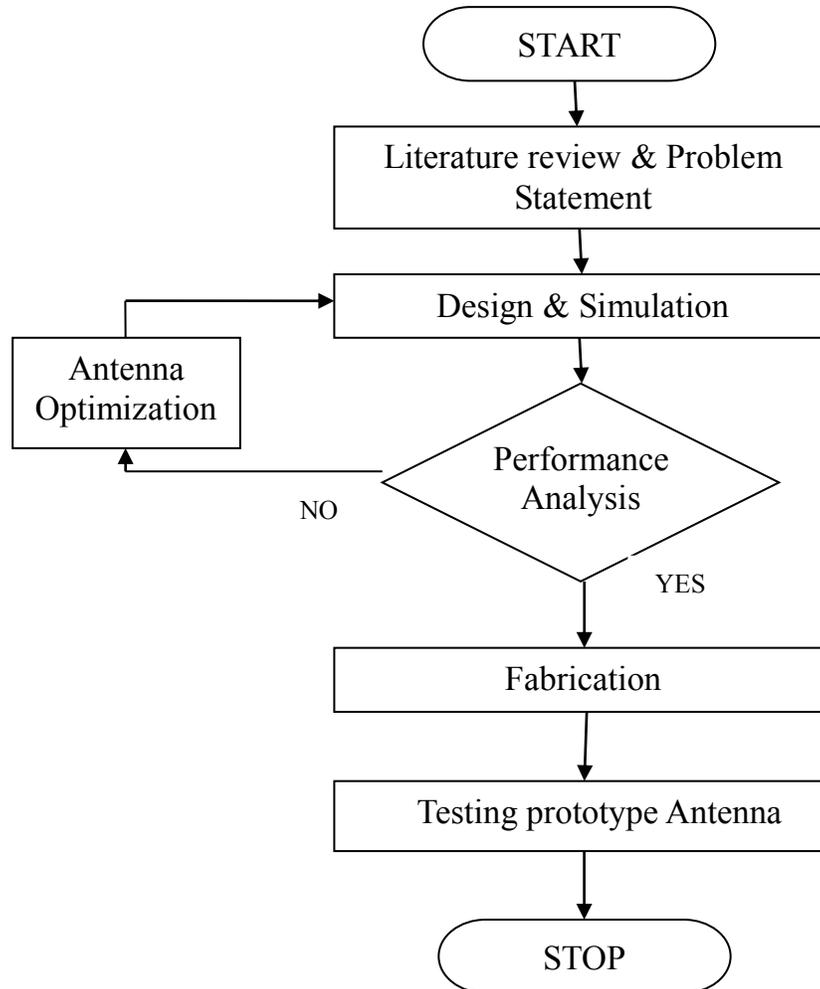
Varies types of Reconfiguration of antenna can be achieved based on these simple mechanism

1) In order to achieve frequency reconfiguration the surface current distribution has to be altered by using varies types of switches.

2) To achieve pattern reconfiguration in the antenna the radiating edges, slots or the feeding network has to be altered accordingly.

3) To achieve polarization reconfiguration in the antenna the surface structure of the antenna or the feeding network has to be altered accordingly.

4) To achieve hybrid reconfiguration above principles has to be done accordingly.

3.3 PROJECT FLOW

The project starts with the problem statement definition. Theories and previous research have been the basic reference in order to define the logic specification to achieve for the microstrip slot antenna. The predefined specification will also be considered at the

application, particularly for the WLAN & WiMAX. Figure 3.5 shows the steps required in designing the microstrip slot antenna.

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                    ┌─────────────┐
                    │    START    │
                    └──────┬──────┘
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             ┌─────────────────────────────┐
             │  Literature review & Problem │
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   │                  │   Design & Simulation  │
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┌──┴────────┐                     ↓
│  Antenna  │                  ◇ Performance ◇
│Optimization│  ←─── NO        ◇   Analysis  ◇
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                                     │ YES
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Figure 3.5: Project flow chart

3.4 ANTENNA SPECIFICATION

Basically, the performance of the antenna depends on its resonant frequency, dimension, operating frequency, radiation efficiency, directivity, and return loss. The characteristics of the antenna are defined mainly by their geometries and the material properties. The design of slot antenna requires precise physical dimensions and power feeding method for the antenna.

The triangular-slot microstrip patch antenna is designed based on three parameters. The substrate used is FR4 which has a dielectric constant of $\varepsilon r = 4.4$ and height, h = 1.6 mm. The operating frequency is 3-13GHz . The predefined specification is shown in Table 3.2. The patch is fed by a 50Ω microstrip feed line.

Table 3.2: Defined Antenna Specification

Parameters	Specification
Operating Frequency	3 - 13 GHz
Gain	> 3 dB
Return Loss	< -10 dB
-10dB Bandwidth	10GHz
Polarization	Circular

A low dielectric constant of the substrate material is used in the prototype design because it gives better efficiency and higher bandwidth. The low value of the dielectric constant will increase the radiated power. The design has a patch size independent of the dielectric constant. Therefore, the reduction in the patch size is accomplished by using higher dielectric constant. Thus, FR4 is good in this agreement. Another important design parameter is the substrate thickness, h. The thickness of the substrate increases the fringing field at the patch periphery. Therefore, the substrate height of 1.6 mm has been chosen. Typically, gain is a useful measurement describing the performance of the antenna. Although the gain of the antenna is closely related to the directivity, it is measure that takes into account the efficiency of the antenna as well as its directional capabilities. In this project, it is a requirement to obtain more than 3dB as the antenna is expected to transmit the signal at the microwave frequency of 3-13GHz.

The return loss is required to be less than -10 dB. The lesser the value indicates the better losses of the antenna. This can be achieved by providing a correct geometrical parameters and transmission line system. For the bandwidth, it is defined as 3-5% for a transmission signal.

In a microstrip feed line the conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. Patch antennas are widely used semi-directional and a patch antenna can have a beam width between 30 to 180 degrees and a typical gain of 9 dB. Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be considered as an extension of patch. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13), due to overall increase in the thickness of the microstrip patch antenna.

The triangular slot antenna design needs to have a circular polarization for the wireless application such us WLAN & WiMAX. Circular polarization is more practical compared to the linear polarization. The signal is able to be transmitted and received for not only in single direction. There are many ways to obtain the circular polarization for example, modification on the patch or the feed arrangement. CP has advanced signal propagation properties. Due to the advanced signal propagation properties, CP antenna technology offers numerous performance advantages over traditional linear technologies. When implemented as a central component within a Wi-Fi network, CP delivers better connectivity with both fixed and mobile devices and ultimately leads to a superior user experience. CP is ideal for addressing challenges associated with mobility, adverse weather conditions, and non-line-of- sight applications.

3.5 ANTENNA DESIGN WITH THEIR DIMENSION

The proposed multiband antenna is designed on a commercially available FR4 substrate with dielectric constant of about 4.4 thickness of 1.6mm, and loss tangent of 0.02.The multiband antenna has a compact size of $25x25x1.6mm^3$ and is fed by 50Ω transmission line using the microstrip feed. Geometrical configuration of the proposed antenna is shown in Figure 3.6. The dimensions of the proposed antenna and their values are shown in Table 3.3. For Simulating the antenna, glass epoxy (FR4) substrate of

relative permittivity ϵ_r=4.4, loss tangent tanδ=0.02, and thickness 1.6mm is used. The ground plane is imprinted on one side of the substrate with the measurements of W x Lmm². A triangular slot is etched on the ground plane which has dimension of Ls x Ws mm². A square patch is etched on the substrate whose length and width are represented as k and m respectively. For increasing the bandwidth the two arcs are attached in the ground plane by using the circle. The triangular slot is excited by a CPW feed line for impedance matching. The widths of the two section of the feed line are indicated by Wf and p where as the length of the section closed to the port is denoted by 'lf'.
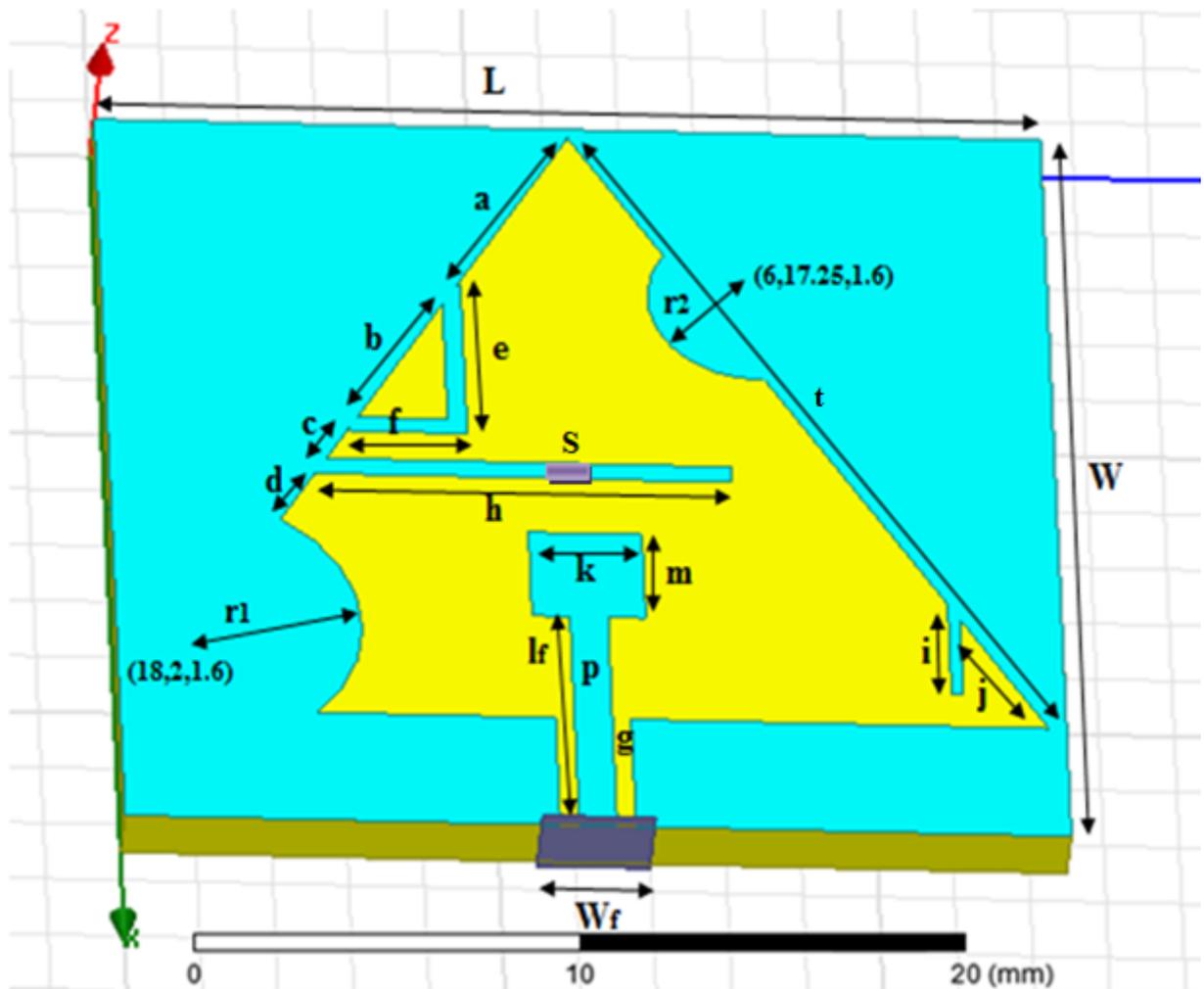
Figure 3.6: Triangular slot antenna configuration

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**Table 3.3 Antenna Dimensions**

S.No	Dimensions	Values(mm)
1	L	25
2	W	25
3	a	6
4	b	4.7
5	c	1.19
6	d	2
7	e	5
8	f	3.1
9	g	0.5
10	h	11
11	i	5
12	j	4.47
13	k	3
14	lf	7.5
15	m	3
16	p	1
17	t	14
18	r1	4.5
19	r2	2.8
20	Wf	3
21	S	1.4

The feed is terminated on a square shaped patch protruding into the slot centre. For obtaining circular polarization characteristic, inverted L-shaped strip,1mm wide are attached to the ground plane. For Frequency reconfigurability the switch S is included into the rectangular slot. If S is ON state it covers wideband and S is OFF state it covers multiple wideband.

3.6 FSS DESIGN

A 6x6 square loop FSS is designed to improve the gain of the proposed antenna. The FSS is formed by printing metallic loops on both sides of FR4 substrate. The substrate has a relative permittivity ε_r of 4.4 and thickness of 1.6mm. A schematic of the FSS is shown in Figure 3.7. The loop type FSS combines the characteristic of the patch type of the FSS and the slot type FSS and is chosen for its broadband operation. By using a double layer structure with these square loop FSS, ultra wide bandwidth can be realized.
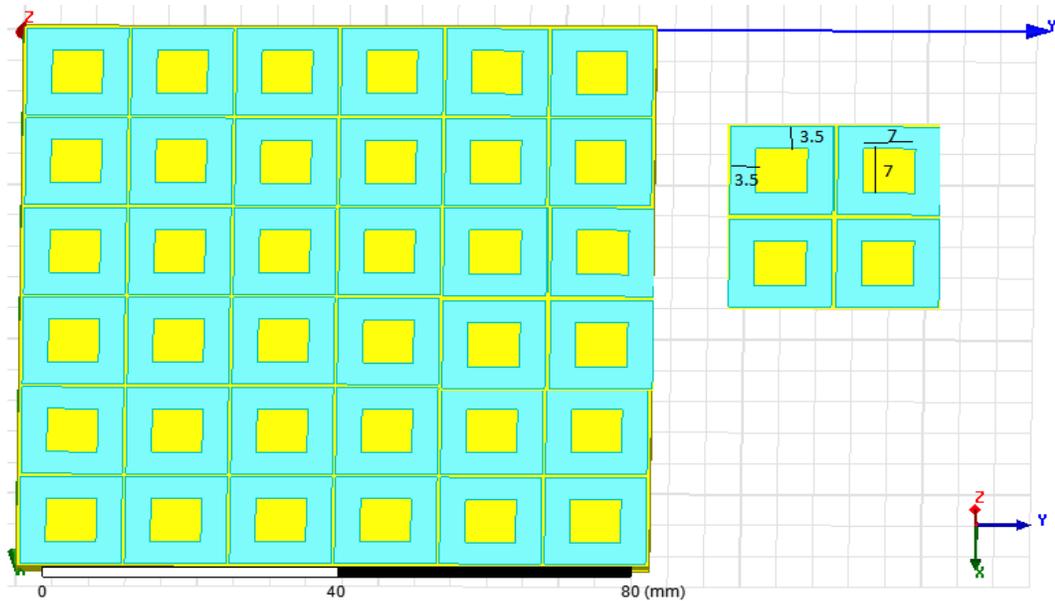
Figure 3.7: FSS Structure of the proposed antenna

A double layer square loop FSS structure is shown in Figure 3.7. An equivalent circuit for the square FSS as proposed in [12] is shown in Figure 3.8. The substrate with its characteristic impedance Z_{sub} is sandwiched between the two FSS section, each represented by a lumped inductance and capacitance in series. Z_o is the characteristic impedance of air. The values of L and C can be computed using Eqs.(5)-(8).

$$\omega L = \frac{d}{p} F(p, 2w, \lambda) \qquad (5)$$
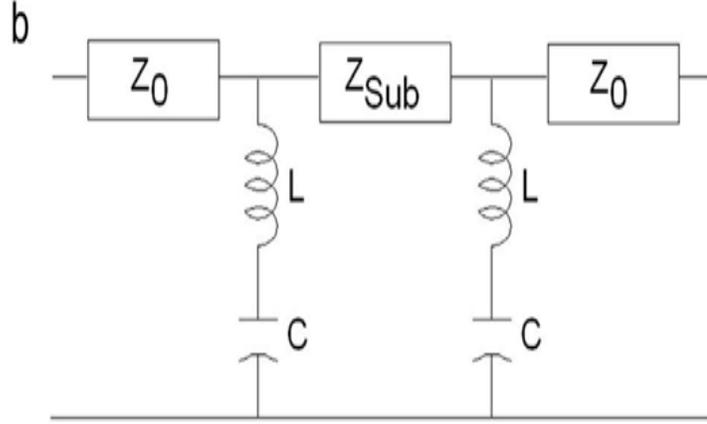
Figure 3.8: Equivalent circuit for double layer, square loop FSS

$$\omega C = 4\varepsilon_r \frac{d}{p} F(p,g, \lambda) \tag{6}$$

$$F(p,2w, \lambda) = \frac{p}{\lambda}[\ln(\text{cosec}\frac{\pi(2w)}{2p} + G(p,w,\lambda)] \tag{7}$$

$$F(p,g, \lambda) = \frac{p}{\lambda}[\ln(\text{cosec}\frac{\pi(g)}{2p} + G(p,g,\lambda)] \tag{8}$$

Here ωL is the inductive associated with L and ωC is the capacitive susceptance associated with C and G is a correction factor. The admittance of the shunt branch FSS is represented as,

$$Y = (j\omega L + \frac{1}{j\omega C}) \tag{9}$$

The magnitude of the transmission coefficient for a single layer FSS is given by

$$|\tau|^2 = \frac{4}{4+|Y|^2} \tag{10}$$

The resonance frequency can be obtained using the condition

$$\omega L = 1 / \omega C \tag{11}$$

For a single layer, square loop FSS substrate has a dielectric constant ε_r of 2.7(the mean of air and FR4), the value of ωL is $5.2416\lambda^{-1}$, ωC is $440.929\ \lambda^{-1}$. By substituting these values in Eq.(11),the calculated resonance comes out to be 6.24GHz which matches well the simulated values of 6.27GHz. Also, the transmission coefficient magnitude $|\tau|$ calculated using (9) and (10).

The separation from the antenna at which the FSS screen is to be placed is decided from the reflection phase behavior. The separation should allow for constructive interference between the radiation reflected from the FSS and the antenna radiation. For this requirement, a simple expression can be written as given in Eq.(12).

$$\Phi_{FSS}-2\beta h=2n\pi \qquad n=....-2,-1,0,1,2,... \tag{12}$$

In the equation, Φ_{FSS} is the reflection phase of the FSS. h is the distance at which the FSS is to be placed and β is the free space propagation constant is given by $2\pi/\lambda$. If the reflection phase is chosen to be 0, from Eq.(5), the optimal height can be shown $h=\lambda/2$. Hence, the optimal height can be taken equal to half of the wavelength at that particular frequency where the reflection phase of the FSS is zero as shown in Figure 3.9. Hence, the optimal height is calculated as 9mm.
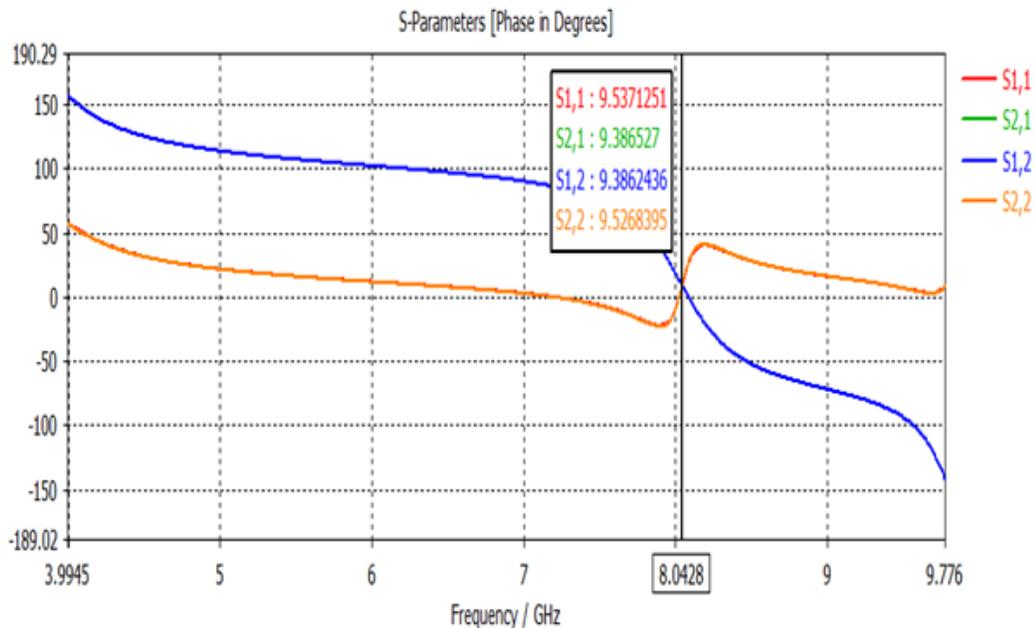

Figure 3.9: S-Parameters (transmission coefficient S_{12} and reflection coefficient S_{11})

3.7 ANTENNA SIMULATION TOOL

The software used to model and simulate the triangular-slot microstrip antenna is HFSS (High Frequency Structural Simulator). Figure 3.10 shows a screenshot of Ansoft-HFSS main window. This software provides a user-friendly interface to handle multiple projects and views at the same time. Modelling with HFSS allows the use of an interactive mouse for data input, design capture, template assistance for specific applications and fully parametric 3D modeling. The navigation tree is an essential part of the user interface where the structural elements and simulation results may be accessed.

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for 3D volume and it employs the Finite Element Method (FEM), adaptive meshing & brilliant graphics. It is an interactive simulation system whose basic mesh element is a tetrahedron. A history list permits unlimited 'undo' and 'redo' functions for editing. The software also has advanced solid modelling features and Boolean operations such as adding and subtracting solid objects from existing structures. Simulation materials can be arranged in layers, whether they are isotropic or anisotropic, linear or non-linear, magnetic or nonmagnetic. RF energy excitation sources include waveguide ports, lumped ports, and discrete voltage and current sources.

The post-processing includes the VSWR and Smith chart plots, port signal plots, polar radiation pattern plots, and 2D and 3D field plots. The software can also calculate and plot the antenna axial ratio, which is important for circularly and elliptically polarized antennas. The first step in the antenna design processes is determining the criteria to use in selecting an optimal antenna. The first criterion is to achieve power transfer from the feed transmission line to the antenna. This is accomplished by matching the antenna input impedance to the characteristic impedance of the transmission line.
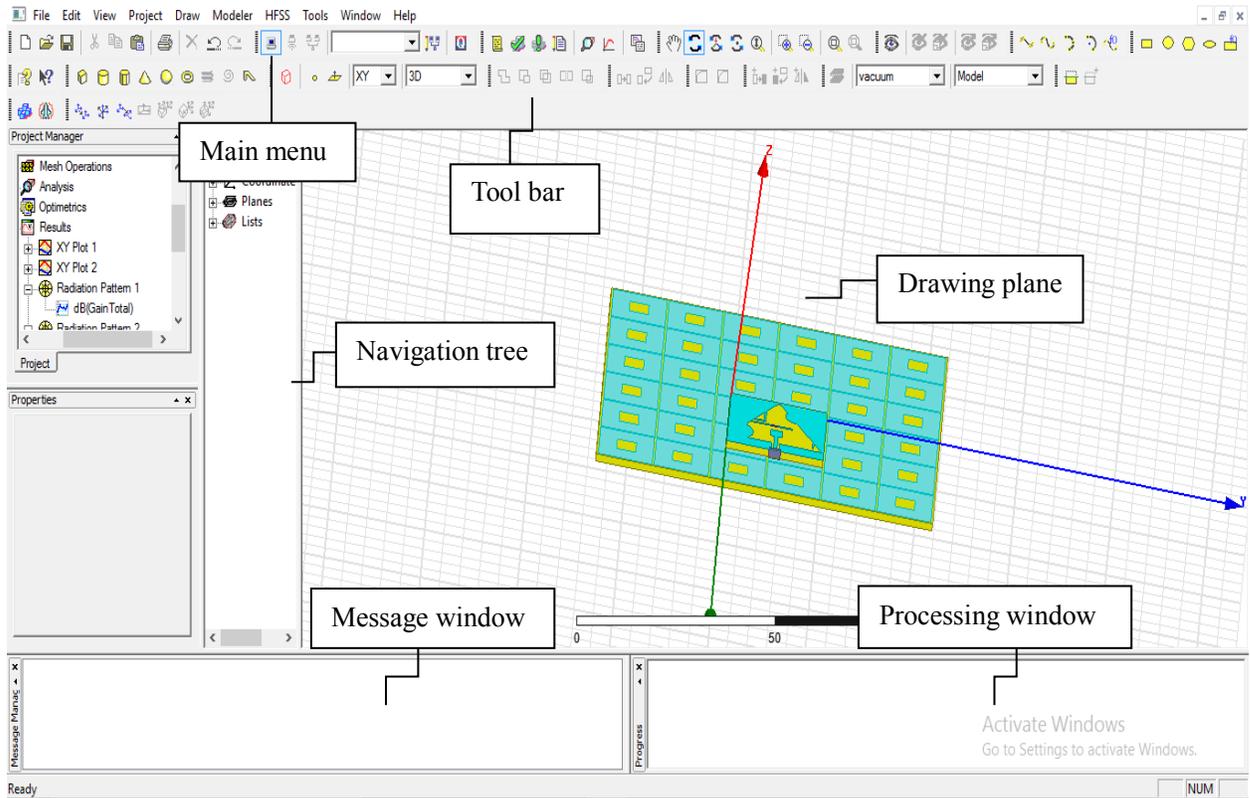
Figure 3.10: A screenshot of HFSS main window

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 ANTENNA WITHOUT FSS SUBSTRATE

The proposed antenna without FSS was simulated on HFSS and their corresponding reflection coefficients are shown in Figure 4.1.The impedance bandwidth seen from the reflection coefficient (for $S_{11}>-10dB$) starts from 3GHz and extends well beyond 13GHz.From the reflection coefficient, resonance can be noted at 10GHz (3GHz-13GHz).

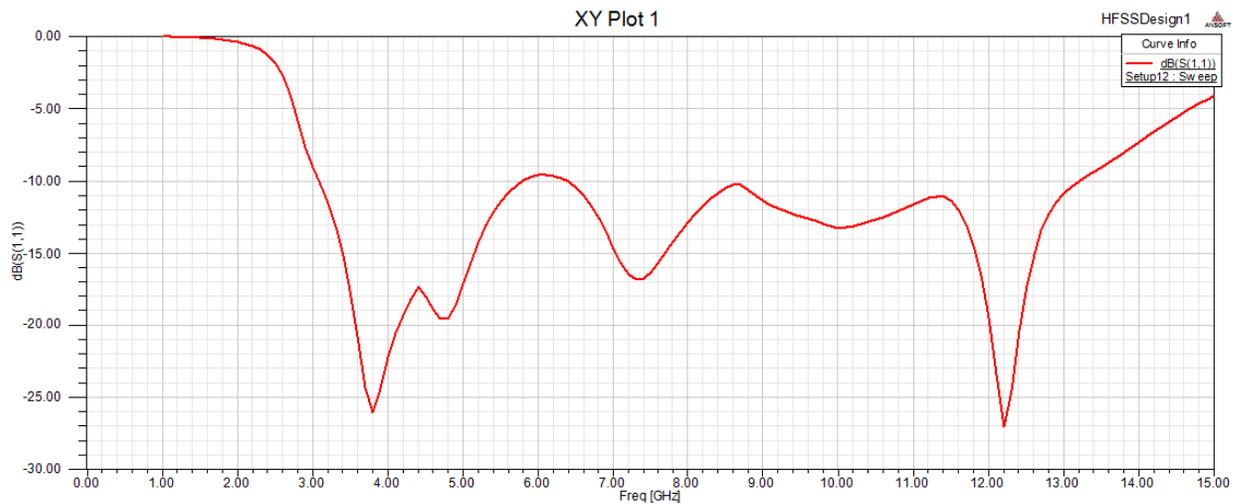**Figure 4.1: Reflection coefficient of the proposed antenna (without FSS)**

The first resonance and second resonance are controlled by wide triangular slot of dimensions 's' and rectangular patch. The slot perimeter being approximately equals to one guide wavelength at this frequency. The rectangular at the end of the CPW feed line acts like a monopole antenna. The triangular slot with inverted L shaped slot is mainly provided for circular polarization. The two arcs which cut in the triangular slot gives multiband. The rectangular slit is attached to the ground plane for achieving wide bandwidth. The antenna gain is 2.55dB in most of the operating frequency shown in Figure 4.2.
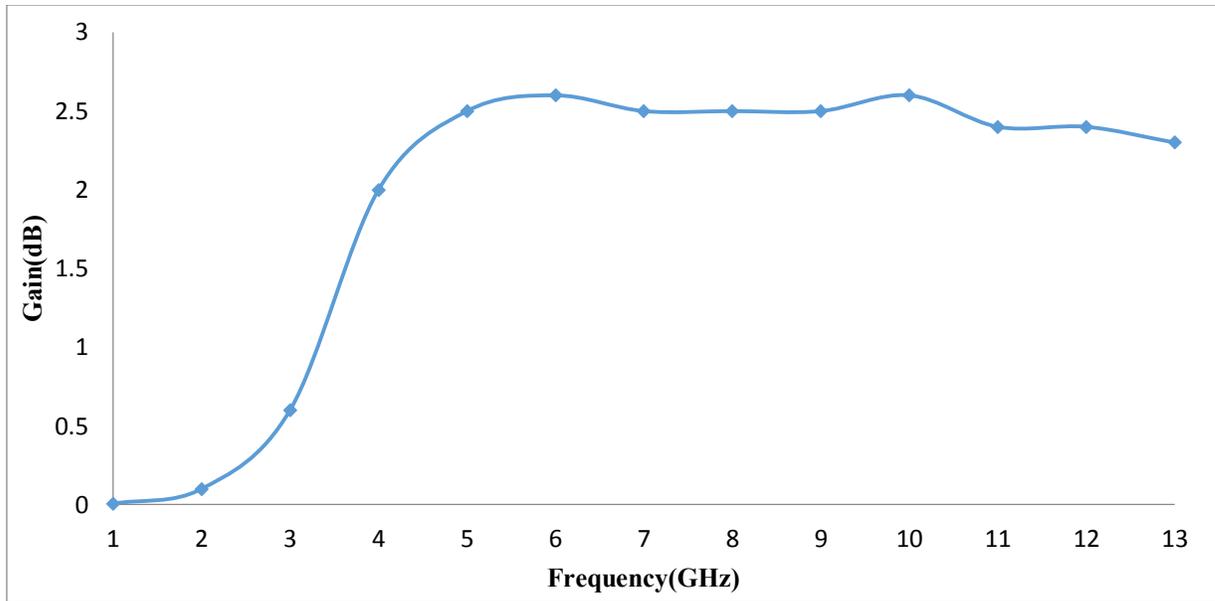
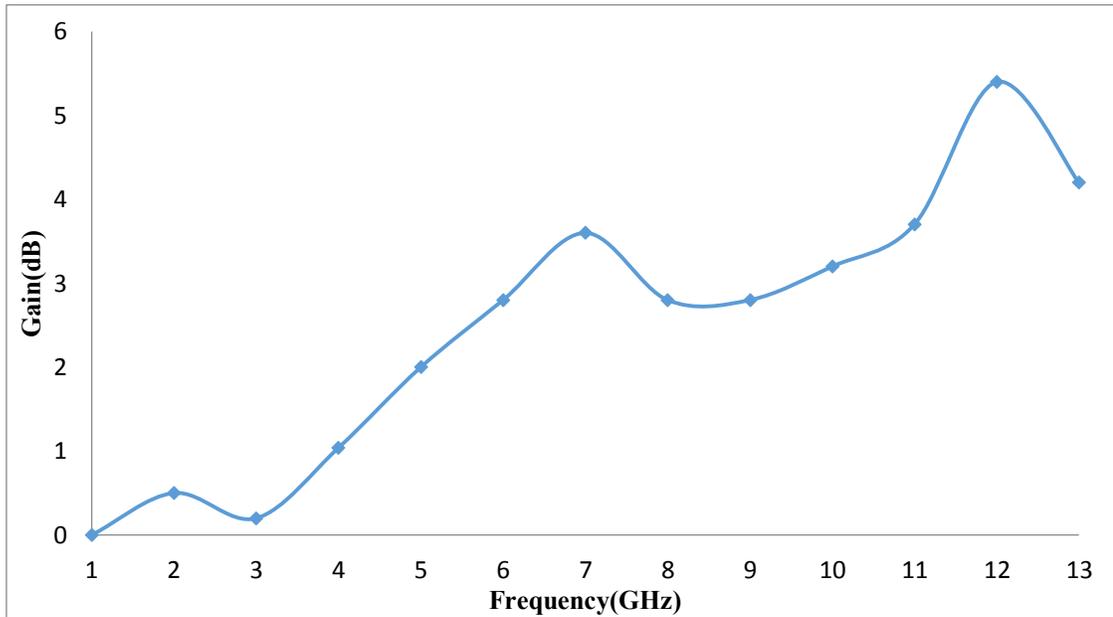**Figure 4.2: Gain of the proposed antenna (without FSS)**

4.2 ANTENNA WITH FSS SUBSTRATE

The reflection coefficient of the antenna without the FSS is shown in Figure 4.1 and the reflection coefficient of the antenna with the double layer square loop FSS is shown in Figure 4.3. The impedance bandwidth seen from the reflection coefficient (for $S_{11} > -10dB$) starts from 3GHz and extends well beyond 13GHz.


Figure 4.3: Reflection coefficient of the proposed antenna (with FSS)

The reflection coefficient is similar to the antenna without FSS. From the reflection coefficient, resonance can be noted at 10GHz (3GHz-13GHz). The first resonance and second resonance are controlled by wide triangular slot of dimensions 's' and rectangular patch. The FSS substrates are mainly for gain improvement. The antenna gain is 5.4dB at maximum operating frequency where the gain of the antenna with FSS substrate is shown in Figure 4.4. From the Figures 4.2 and 4.4 the gain is improved by using FSS substrate.


Figure 4.4: Gain of the proposed antenna (with FSS)

Figure 4.5 show simulated VSWR of the proposed triangular slot with rectangular patch antenna. With the ≤2 VSWR impedance bandwidth, this is acceptable for the practical applications. The proposed antenna achieves ≤2 VSWR impedance bandwidth in most of the operating frequency. However, at frequencies (9GHz), the impedance matching somewhat deteriorates in the presence of the FSS. In case of without FSS, the deterioration results and is not so evident. By using the FSS substrate in antenna the first notch point is at -43dB but in without FSS substrate the first notch point is at only -35dB. The 2D radiation plots for 5GHz and 10GHz are shown in Figure 4.6 and Figure 4.7 respectively.
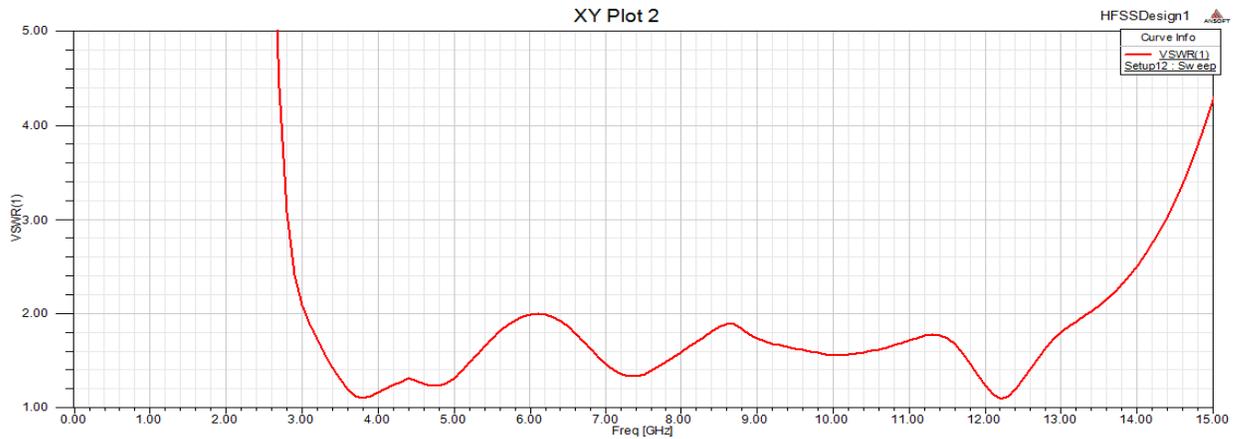
Figure 4.5: VSWR of the proposed antenna (with FSS)

Figure 4.6 and 4.7 exhibit the radiation pattern in the E-palne and H-plane with co-polarization and cross polarization over the operating bandwidth.
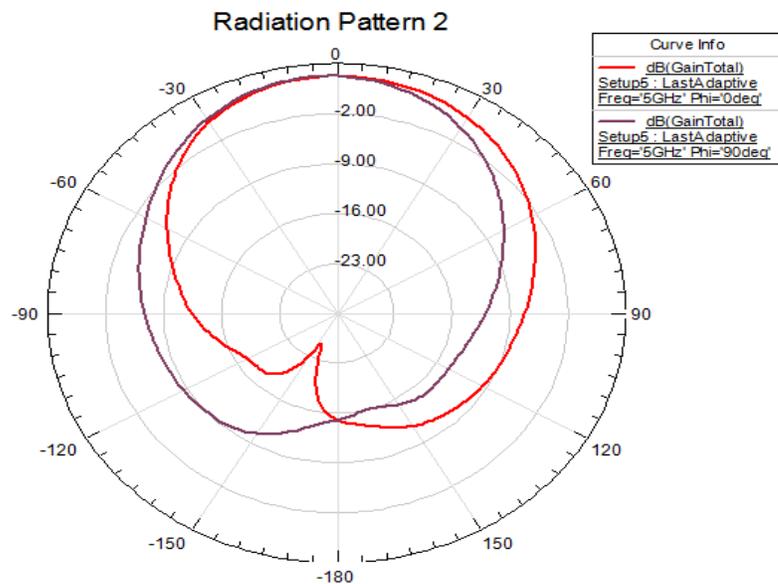
Figure 4.6: Radiation pattern at 5GHz

The H-plane pattern at 5 GHz shows the pinch-off along the end-fire directions (θ= 90). This is because of the increased cross polarization at this frequency. As expected the radiation becomes unidirectional in nature and the back lobes (along θ = 180) are considerably reduced. This indicates a reduction in the cross polar component after the application of the FSS.
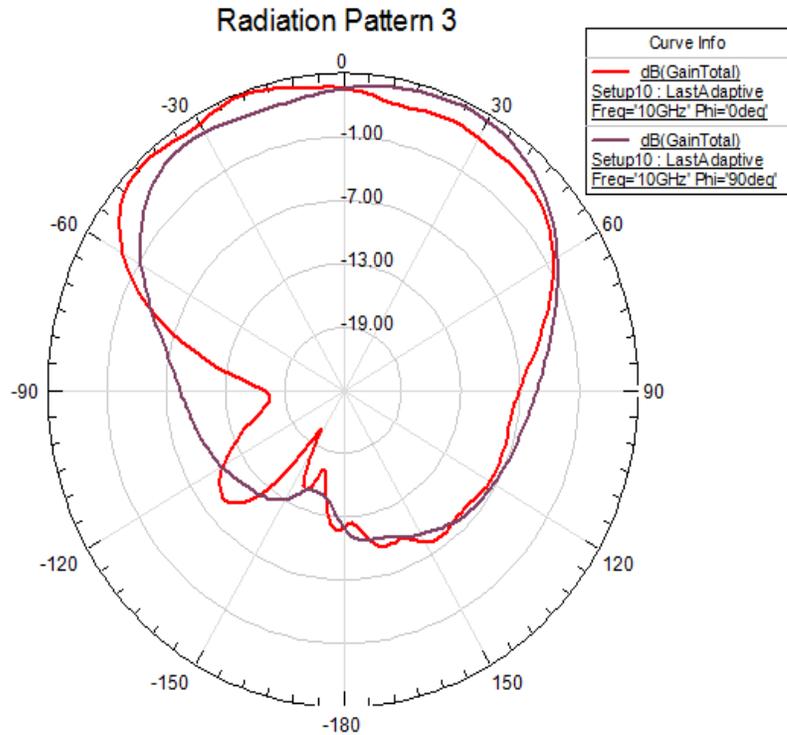
Figure 4.7: Radiation pattern at 10GHz

The E-Plane pattern and H-Plane pattern at 10GHz are almost similar to 5GHz radiation pattern. The designed antenna could be accommodated in high data rate wireless dongle for indoor communication, based on the IEEE 802.11a standards at bands 5.2/5.8GHz.

4.3 SWITCH OPERATION

The proposed antenna can be reconfigured for frequency using switch S. This switch act as a perfect conductor when it's in ON state. When the switch is ON, it covers wide bandwidth. The reflection coefficients of the proposed antenna without FSS are shown in Figure 4.8. The impedance bandwidth seen from the reflection coefficient (for S_{11}>-10dB) starts from 3GHz and extends well beyond 13GHz when switch is in ON state and its covers from 3.6GHz to 4.4GHz, 6.4GHz to 9GHz & 12.2GHz to 13.4GHz when the switch is in OFF state.
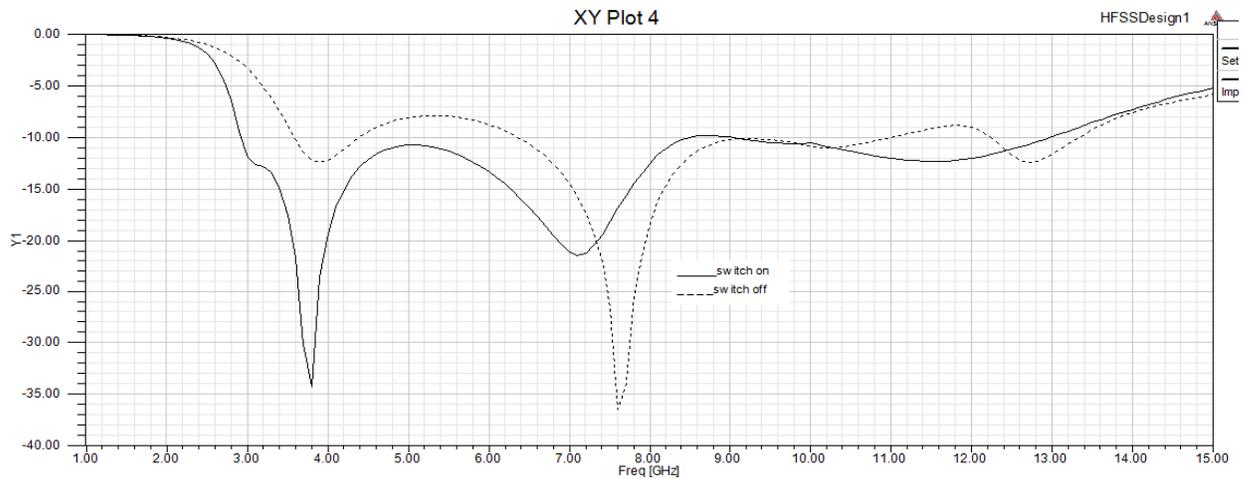
Figure 4.8: Simulated Reflection Coefficient of the proposed antenna without FSS substrate (ON & OFF states)

The reflection coefficients of the proposed antenna with FSS are shown in Figure 4.9. The impedance bandwidth seen from the reflection coefficient (for S_{11}>-10dB) starts from 3GHz and extends well beyond 13GHz when switch is in ON state.
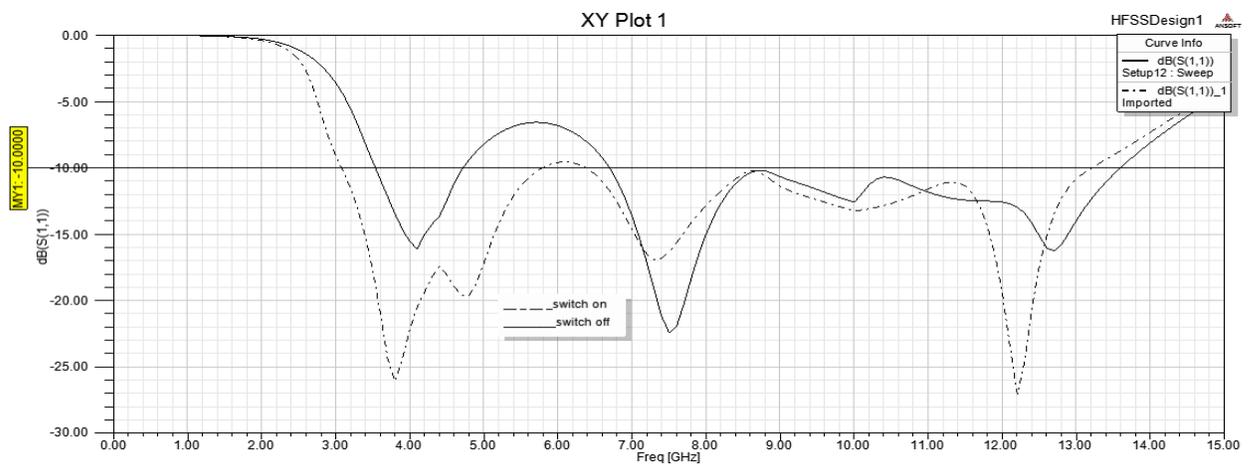
**Figure 4.9: Simulated Reflection coefficient of the proposed antenna with FSS (ON & OFF states)**

When the switch is OFF it covers multiple wide bandwidth. The impedance bandwidth seen from the reflection coefficient (for S_{11}>-10dB) starts from 3.6GHz-4.8GHz and 6.8GHz- 13.6GHz.

CHAPTER 5

EXPERIMENTAL RESULTS OF FABRICATED ANTENNA

The design of the proposed antenna was validated by simulating the antenna reflection coefficient against frequency. The full wave simulators were employed in the proposed work; the commercial software ANSYS-HFSS is used to measure S_{11}, VSWR Gain, etc. Next, the simulating results are compared to the experimental results using Agilent Technologies Microwave Vector Network Analyzer.

Figure 5.1 & 5.2 show the prototype of the proposed antenna without FSS substrate and with FSS substrate. FSS substrate is mainly used for gain enhancement. For switching the frequency, the electronic switch is used at the time of fabrication process.
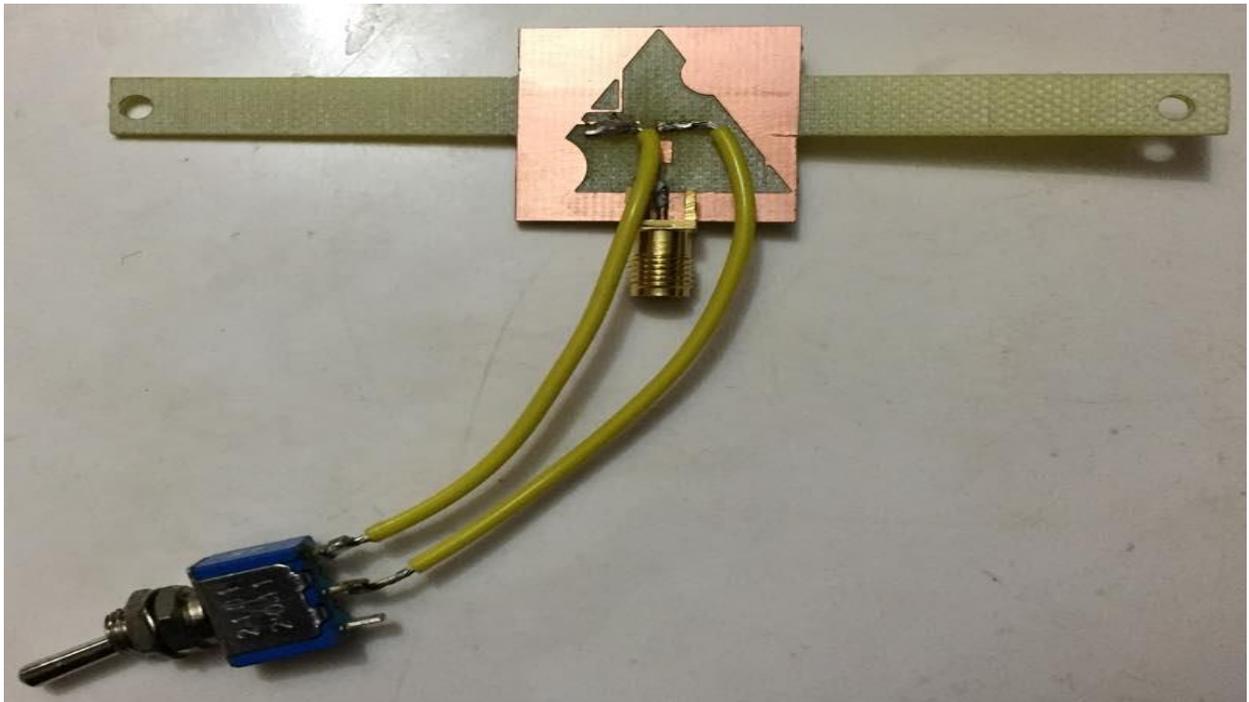
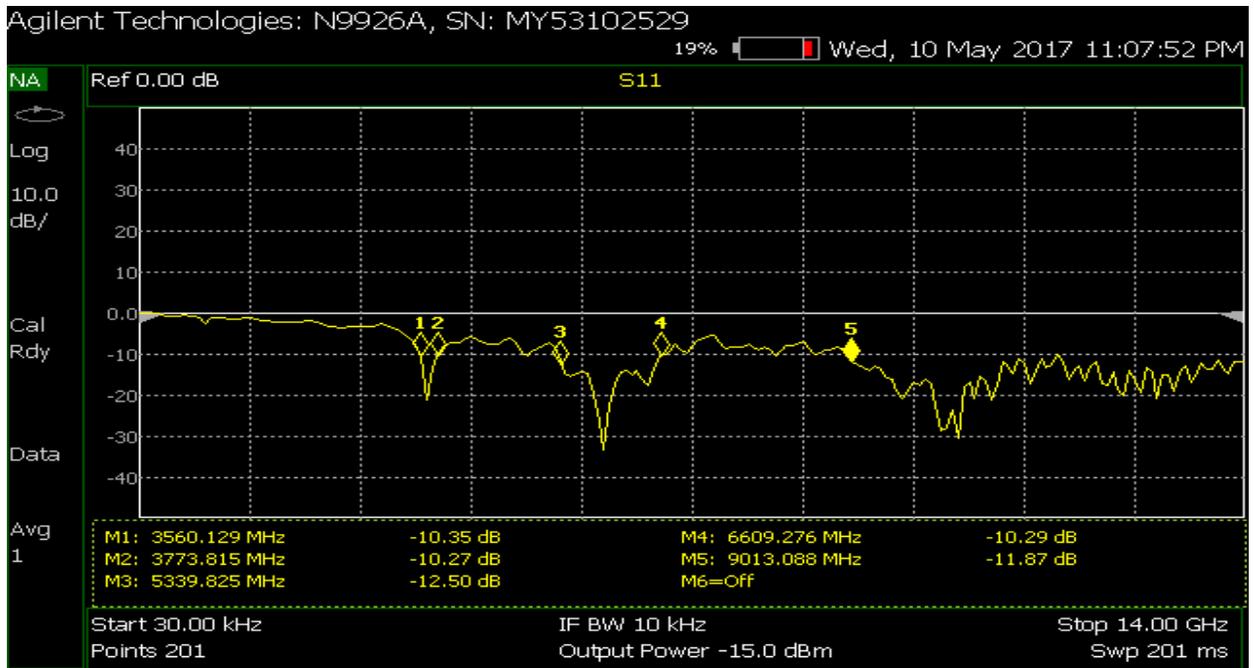**Figure 5.1: Prototype of the Proposed Antenna without FSS Substrate**
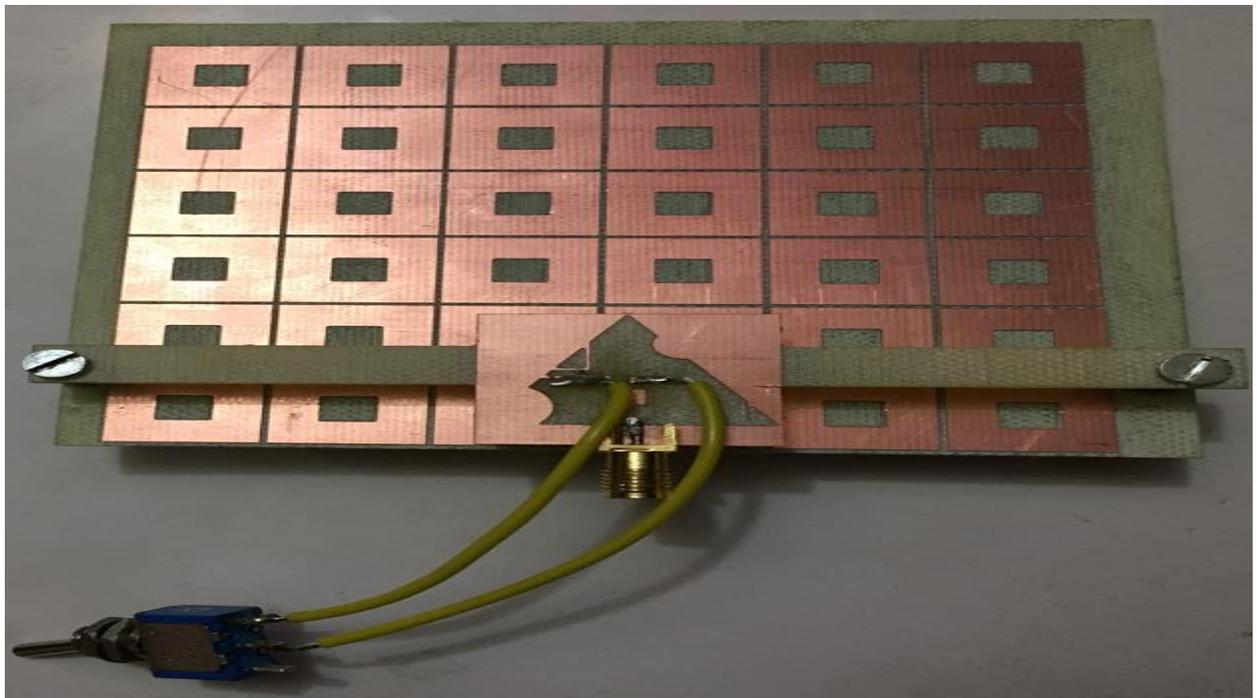
Figure 5.2: Prototype of the Proposed Antenna with FSS Substrate

In simulation the antenna without FSS substrate covers the bandwidth of about 10GHz (3GHz-13GHz) under ON state and OFF state it covers the bandwidth of about

(a)

Agilent Technologies: N9926A, SN: MY53102529

19% | | Wed, 10 May 2017 11:07:52 PM

NA   Ref 0.00 dB   S11

Log
10.0
dB/

Cal
Rdy

Data

Avg
1

M1: 3560.129 MHz   -10.35 dB   M4: 6609.276 MHz   -10.29 dB
M2: 3773.815 MHz   -10.27 dB   M5: 9013.088 MHz   -11.87 dB
M3: 5339.825 MHz   -12.50 dB   M6=Off

Start 30.00 kHz   IF BW 10 kHz   Stop 14.00 GHz
Points 201   Output Power -15.0 dBm   Swp 201 ms

(b)

Figure 5.3: Measured Reflection Coefficient of the proposed antenna without FSS substrate (a) ON state (b) OFF state

1.2GHz (3.6GHz - 4.8GHz), 2.8GHz (6.2GHz - 9GHz) & 1.2GHz (12.2GHz – 13.4GHz). Figure 5.3 shows the experimental return loss plot of the proposed antenna without FSS substrate with switch ON and OFF states. In experimental measurements the antenna without FSS substrate covers the bandwidth of about 9.1GHz (3.6GHz-12.9GHz) under ON state and OFF state it covers the bandwidth of about 0.2GHz (3.5GHz-3.7GHz), 1.3GHz (5.3GHz-6.6GHz) & 4GHz (9.0GHz-13GHz). In simulation the antenna with FSS substrate covers the bandwidth of about 10GHz (3GHz-13GHz) u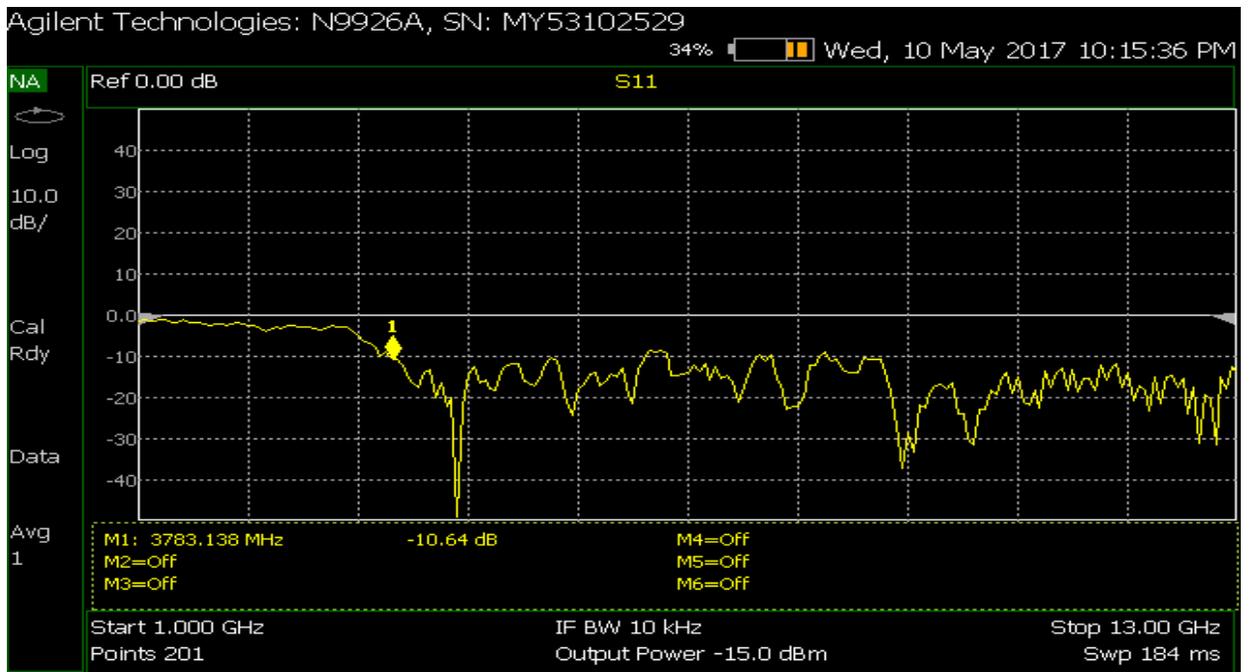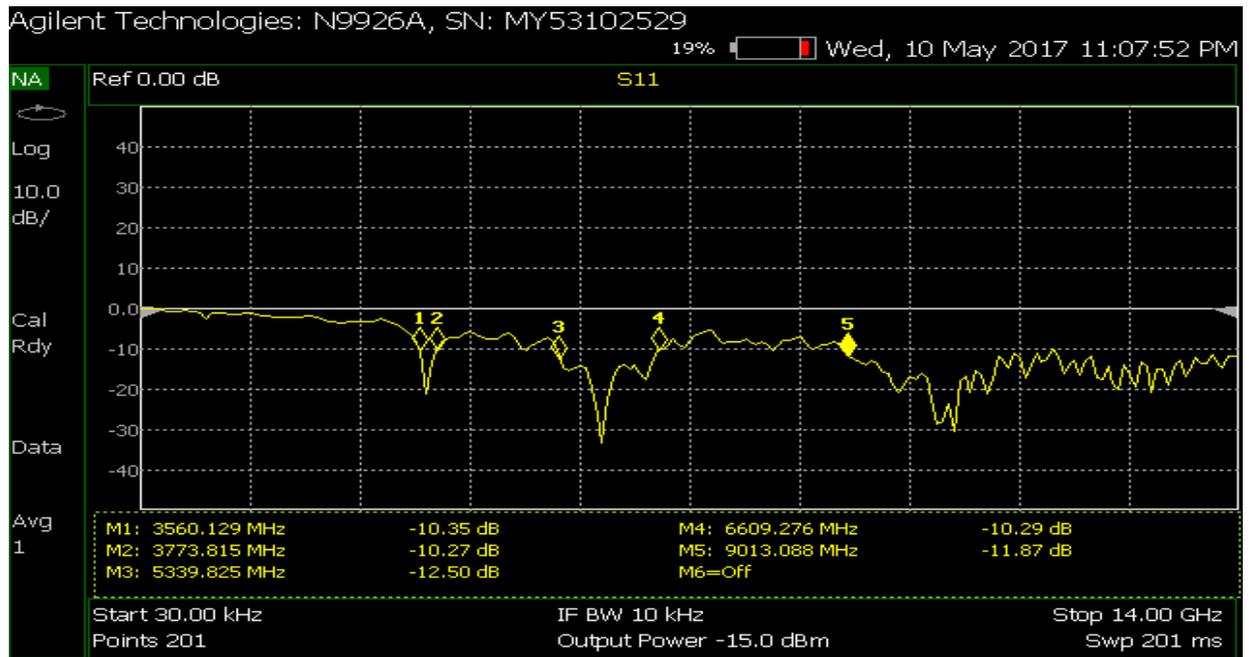nder ON state and OFF state it covers the bandwidth of about 1.2GHz (3.6GHz-4.8GHz) & 6.8GHz (6.8GHz-13.6GHz). Under ON state the low return loss of -30dB is achieved at 3.7GHz and for OFF state the low return loss of -30dB is achieved at 5.7GHz. Figure 5.4 shows the experimental return loss plot of the proposed antenna with FSS substrate with switch ON and OFF states.

(a)

(b)

Figure 5.4: Measured Reflection Coefficient of the proposed antenna with FSS substrate (a) ON state (b) OFF state

In experimental measurements the antenna with FSS substrate covers the bandwidth of about 9.4GHz (3.6GHz-13GHz) under ON state and OFF state. It covers the bandwidth of about 0.2GHz (3.5GHz-3.7GHz), 1.3GHz (5.3GHz-6.6GHz) & 4GHz (9.0GHz-13GHz). Under ON state the low return loss -40dB is achieved at 5.2GHz. The difference of antenna without FSS substrate and antenna with FSS substrate is, that the antenna with FSS substrate has less return loss and high gain when compared to the antenna without FSS substrate.

CHAPTER 6
CONCLUSION

In this project, the circularly polarized triangular slot reconfigurable antenna is designed, fabricated and the performance is experimentally validated. The radiating element in the proposed antenna is a triangular slot which is excited using the coplanar waveguide feed. The feed line is terminated on a rectangular shape protrusion. For achieving circular polarization, inverted L-shaped strips are attached to the triangular slot. The rectangular at the end of the CPW feed line acts like a monopole antenna. The rectangular slit is attached to the ground plane for achieving wide bandwidth. The impedance bandwidth of the proposed antenna is 10GHz (3GHz-13GHz). To improve the gain of the antenna, the frequency selective surface designs are presented. A square loop FSS designed at the center frequency of 8GHz which improves the antenna gain by about 5.4dB. The switch S is attached to the rectangular slot for switching the frequency range. The proposed antenna can be reconfigurable using switch S. The complexity of the DC bias is decreased by using a reduced number of switches. The antenna has only one switch to achieve two frequency bands. When the switch is ON and OFF state, antenna covers the following frequency ranges 3.6GHz-13GHz and 3.5GHz-3.7GHz, 5.3GHz-6.6GHz & 9GHz- 13GHz. This antenna is used in wireless services like WLAN, GPS, PCS, CDMA, WIFI, WIMAX and satellite services like Fixed Satellite Service (FSS), FSS military, terrestrial earth exploration, meteorological satellites.

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