Microwave Electronics

INVESTIGATION ON RADIATION CHARACTERISTICS AND PATTERN RECONFIGURABILITY OF ASYMMETRIC COPLANAR STRIP ANTENNA

A thesis submitted by

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Under the guidance of

Prof. C. K. AANANDAN

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The almighty Allah …

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Also certified that thesis is adequate and complete for the award of the Ph.D. Degree.

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Declaration

*I hereby declare that the work presented in this thesis entitled "**Investigation on Radiation Characteristics and Pattern Reconfigurability of Asymmetric Coplanar Strip Antenna**" is a bonafide record of the research work carried out by me under the supervision of Dr. C. K. Aanandan, Professor, in the Department of Electronics, Cochin University of Science and Technology. India. The result presented in this thesis or parts of it have not been presented for any other degree(s).*

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Abstract

Modern wireless network face an ever increasing demand on compact smart antennas with reconfigurable features. Reconfigurable antennas have the potential to improve the system performance according to the changes in environmental conditions.

This thesis investigates on the radiation characteristics of an asymmetric coplanar strip antenna and to integrate reconfigurable functionality. It also demonstrates a method to steer the radiation pattern without using complex feeding network. The direction of main lobe of radiation is controlled using a set of switches shorting radiating arm with the stubs at selected points.

A typical asymmetric coplanar strip antenna radiates a tilted beam upon excitation. An analysis of radiation characteristics of asymmetric coplanar strip antenna realizes the parameters, which control the direction of main beam of radiation. A model of the antenna is constructed and switches are placed to control the effective resonating length.

A compact folded antenna with both frequency and pattern reconfiguring capabilities are also presented. The antenna can steer its beam according to the state of switches. The possibility of switching antenna between different radiation pattern and frequencies makes them useful for modern wireless gadgets to use multiple services on same receiver.

Finally, the thesis presents an approach to switch the radiation patterns between orthogonal planes along with change in polarization. The measured performance of the antenna correlates well with simulated results.

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ACRONYMS

ACPS	Asymmetric Coplanar Strip
AUT	Antenna Under Test
CPS	Coplanar Strip
CPW	Coplanar Waveguide
CR	Cognitive radio
CREMA	Centre for Research in Electromagnetics and Antennas
DCS	Digital Communication System
DRA	Dielectric Resonator Antennas
FIT	Finite Integration Technique
FNBW	First Null Beam width
GPS	Global Positioning System
GSM	Global System for Mobiles
HPBW	Half Power Beam Width
ISM	Industrial Scientific and Medical
LHCP	left hand circular polarization
MIMO	Multiple Input Multiple Output
MMIC	Microwave Integrated Circuits
PBA	Perfect Boundary Approximation
PCB	Printed Circuit Board
PCS	Personal Communications Service

PEC	Perfect Electric Conductor
PNA	Programmable Network Analyzer
RF MEMS	Radio Frequency Micro Electro Mechanical System
RHCP	right hand circular polarization
SMA	Sub Miniature Architecture
UWB	Ultra Wide Band
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Today, communication systems with radio waves have greatly influenced our social life and culture. Life without wireless gadgets or devices is unimaginable. Wireless communication technologies continue to evolve and spread out at an extreme pace. The demand and enthusiasm for innovations drives the rapid growth of wireless technology and changes the people's life in all sort of useful ways. The wireless technology finds applications in telecommunication industry, healthcare, medical diagnosis, treatment and monitoring systems, industrial and automotive sectors. There are vast opportunities for wearable and logistic applications. In contemporary situation every communication system is going to wireless, and it demands for more innovations in antenna research.

The history of antennas dates back to James Clerk Maxwell who combined the theories of electricity and magnetism, and represented their relations through a set of equations known as Maxwell's Equations [1]. In 1886, Professor Heinrich Rudolph Hertz physically demonstrated the existence of radio waves. He used a dipole and loop to transmit and receive radio waves. Figure 1.1 shows the experimental set-up of Hertz's apparatus. Later Guglielmo Marconi used a vertical monopole (near quarter wavelength) to transmit radio telegraph signal across the Atlantic. In 1902 he began regular transatlantic message service [2]. During World War II, British and American scientists developed radar technologies to spot targets from hundreds of miles away even at night [3].

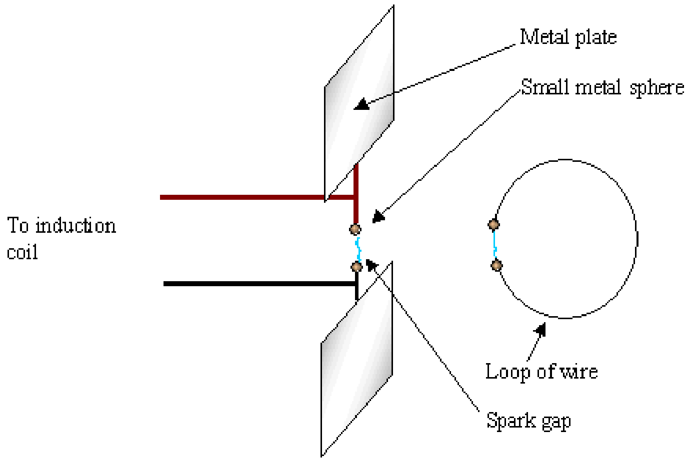

Figure 1.1: Experimental setup of Hertz's apparatus

The antenna acts as the physical interface between the hardware part of the communications system and transmission medium. The antenna in the transmitting end converts the information signal into an electromagnetic energy and transmits into free space. At the receiving end, the received electromagnetic wave is converted back to information signal. In other words antenna is a transducer which allows the transition of guided wave into unguided wave and vice versa .

Investigations in antenna research results in the development of high frequency antennas and aperture antennas like reflector and horn antennas. Later broadband and circularly polarized antennas were developed for various applications. As the communication systems have become much more complex and sophisticated, there has been a requirement for new and improved antennas to suit existing and emerging applications.

Service	**Frequency Band (MHz)**
GSM (Global System for Mobiles)	880–960
GPS (Global Position System)	band1: 1227–1575 band2: 1565–1585
DCS (Digital Communication System)	1710–1880
PCS (Personal Communication System)	1850–1990
UMTS (Universal Mobile Telecommunication System)	1900–2200
IMTS (International Mobile Telecommunication System)	1920–2170
ISM (Industrial Scientific and Medical)	band 1: 2400–2484 band 2: 5150–5350 band 3: 5725–5825
WiMAX (Worldwide Interoperability for Microwave Access	band 1: 2495–2695 band 2: 3250–3850 band 3: 5250–5850

Table 1.1: Summary of the existing wireless communication services.

As stated the antenna is an essential component of any Radio and wireless communication, because of its ability to transmit and receive electromagnetic energy. The frequencies for carrying this communication can be obtained from electromagnetic spectrum. Table 1.1 shows the summary of the existing wireless communication services.

1.2 Microwave Antennas

An antenna, a very important part of a radio system, is defined as a device which can transmit and receive electromagnetic energy in an efficient and desired manner. Antenna is normally made up of metal, but other materials like ceramic have been used to make non metallic antennas like dielectric resonator antennas (DRAs) [3].

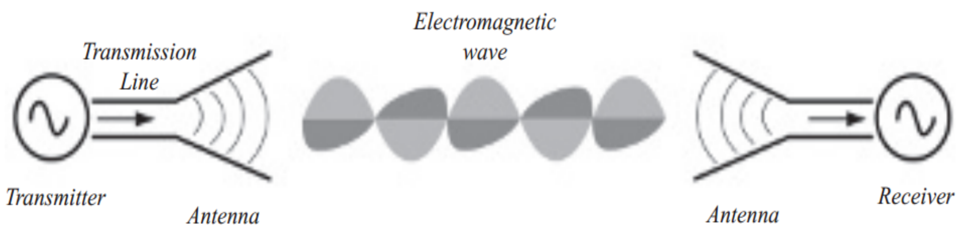

Figure 1.2 - Typical radio communication system [3].

Figure 1.2 shows a simple radio communication system. The message signal is first modulated and amplified in the transmitter and then given to a transmitting antenna through a transmission line. The antenna radiates the signal as electromagnetic wave. The receiving antenna picks up these electromagnetic signals and passed to the receiver. The received signal is demodulated and then the original information is recovered.

An antenna can be considered as a transformer which converts electrical signals like current or voltage from the transmission line into electric field or magnetic fields. So in a radio system care should be taken while connecting an antenna to a transmission line so that the signal should radiate into the air in an efficient and better way. So there must be tradeoff between the applications and compactness during the design of antenna. For example antenna for portable devices expected to have compact in size and it should be embedded. Therefore, much effort has been devoted to miniaturizing the size of antennas to meet the demand for devices with smaller volume and lighter weight. In the past two decades, antenna researchers and engineers have achieved considerable reductions in the size of antennas installed in portable devices, although physical constraints have essentially limited such reductions. Today, almost all antennas for portable devices can be embedded in the devices. [4].

Thus designing and making antenna is interesting and difficult subject. For different applications, the required antenna features may be different, even for the same frequency band. The modern antenna is expected to match specifications like size, shape, weight, frequency, bandwidth, functionality [3].

1.3 Classification of antenna

Since the beginning of radio communications, different types of antennas have been investigated and developed. Modern antennas require careful design and thorough understanding of the radiation mechanism involved. The electrical and mechanical parameters like gain, polarization, radiation pattern, impedance, size, weight and reliability determines which type of the antenna is to be used. Antennas can be classified into different types in terms of:

- **Physical Structures** – Wire antenna or aperture antenna or planar antenna
- **Bandwidth** – narrowband, broadband or ultra wideband antennas;
- **Polarization** - linearly or circularly polarized antennas;
- **Resonance** – resonant (dipole, patch) or traveling wave (Yagi-Uda, periodic) antennas;
- **Number of elements** – single element antennas or antenna arrays.

Extensive studies have been conducted across the world on various types of antennas. Here a few important types of antennas which are broadly used in real life are presented.

Different types of antenna exhibit different features and can be analyzed using different methods and techniques. It is very important for an antenna designer to select an antenna which meets all the required specifications.

1.3.1 Wire Antennas

Wire type antennas are made of long conducting wires suspended above the ground. Wire antennas are considered as one of the cheapest antenna and are easy to construct. Some of the examples include dipoles, monopoles, loops, helices, Yagi-Uda and log-periodic antennas.

Dipoles are the one of the simplest and widely used wire antennas, which can be constructed from an open end two wire transmission line. Dipoles are also considered as resonant antenna, in which the standing wave of current flows back and forth on the structure. The wavelength of the radio wave determines the length of dipole; often half wavelength dipole is used. The radiation pattern of a vertical dipole is omnidirectional in H-plane.

A monopole antenna consists of a straight rod-shaped conductor mounted perpendicularly over a ground plane. The most common form of monopole antenna is the quarter-wave monopole, in which the antenna is approximately 1/4 of a wavelength of the radio waves. Just like dipole antenna, a monopole antenna too has an omnidirectional radiation pattern. Because it radiates only into the space above the ground plane, the directivity doubled and input impedance halved of its corresponding dipole [5].

1.3.2 Aperture antenna

When the frequency of operation is very high, thin wires and dielectrics antennas cause very high loss. Coaxial lines may too have loss around 10dB per meter. Thus waveguides are often used in its place. Aperture type antennas are constructed by making a smooth transition from waveguide to free space. They are often used for high frequency applications. Example for aperture antenna is horn antenna. This type of antenna is wideband, low loss and can be used to make highly directive antennas. Gain of aperture antenna can be accurately characterized.

1.3.3 Reflector Antennas

Reflector antenna uses a large reflective surface to direct or focus the radiated energy. They are the most widely used antenna for high frequency and high gain applications. Moreover they can accommodate high levels of power. Reflector antennas have a variety of geometrical shapes and require careful design. Reflector antennas produce narrow beams and are used in deep space communication.

1.3.4 Antenna Arrays

When applications require radiation characteristics that cannot be met by a single radiating element, multiple antennas are connected and arranged in a regular structure to form a single antenna. The array antenna has improved directional characteristics and higher gain than the individual elements. The array antenna is used to provide diversity reception. It is also used to cancel out interference from a particular set of directions and to steer the array so that it is most sensitive in a particular direction. Antenna array can be used to determine the direction of arrival of the incoming signals.

1.3.5 Microstrip Antenna

Microstrip antennas have become very important class of antenna. These antennas are light weight, low profile and can be mounted on surfaces. A microstrip antenna consists of a metallic patch on a grounded substrate. The metallic patch can take many different configurations as shown in Figure 1.3 [1]. The shape of the patch depend on the application and demand, more common shapes are square, rectangular, and circular. Usually the length of the patch is about one half of the dielectric wavelength corresponding to the resonant frequency [6, 7].

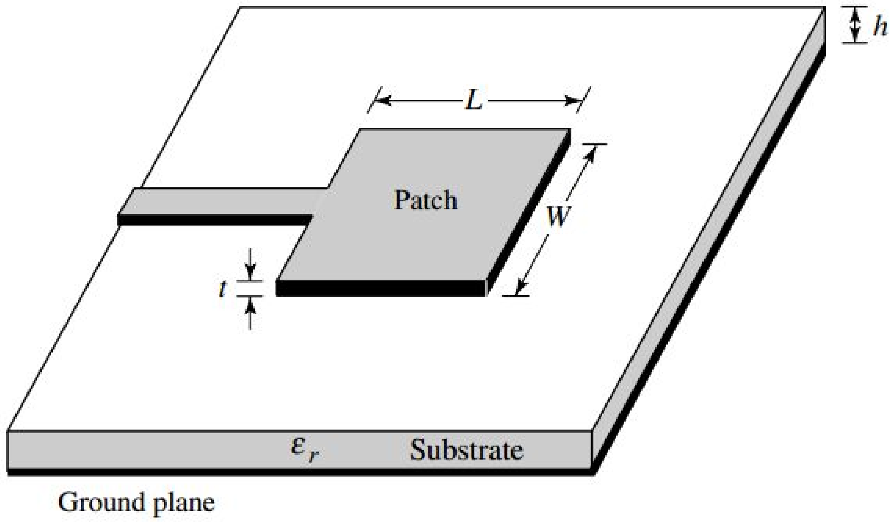

Figure 1.3: Microstrip Antenna

Microstrip antennas offer greater flexibility in terms of radiation pattern polarization, and frequency of operation. Lot of works had been reported over the years [8-11]. Due to the presence of conductor losses and surface wave losses microstrip antenna is considered as narrow bandwidth and less efficient antenna. Efforts have been taken to widen the bandwidth by increasing substrate thickness but it results in decrease of efficiency due to increased surface waves [12-13]. Microstrip antenna shows more directional radiation characteristics [14]. This may limit its use in Omni directional radiation applications but can be used in directional application.

The radiation properties of a circular microstrip antenna are compared with those of an equivalent square microstrip antenna and a simple method for the computation of the farfield of a circular microstrip antenna is suggested

[15]. By loading of a high-permittivity superstrate layer and a chip resistor enhanced gain and wider bandwidth can be implemented [16-17]. A packaged microwave bipolar transistor has been integrated directly onto a rectangular microstrip patch to obtain extra power gain and to reduce power losses [18-19]. By meandering the patch there by increasing the surface current paths, the half wavelength length antennas can be made electrically large and the fundamental resonant frequency can be lowered [20-24]. An approach for gain and bandwidth enhancement of microstrip patch antennas based on the emerging photonic band gap structures is also presented [25].

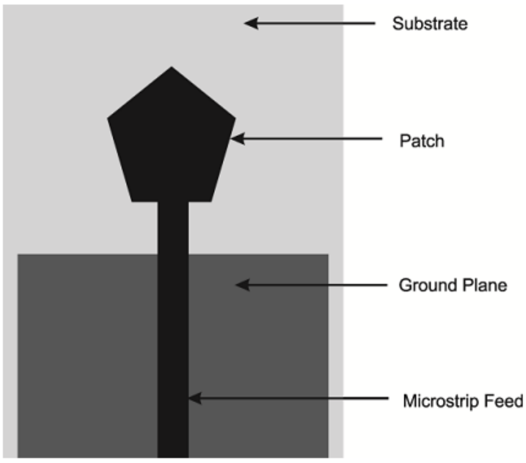

Figure 1.4: Geometry of planar monopole with a loaded patch antenna

The ground plane of the antenna should be infinite in the ideal condition. Truncation of ground plane results in the realization of a planar quarter wavelength monopole antenna. Planar monopole antennas are much compact than microstrip antennas. The truncated ground plane structure offers a omnidirectional radiation pattern [26]. The bandwidth of these antennas can be further improved by loading an arbitrary shape on the monopole [27]. By properly truncating the ground plane the bandwidth can be further enhanced by exciting an additional resonance and merge with the fundamental resonance mode [26-28]. Monopoles with circular, elliptical, rectangular, bow-tie, diamond, and trapezoidal sheets, have been designed and investigated [29-37]. Geometry of planar monopole is shown in figure 1.4. Different techniques have been applied for the design of dual band and multi band antennas [38-42].

1.3.6 Printed dipoles

The printed dipole antenna is often used in planar microwave applications that require an omnidirectional pattern. Compared with traditional wire antennas, printed dipole antennas have extra advantages including planar structure, small volume, light weight and low cost, which are significantly suitable for applications sensitive to the receiver sizes. Recently, various types of printed dipole antennas have been studied [43-45] to comply with the compact high performance broad band/multiband requirements. With the use of parasitic elements printed dipoles can be effectively used for multiband operations. Geometry of a typical microstrip fed printed dipole antenna is depicted in Fig 1.5.

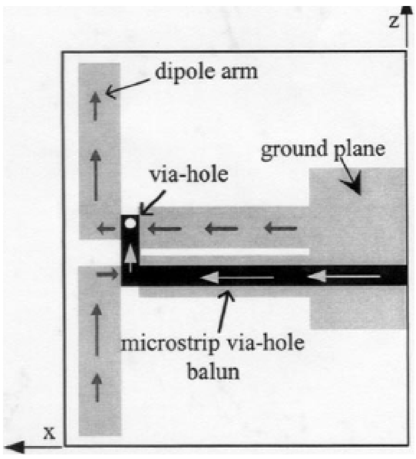

Figure: 1.5: Geometry of a printed dipole antenna

1.4 Antenna excitation techniques

Transmission lines are used to excite antenna. There are different types of transmission lines developed to feed an antenna for various applications. The most popular feeding techniques are shown in Figure 1.6. They are two-wire transmission line, the coaxial cable, the microstrip, the coplanar waveguide (CPW) and the coplanar stripline.

Two-wire transmission line is the simplest transmission line, it consists of two identical wires separated by a distance with a medium of permittivity. The characteristic impedance of two wire transmission lines is 300Ω. The electromagnetic field distribution around the two-wire transmission line is TEM(transverse electro magnetic) mode.

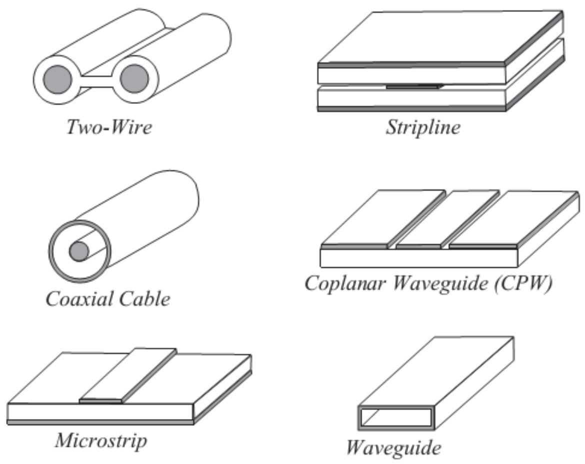

Figure 1.6: Various transmission lines [2].

The coaxial cable consists of a central, insulated wire (inner conductor) mounted inside a tubular outer conductor. The inner conductor is insulated from the outer conductor by a dielectric material with good insulating characteristics. The dielectric material reduces the velocity of the wave inside the cable. Typical characteristic impedance of coaxial cable is 50Ω or 75Ω.

1.4.1 Microstrip line

A microstrip line is a widely used transmission line. The general structure of a microstrip is shown in Figure 1.7. A conducting strip (microstrip line) with a width *W* and a thickness *t* is on the top of a dielectric substrate that has a relative dielectric constant ε_r and a thickness *h*, and the bottom of the substrate is a ground (conducting) plane. The fields in the microstrip extend within two media that is, air above and dielectric below. The typical value of the characteristic impedance for industrial standard lines is 50 **Ω**. [3].

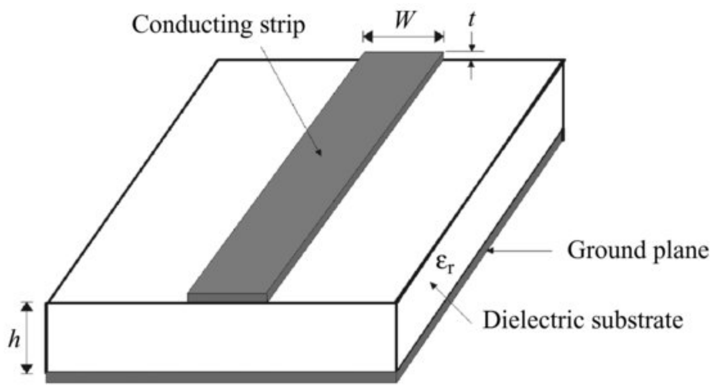

Figure 1.7: Microstrip Transmission line

1.4.2 Coplanar waveguide (CPW)

The CPW is another popular planar transmission line evolved from a coaxial cable. A coplanar waveguide consists of a dielectric substrate with conductors on the top surface [46]. The central conductor is separated from a pair of ground planes. They all sit on a substrate with a dielectric permittivity of ε. A variant of the coplanar waveguide is formed when a ground plane is provided on the opposite side of the dielectric; this is called a grounded coplanar waveguide (GCPW) and was originally developed to counter the power dissipation problems of CPW [3].

Coplanar Waveguide transmission line offers low loss than microstrip transmission line. CPW lines are uniplanar structures, which are compatible with Microwave Integrated Circuits (MMIC's), have low radiation loss and less dispersion than microstrip line. It can be easily integrated with series or shunt lumped passive elements without any need of via hole as in the case of microstrip technology. CPW fed monopoles are increasingly popular for dual band broadband operations [47-48].

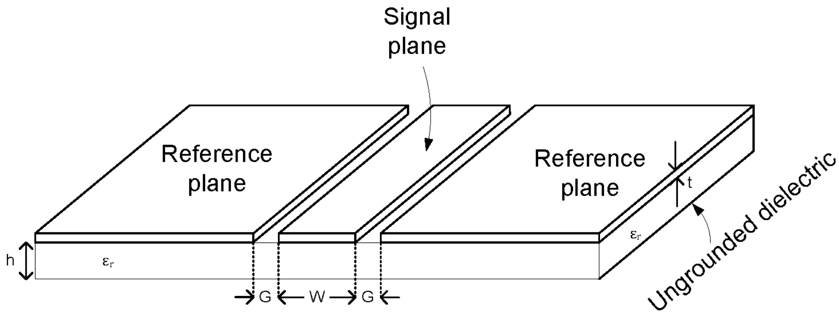

Figure 1.8: Coplanar Waveguide transmission line

(*w* = Width of strip , G= gap, *h*= substrate height)

Figure 1.8 shows a CPW transmission line. A CPW feed require two ground planes which consumes much of the antenna dimension. So the antenna designer must make a tradeoff between compactness and performance. Coplanar strip lines are recognized as an alternative solution to this problem. The microstrip line and the coplanar wave guide are the commonly used transmission lines to feed signal to the antenna. Based on the challenges and constraints before the designer various interesting modified designs of these transmission lines have been proposed. Recently uniplanar feeding techniques like slotline, Coplanar strips, Asymmetric coplanar strips are gaining the attention of antenna designers [49-50].

1.4.3 The Co-Planar Strip (CPS)

The coplanar stripline (CPS) consists of a dielectric substrate with two parallel strip conductors separated by narrow gap. A coplanar strip (CPS) is a balanced transmission line. CPS offers flexibility in designing planar microwave circuits by mounting devices in series or in parallel [51-52]. Geometry of a typical coplanar stripline (CPS) on a dielectric substrate of finite thickness is given in Fig.1.9.

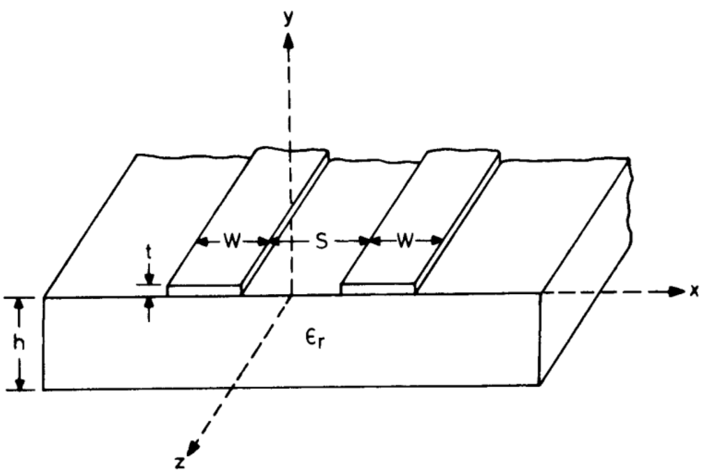

Fig.1.9. Coplanar Strip line (*s* = gap, *W*= strip width, *h*= substrate height)

The main advantage of this transmission line is the ease of mounting active and passive circuits into these lines. Here the width of the slot and the height of the substrate determine the characteristic impedance. The main disadvantage of the CPS is that because it lacks a ground plane, the line can support besides the fundamental CPS mode two other parasitic modes, namely the TE and TM dielectric slab waveguide modes. These parasitic modes do not have a cutoff frequency. The TE_0 and TM_0 modes have their electric fields predominantly parallel and perpendicular to the dielectric-air interface, respectively [52].

1.4.4 The Asymmetric Coplanar Strip feed

A coplanar strip line (CPS) with two unequal width strips is called an asymmetric coplanar strip (ACPS). ACPS is a uniplanar transmission lines desirable in practical device design because of its flexibility to use, simple structure and moreover easy to mount in microwave circuits. The advantage of the asymmetric CPS over conventional CPS is the flexibility to adjust the propagation parameters by changing the width of one of the strips while keeping the widths of the other strip and the gap fixed [51-52]. Thus ACPS is more preferred to design compact antennas.

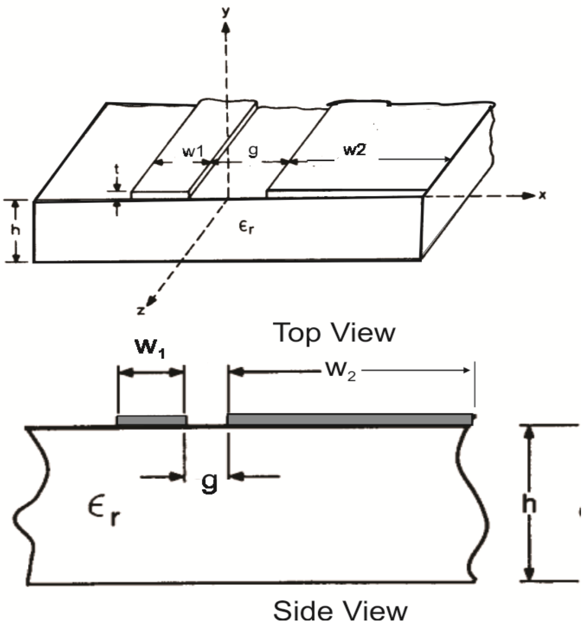

Fig.1.10: Geometry of an Asymmetric Coplanar Strip (ACPS) feed

In an asymmetric coplanar stripline (ACPS) one of the strip is wider than the other, as shown in Figure 1.10. This allows the designers a freedom to adjust the characteristic impedance by changing the width of one strip while keeping the width of other and slot width fixed [51]. An asymmetric coplanar strip is effectively used in this thesis for the design of compact reconfigurable antennas.

The effective dielectric constant ε_{re} and the characteristic impedance Z_0 are related to the capacitance of the structure. The characteristic impedance of the transmission line on a substrate (dielectric constant ε_r and height h) with strip widths W_1 , W_2 and gap g is calculated using the analytical conformal mapping expressions in [52]. The capacitance per unit length of the line in the absence of the dielectric substrate is given by the expression,

$$C_0 = 2\varepsilon_0 \frac{K(k')}{K(k)}$$

Where ε_0 is the permittivity of free space and K is the complete elliptic integral of the first kind. The arguments k and k' are

$$k = \sqrt{\frac{2a(b1+b2)}{(a+b1)(a+b2)}} ,$$

$$k' = \sqrt{1-k^2} = \sqrt{\frac{(b1-a)(b2-a)}{(a+b1)(a+b2)}}$$

Where $a = \frac{g}{2}$, $b_1 = a + W_1$, $b_2 = a + W_2$

The characteristic impedance of the ACPS line in the presence of a dielectric substrate is given by

$$Z_0 = \frac{60\pi}{\sqrt{\varepsilon_{re}}} \frac{K(k)}{K(k')}$$

The effective dielectric constant of the ACPS is given as ;

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} \qquad \text{For infinitely thick substrate}$$

$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K(k)}{K(k\prime)} \frac{K(k_1{}')}{K(k_1)} \qquad \text{For finite thick substrate}$$

Where ε_r is the permittivity of the dielectric substrate The arguments k_1 and k_1' are argument are obtained by ;

$$k_1 = \sqrt{\frac{\{\exp[2\pi(b_1+a)/h] - \exp[2\pi(b_1-a)/h]\}\{\exp[2\pi(b_1+b_2)/h] - 1\}}{\{\exp[2\pi(b_1+b_2)/h] - \exp[2\pi(b_1-a)/h]\}\{\exp[2\pi(b_1+a)/h] - 1\}}}$$

$$k'_1 = \sqrt{1 - k_1{}^2} \qquad \text{Where } h \text{ is the substrate thickness.}$$

But when the width of one of the strips (w_2) is very much larger compared to the other (w_1), its effect on the characteristic impedance is found to be less and hence w_2 can be omitted from characteristic impedance calculations, without much error. Recently studies are conducted on the rigorous analysis of reflection characteristics of ACPS fed compact and ultra compact antennas [49-50]. A detailed look on the radiation characteristics has much importance. Thus in this thesis a detailed account on radiation performance of ACPS and how it can be utilized for the development of reconfigurable antenna is also presented.

1.5 Reconfigurable Antenna

Reconfigurable antennas have received great attention of antenna researchers recently. Modern wireless communication systems demand for an intelligent antenna with different functionality and adjust their basic operating parameters like frequency of operation, polarization and radiation pattern according to requirement. Reconfigurablity is the capacity of antenna to change its fundamental operating characteristics through electrical, mechanical, or other means. The reconfiguration is achieved through an intentional redistribution of the currents or the electromagnetic fields of the antenna's effective aperture, resulting in reversible changes in the antenna impedance and/or radiation properties. Different methods are proposed to achieve reconfigurability like switching and material tuning [53].

1.5.1 Frequency Reconfigurable Antennas

Frequency reconfigurable antennas are also known as tunable antennas. The frequency reconfigurability is achieved by actively controlling the effective electrical length of the antenna there by enabling the antenna to operate in different frequency bands [54]. The frequency reconfigurable antenna is thus capable of varying the resonant frequency while maintaining stability in the other parameters such as radiation pattern and polarization.

The frequency reconfigurability can be accomplished by using different mechanisms, such as material tuning and switching. System control is then applied to reconfigure the resonant frequency. The selection of reconfiguration method presents trade-offs in performance, complexity, and cost. The functionality that the frequency reconfigurable antenna provides should offset the complexity and the cost of the reconfiguration. There are many ways for achieving the frequency reconfigurability [54-55], like Switching between different external matching circuits, Changing the properties of the substrate (i.e. permittivity or thickness), Utilizing switches/varactors to alter the resonance length, Mechanical reconfiguration, such as RF MEMS.

The operating frequency of a resonant antenna can be varied by adding a few switches to adjust the resonance length or aperture of its resonator or by means of switching the antenna grounds [56].

Lot of study on frequency reconfiguration have been done on the slot antenna [57], microstrip Yagi antenna [58], loaded patch antenna, and a rectangular patch antenna amid square slot with two PIN diodes [59]. Frequency reconfigurable antennas are used widely in frequency-agile wireless systems [60].

1.5.2 Polarization reconfigurable antennas

Polarization reconfigurable antennas are used to mitigate the fading caused by multipath propagation environment. They are used in applications like adaptive multiple-input multiple-output, which allows the dynamic change of the radiating properties of each antenna according to the fast changing channel conditions. A polarization reconfigurable patch with a single feed is capable of achieving right hand circular polarization (RHCP) and left hand circular polarization (LHCP). By controlling the switches the antenna can switch between RHCP and LHCP [61].

A polarization reconfigurable antenna using a circular patch fed by an open-end coplanar waveguide (CPW) through a diagonal slot is reported in [62]. Two PIN diodes are inserted across the coupling slots which have 45^0 inclinations to the CPW open end. A bias voltage is applied through the divided ground plane and DC isolation capacitors are soldered across the slits. By activating one pair of switches at a time, the antenna can switch between RHCP and LHCP. The antenna resonates at 5.8 GHz with a measured 3 dB axial ratio bandwidth of 1.8%.

1.5.3 Pattern Reconfigurability

Radiation patterns of an antenna give graphical interpretation of far-field radiation properties and measure antenna capability to transmit or receive signals in exact directions [54]. Radiation pattern reconfigurable antenna permits an effective strategy to direct the signal in the desired directions without significant changes in operating frequency. Noise and electronic jamming can be avoided by utilizing a pattern reconfigurable antenna [54].

Employing an array of antennas (e.g. phased array) is a common method to achieve radiation pattern manipulation [2]. The field can be controlled by adjusting the separation between elements and/or phase excitation difference. Therefore, the radiation pattern reconfigurability can be achieved.

An electrically small pattern reconfigurable Yagi antenna is presented in [63]. It consists of a driver and two directors which are located at opposite sides of the driver. The pattern can be controlled by using two PIN diodes with one PIN diode at the bottom of each director. The operation is based on activating at time. If switch one is activated, the beam will be steered towards the direction of director 1. When the switch 2 is activated, the beam will be steered towards director 2.

A simple pattern reconfigurable antenna which consists of monopole and dipole is presented in [64]. By controlling three switches which are utilized in the antenna, the antenna can operate as either monopole with omnidirectional pattern or dipole with directional pattern.

A pattern reconfigurable antenna with Omni-directional beam steering capacity is investigated to pick up the capacity of multiple-input multiple output (MIMO) systems [65].

Enormous efforts were devoted to the design of pattern reconfigurable antennas based on microstrip patch antennas. Basically, the work can be classified into three categories in terms of the radiation patterns of antenna provided [66]. The first one focuses on the reconfiguration of the main beam shape, such as reconfiguring the radiation patterns of resonant square spiral microstrip antenna between end fire and broadside [67].

An L-probe coupled circular patch antenna with four metallic posts at appropriate locations demonstrates a pattern switching between conical and broadside modes which are excited separately by two different sets of L-shaped probes and can be operated at the same frequency range[68].

A single-feed reconfigurable square-ring patch antenna with pattern diversity is presented in [69]. By controlling the states of the pin diodes, radiation pattern can be switched electrically between conical and broadside radiations at a fixed frequency. A slotted bow-tie antenna with a pair of reconfigurable CPW-to-slotline transitions alternatively switch its radiation pattern between an almost omnidirectional pattern and two end-fire patterns whose main beams are directed to exactly opposite directions [70].

Changing the null positions either in a discrete way using PIN diodes [71] or a continuous way using varactor diodes [72] and Steering the main beam direction are other focusing areas. Some antennas were proposed to steer the main beam to predefined directions by using electronic switches, such as PIN diodes, to activate one or several elements out of a few radiators [66].

A four-element L-shaped antenna array was proposed that can achieve beam steering over 360 in the azimuth plane with a gain around 0.5–2.1dBi [73]. Also, spiral structure was employed to change the main beam direction by altering the length of the spiral. In [74-76], rectangular single-arm spiral antennas were designed to change the main beam over five directions, three directions and four directions, respectively. In addition, work has gone into developing beam-steering antennas based on the Yagi-Uda type array [77-80].

Usually, such antennas have one driven element and several parasitic elements integrated with switches. By controlling the switches, the directive and reflective roles of the parasitic elements are changed and hence to change the direction of main beam.

A microstrip dipole [77], a microstrip patch [78-79], or a wire antenna [80] can be used as driven element. Instead of using an electronic switch to steer the parasitic elements of the Yagi-Uda antenna array, a movable liquid metal parasitic is used to change the position of reflector and director and there by achieving beam steering [81].

Recently, a novel fixed-frequency electronically beam steerable leaky-wave antenna was introduced [82]. The antenna can provide beam scanning in an angular range from 9 to 30 with a gain higher than 11dBi at 5.6 GHz. However, the bulky three dimensional waveguide structures make it hard to be integrated with mobile wireless devices. While there have been substantial advances in the design of pattern reconfigurable antennas, it is found that most of the reported microstrip beam steering antennas suffer from complex design and bulky nature, which may significantly limit their applications. In the last decade number of researchers has contributed to make tunable or reconfigurable antenna by adding switches on or between the patch and the ground plane. The future for this antenna seems bright and exciting.

Although various techniques have been examined in the literature, it can be summarized that reconfiguration of frequency is achieved by altering the surface current distribution of antenna through physical planar changes. Altering the radiating edge, slot, or feeding network results in pattern reconfiguration.

1.6 Motivation of research

Wireless communication systems have evolved substantially in recent years. The explosive growth of wireless communication users and applications necessitate the development of various types of wireless standards and increased functionalities within a confined volume. Since antennas are the primary and critical part of a wireless system, novelties in communication systems demand the design of antennas with intellectual competencies. For example a cognitive radio system can adjust their operational characteristics with respect to the changes in environmental conditions. This motivates researchers to develop an antenna that can alter their operating parameters like operating frequency, polarization and radiation pattern with the varying request. Reconfigurable antennas can address such complex system requirements by modifying their geometry and electrical behavior, thereby adapting to changes in environmental conditions or system requirements [55].

A pattern reconfigurable antenna is able to tune its radiation pattern in the desired directions. The ability to guide the beam's directions electronically adds more flexibility and extends the functionalities of the antenna. The radiation pattern agility characteristic give a chance to avoid noisy environments, improving security, and saving energy by properly directing the signal towards the intended user which enhance overall performance of the communication systems.

Moreover modern wireless systems demand the development of compact wideband and multiband antennas. Substantial efforts have been paid for the development of compact antennas to cope with the demands of the industry. Uniplanar structures are found to be promising candidate for the development of compact antennas. Miniaturizations of antenna feed as well as radiating structure are utilized for the development of compact antenna recently. Coplanar strip line (CPS) and asymmetric coplanar strip line (ACPS) are effectively used in the design of compact antennas.

Designing compact antenna using asymmetric coplanar strip feed are attractive because ACPS has all the advantages of a uniplanar feed along with compactness. This feeding mechanism is analogous to the coplanar wave guide feed except that the ACPS feed has a single lateral ground strip [49]. Study on the radiation characteristics of the ACPS antenna is quite interesting one. The antenna exhibits a tilt in the radiation pattern. A thorough investigation on the tilt in the radiation pattern is of much interested area. The main objective of this research work is to investigate the radiation pattern of ACPS and how it can be utilized to develop a simple pattern reconfigurable antenna using simple and efficient tuning mechanisms.

The main objectives of this research are:

- To investigate the radiation characteristics of the Asymmetric coplanar strip antennas.
- To investigate the possibility to change the main lobe direction of radiation pattern.
- To develop a dual band pattern agile antenna.
- To investigate a compact folded arm and folded ground asymmetric coplanar strip fed antenna with pattern reconfiguration capability.
- To develop a reconfigurable antenna using an asymmetric coplanar strip antenna to steer the main bam from bore-sight to end-fire direction.

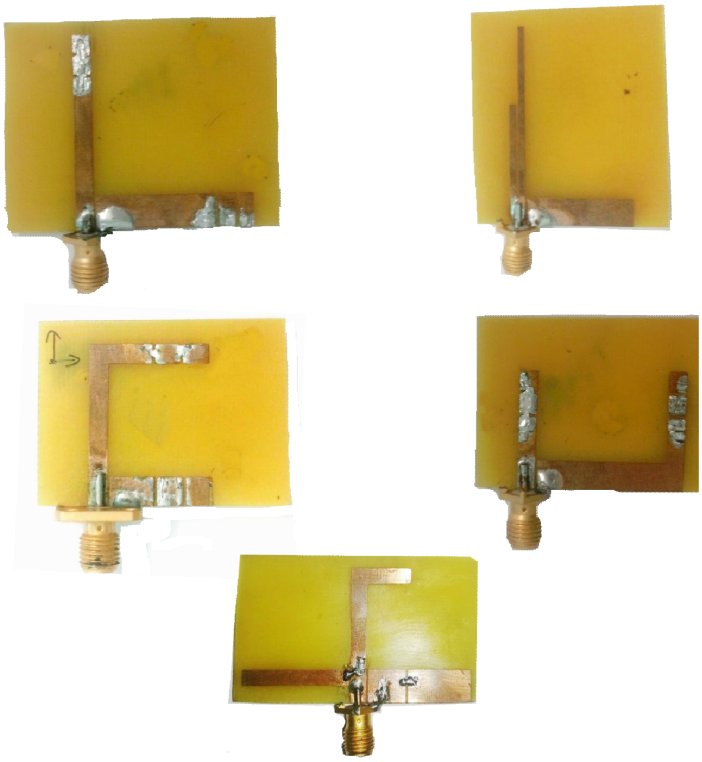

Figure 1.11: Photographs of the fabricated antennas

1.7. Layout of the Thesis

The thesis is organized into six chapters.

Chapter 1 presents a brief introduction to the wireless communication system, different types of antenna and concept of reconfigurability. Brief descriptions on antenna excitation techniques are presented. The motivation and the objective of the thesis are also presented.

Chapter 2 gives a brief review on antenna theory and antenna parameters. Fabrication method adopted and experimental techniques used to measure the prototype of the antenna are also discussed in this chapter.

In Chapter 3, an investigation on the radiation characteristics of an asymmetric coplanar strip antenna is presented. Simulation results and experimental validations are also presented. A dual band pattern agility antenna is also discussed.

A compact asymmetric coplanar strip reconfigurable antenna is presented in chapter 4. A Folded radiating arm is effectively utilized to get reconfiguration and compactness. A detailed analysis and discussions are presented in the subsequent sections. Experimental validations of the results are also presented.

In chapter 5, a pattern reconfigurable antenna capable of switching its radiation pattern from bore-sight direction to end-fire direction is presented. Details of currents and radiation patterns are discussed. The simulation and measured results in the far field region of the antenna are also discussed.

In Chapter 6, important conclusions from the research study are summarized and some possible future works are suggested. Finally, Appendix I describes a compact dual band antenna for DCS and WLAN application.

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Chapter 2

METHODOLOGY

This chapter presents the properties of antenna, fabrication techniques and measurement used for the analysis of different types of antennas. The design and simulations are performed using the CST Microwave studio. Photolithographic technique is used for the fabrication of antenna. Vector Network Analyzer HP8510C and Agilent Performance Network Analyzer 8362B are used for the measurement of antenna characteristics such as return loss, Radiation pattern, Gain, Efficiency.

2.1 Antenna Properties

Antenna is a critical part of a wireless communication system. A good design of antenna would bring improvement in the overall system performance. Various parameters which describe the performance of an antenna are briefly explained in this section.

There are two types of antenna parameters;

- Network parameters – which define the input or output interface of the antenna like input impedance, VSWR, reflection coefficient, S-parameter, Z-parameter.
- Radiation parameters – which defines the spatial selectivity of antenna and how the power is sent and collected like radiation pattern, field regions, directivity, gain, radiation power density.

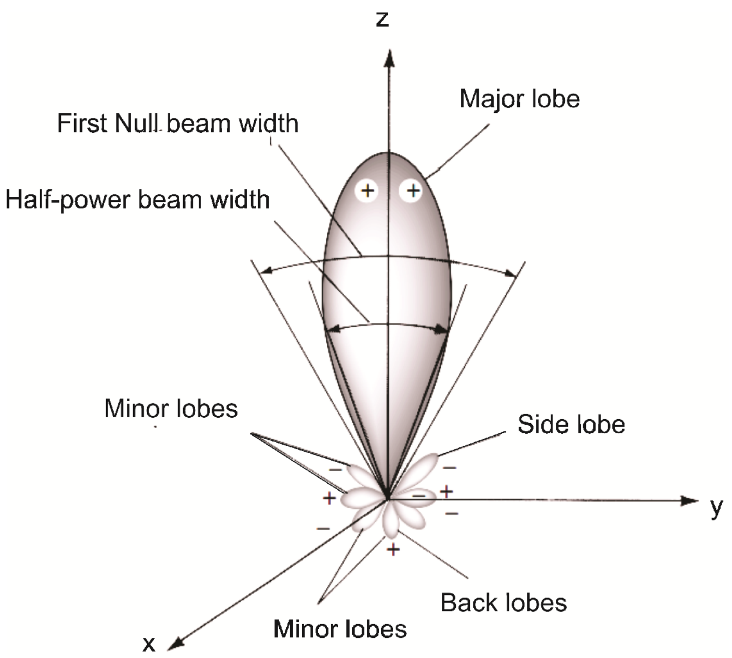

Figure 2.1 Radiation lobes and beamwidths of an antenna pattern. [1]

An antenna analysis and design become easier if one understands the current distribution well. Once the current distribution is known, all other parameters can be obtained. Some of these parameters are discussed in this section.

2.1.1 Radiation pattern

An antenna radiation pattern is described as a graphical representation or mathematical function of radiation (or reception) properties as a function of spatial coordinates. A radiation pattern is the spatial distribution of these radiated powers by an antenna as a function of the direction away from it [1]. It is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power density, field strength, directivity, gain, phase and polarization.

A trace of the power radiated or received at a fixed radius is called a power pattern, while spatial variation of the electric or magnetic field along a constant radius is called amplitude field pattern. The field and power patterns are often normalized with respect to their maximum value, yielding normalized field and power patterns [1]. A logarithmic scale (in decibels – dB) is commonly used to plot power pattern. Figure 2.1 shows different parts of radiation pattern. The plus and minus sign indicate the relative polarization of the amplitude between the various lobes, which change as the nulls are crossed.

A radiation pattern has different parts like major, minor, side and back lobes. A major lobe is defined as the radiation lobe containing the direction of maximum radiation. A minor lobe is any lobe other than a major lobe. A side lobe is a radiation lobe in any direction other than the intended lobe. A back lobe is a radiation lobe whose axis makes an angle of approximately 180 degree with respect to the main beam of an antenna [1].

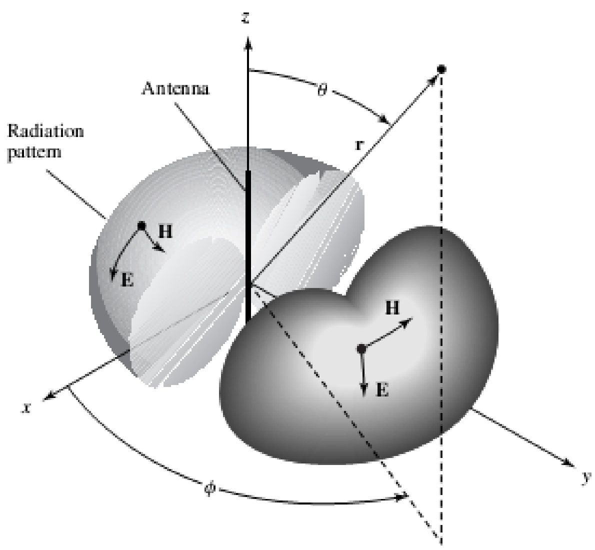

Figure 2.2 Omni directional antenna pattern [1]

Depending on the directivity pattern antenna can be categorized into isotropic, directional and omnidirectional. An isotropic radiator is a lossless antenna having equal radiation in all directions. The directive properties of actual antennas are often expressed with reference to this ideal and physically unrealizable antenna.

A directional antenna radiates or receives electromagnetic waves more effectively in some directions than in other. An omnidirectional antenna has a directional pattern in one plane and a non-directional pattern in the orthogonal plane. Figure 2.2 shows an omnidirectional pattern where the pattern is non-directional in the azimuth plane and directional in the elevation plane [1].

2.1.2 Beam Width

The angular separation between the two identical points on opposite sides of the pattern maximum is called beam width. One of the most widely used beam widths is Half Power Beam Width (HPBW). HPBW is defined by IEEE as: "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam" [1]. The angular separation between the first nulls of the pattern is First Null Beam width (FNBW). The beam width of antenna is a very useful in determining the figure of merit of an antenna. When the beam width of the antenna increases the side lobes decreases and vice versa.

2.1.3 Antenna Directivity, Gain and Radiation Efficiency

Directivity D and the gain G are the most important parameters of antenna. The directivity D is defined as the ratio of the radiation intensity U in a given direction from an antenna to the radiation intensity averaged over all direction. The average radiation intensity is calculated by dividing the total power radiated by the antenna (P_{rad}) by 4π. Thus the directivity D is given by:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{2.1}$$

Gain (G) of antenna is very closely related to the directivity, the relation to find the gain of the antenna is given as given by:

$$G = e_{rad} D \tag{2.2}$$

Where e_{rad} is the radiation efficiency which is calculated as the the ratio of the radiated power P_{rad} to the input power at the terminals or the antenna, P_{in},

$$e_{rad} = \frac{P_{rad}}{P_{in}} = \frac{G}{D} \tag{2.3}$$

2.1.4 Polarization

The polarization of an electromagnetic wave is defined by the figure traced by the instantaneous electric field vector at a fixed observation point. The polarization of an antenna in a given direction is defined as the polarization of the wave radiated in that direction. If the geometric figure traced by the sum of the electric field vectors over time is an ellipse then the field is said to be elliptically polarized. Under certain conditions the ellipse may break into a straight line then polarization is called linear polarization. If the field vectors are traced into a circle then the polarization is called circular polarization. The figure of the electric field can be traced in a clockwise or counter-clockwise direction. Clockwise rotation of the electric-field vector is defined as a right-hand polarization and counter clockwise as left-hand polarization.

2.1.5 Bandwidth

Bandwidth is the main characteristic of the wideband antenna. The bandwidth can be considered to be the range of frequencies, on either side of the centre frequency, where the antenna characteristics are within an acceptable value. The bandwidth can be described in terms of percentage of the centre frequency, f_c of the band.

$$BW = \frac{f_H - f_L}{f_C} \times 100 = 2\frac{f_H - f_L}{f_H + f_L} \times 100 \qquad (2.4)$$

where f_H is the highest frequency in the band and f_L is the lowest frequency in the band. The centre frequency can is calculated from:

$$f_C = \frac{f_H + f_L}{2} \qquad (2.5)$$

For broadband antennas, the bandwidth can also be expressed as the ratio of the highest frequency to the lower frequency, where the antenna performance is acceptable. It is given by:

$$BW = \frac{f_H}{f_L} \qquad (2.6)$$

2.2 Methodology

This section presents the methodology and facilities used to study the characteristics of a typical asymmetric coplanar strip antenna. An explanation of the simulation software, fabrication methods and measurement setup for the characterization of the antenna is also discussed. Description on the fabrication of the antenna on microwave laminates by photolithography and experimental set up used to study radiation pattern, gain, reflection characteristics and other associated parameters are also presented.

2.2.1 Simulation software

A clear-cut knowledge of propagation of fields and waves is prerequisite for the design and development of antenna. Simulation software plays an important role in predicting antenna behavior before it is constructed. This leads to reduce the cost and time required for the design procedure. One of such commercial simulation software used for the design and optimization of the antenna discussed in this thesis is CST Microwave Studio® (CST MWS) a product from Computer Simulation Technology [2].

CST Microwave Studio® is a fully featured electromagnetic software package based on the Finite Integration Technique (FIT). It provides a universal spatial discretisation scheme, appropriate for the analysis and design of various electromagnetic high frequency structures. The Finite Integration Technique was first introduced by Weiland in 1977 [3]. FIT discretizes the integral form of Maxwell's equations.

In order to solve the Maxwell's equations numerically finite calculation domain enclosing the necessary space region is to be defined. Then decomposing the computational domain into a finite number of tetra or hexahedra unit cells, and electric and magnetic vectors can be aligned on the facet of these cells [4]. The spatial discretization of Maxwell's equations is finally performed on these grid systems. The calculation process is repeated for all grid cells within the boundary until the desired accuracy is reached.

CST MWS enables the fast and accurate analysis of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures. A key feature of CST is that the software supports transient solver, frequency domain solver, integral equation solver, multilayer solver, asymptotic solver, and Eigen mode solver to best suit various applications. CST uses hexahedral grids in combination with Perfect Boundary Approximation (PBA) technique with hexahedral meshing [2]. CST support different solvers they are:

- **Transient Solver**: It is the most flexible tool uses a hexahedral grid, which can obtain the entire broadband frequency behavior of the simulated device from only one calculation run (in contrast to the frequency step approach of many other simulators). This solver is remarkably efficient for most high frequency applications such as connectors, transmission lines, filters, antennas, amongst others [2].
- **Frequency domain solver**: The transient solver is less efficient for structures that are electrically much smaller than the shortest wavelength. In such cases it is advantageous to solve the problem by using the frequency domain solver. The frequency domain solver may also be the method of choice for narrow band problems such as fillers or when the use of tetrahedral grids is advantageous. Besides the general purpose solver (supporting hexahedral and tetrahedral grids), the frequency domain solver also contains alternatives for the fast calculation of S-parameters for strongly resonating structures only [2].
- **Integral equation based solver**: For electrically large structures, volumetric discretization methods generally suffer from dispersion effects which require very a fine mesh. CST Microwave studio therefore contains an integral equation based solver which is particularly suited to

solving this kind of problem. The integral equation solver uses a triangular surface mesh which becomes very efficient for electrically large structures. The multilevel fast multipole method (MLFMM) solver technology ensures an excellent scaling of solver time and memory requirements with increasing frequency. For lower frequencies where the MLFMM is not as efficient, an iterative method of moments solver is available [2].

- **Eigen mode solver**: Efficient filter design often requires the direct calculation of the operating modes in the filter rather than an S-parameter simulation. For these applications an eigen mode solver which efficiently calculates a finite number of modes in closed electromagnetic devices [2].

The antenna structure to be simulated using CST is modeled after selecting a predefined templates that suit a problem in which parameters such as boundary conditions, mesh size and type. The antenna is constructed using graphical solid tools by specifying the coordinates for each point of the structure and giving material properties. The frequency sweep is then defined to get solutions for the required band and suitable excitation schemes such as waveguide port or discrete port is assigned. The structure is simulated using a transient solver. Results like scattering parameters, current distributions and 2D, and 3D far field radiation pattern can be displayed. From the parametric analysis, the effect of different geometrical parameters can be formulated.

2.2.2 Antenna Fabrication

Printed antennas are usually fabricated on low loss, thermally stable substrates with constant permittivity. A photolithographic technique is used for the fabrication of antenna. A negative mask of the desired geometry is created and is printed on a transparent sheet. A single side copper clad substrate with a dielectric constant that meets the requirement of application of antenna is selected first. The substrate is cleaned and cut to suitable dimension and dipped into negative photo resist solution and dried in order to make a thin film of the photo resist. It is then exposed to ultra violet radiation through the negative mask for 2 minutes. The layer of photo-resist material in the exposed portions hardens which is then immersed in a developer solution and agitated for a few minutes.

After developing, the unwanted metal portions are removed by washing in Ferric Chloride ($FeCl_3$) solution. All the copper parts except under the hardened photo resist layer dissolves in the $FeCl_3$. After etching board is rinsed in running water and cleaned. Figure 2.3 shows the different steps involved in fabrication.

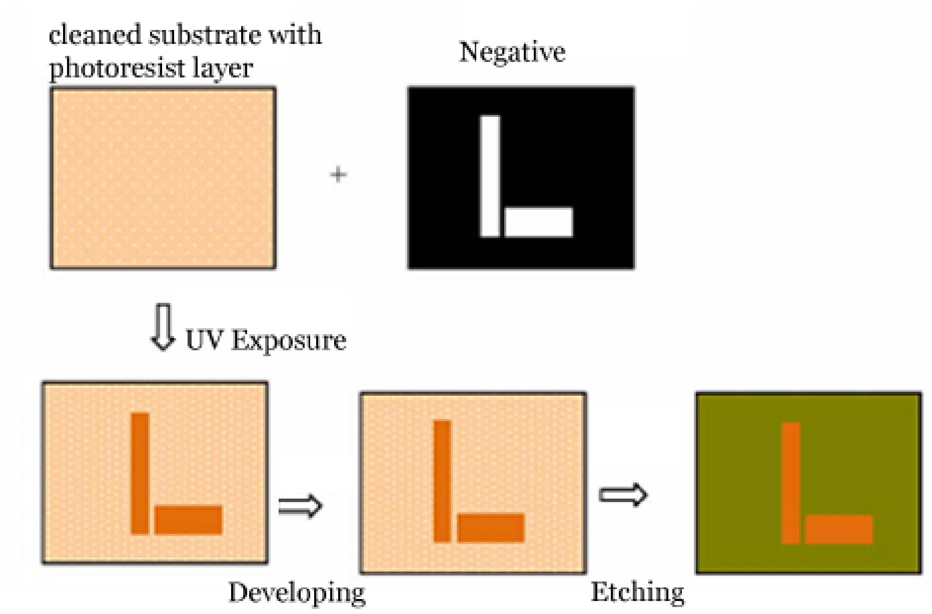

Figure 2.3: Photolithographic technique for antenna fabrication

2.2.3 Antenna Measurement setups

2.2.3.1 HP 8510C Vector Network Analyzer (VNA)

Network analyzer is a sophisticated instrument used for the accurate measurement of the reflection and transmission of signals associated with an electrical network, especially at higher frequencies. HP 8510C vector network analyzer (VNA) is used in the present study, which is capable of making rapid and accurate measurements in frequency domain and time domain [5]. The network analyzer can measure the magnitude and phase of the S parameters. It can measure two port network parameters such as S11, S12, S22,S21 and it's built in signal processor analyses the transmit and receive data and displays the results in many plot formats.

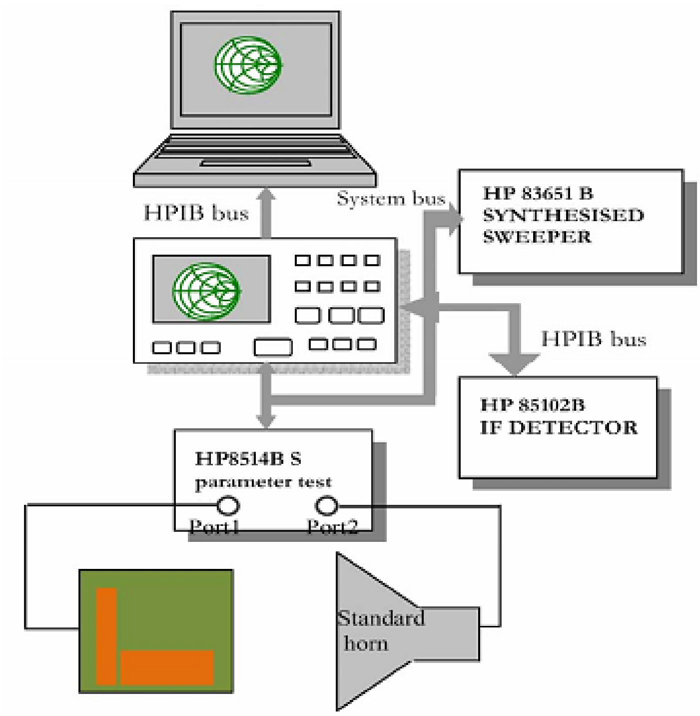

Figure 2.4: Measurement setup using Network Analyzer

The analyzer consists of source, S parameter test set, signal processor and display unit. The synthesized sweep generator HP 83651B uses an open loop YIG tuned element to generate the RF stimulus. It can synthesize frequencies from 10 MHz to 50 GHz. The antenna under test is connected to one of the port in the S parameter test set unit and incident and reflected wave at the port are then down converted to an intermediate frequency of 20MHz and fed to the detector.

An MATLAB based data acquisition software system coordinates the measurements. Schematic diagram of HP8510C NWA and setup for reflection characteristic measurement is shown in Figure. 2.4. The Antenna properties like return loss, radiation pattern and gain are measured using the HP8510C.

2.2.3.2 Agilent E8362B Performance Network Analyzer

The Agilent E8362B vector network analyzer is a member of the PNA Series network analyzer platform and provides the combination of speed and precision for the demanding needs of today's high frequency, high-performance component test requirements [9]. The PNA Series meets these testing challenges by providing the right combination of fast sweep speeds, wide dynamic range, low trace noise and flexible connectivity. The operating frequency of the system is from 10 MHz to 20 GHz. It has 16, 001 points per channel with < 26 µsec/point measurement speed.

2.2.3.3 Anechoic chamber

The accurate measurement of antenna characteristics is done inside an anechoic chamber, which consists of microwave absorbers to avoid EM reflections as shown in figure 2.5. The tapered shapes of the absorber provide good impedance matching for the microwave power upon it. Aluminum sheets are used to shield the chamber to avoid electromagnetic interference from surroundings.

2.2.3.4 Turn table assembly for far field radiation pattern measurement

The radiation pattern of the antenna is measured by placing the Antenna Under Test (AUT) on a rotating platform of turn table assembly, which driven by a stepper motor. The radiation pattern of the antenna is measured by rotating a microcontroller controlled stepper motor. A standard wideband horn (1-18GHz) and automated software 'Crema Soft', developed at the Centre for Research in Electromagnetics and Antennas, CUSAT, coordinates all the measurements.

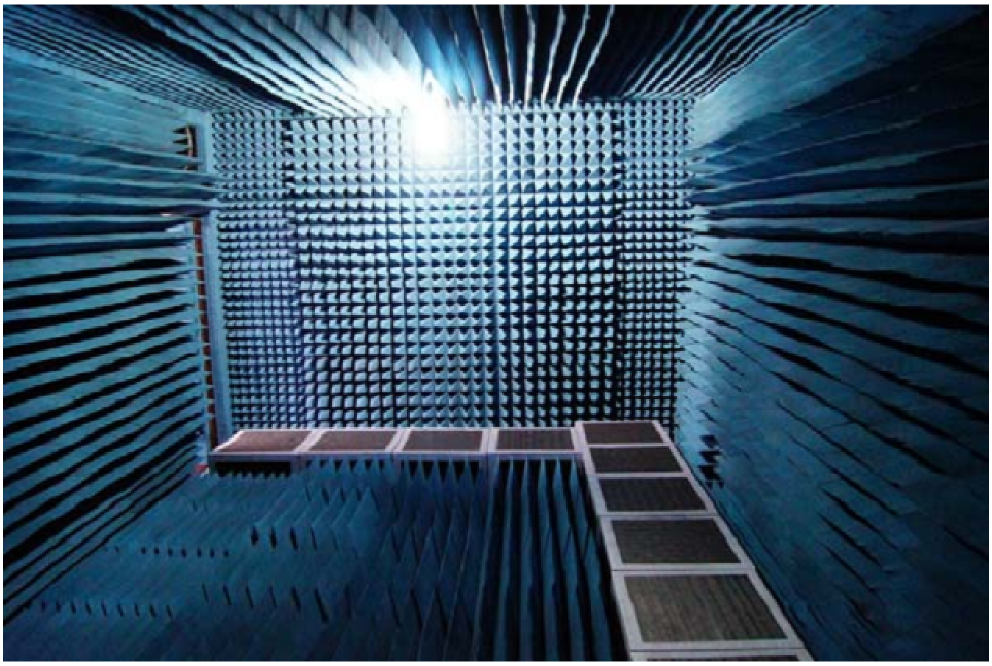

Fig. 2.5: Anechoic chamber used for the antenna measurements

2.2.4 Antenna Measurements

The measurement procedures followed to determine the antenna properties are discussed in this section. The transient response of antenna can be measured either in time domain or in frequency domain. Measurement of the antenna is performed at the antenna research facility at CREMA, Dept. of Electronics, CUSAT. The test facilities available include Network Analyzers (R&S ZVB20, HP8510C, and Agilent PNA 8362), automated antenna positioner, broadband double ridged horn antennas (2-20 GHz) and anechoic chamber. Calibration of Network Analyzer is performed before the measurements using the standard calibration kit.

2.2.4.1 Return loss, resonant frequency and Bandwidth

The impedance of the antenna is a measure of resistance and reactance of an antenna. When there is impedance mismatch in an antenna, the incident energy is reflected back to source. The ratio of reflected power to incident power is called input reflection coefficient, S11. The level of this mismatch is represented using voltage standing wave ratio (VSWR).

The calibration of the port is done by using a standard open, short and matched load for the given range of frequencies. The one terminal of calibrated instrument is now connected to antenna. The frequency versus return loss parameter (s_{11}) is then stored on a computer.

The frequency for which the return loss value is the minimum is taken as resonant frequency of the antenna. The range of frequencies for which the return loss value is within the -10dB points is usually treated as the bandwidth of the antenna. The -10 dB points corresponding to the frequency at which 90 % of the fed power is transmitted and only 10 % power reflected back.

The equation to find the percentage bandwidth of the antenna is,

$$\%Bandwidth = \frac{f2 - f1}{fc} \times 100 \tag{2.7}$$

Where *f1* and *f2* denotes lower and upper frequencies at -10 dB point and *fc* is the centre frequency. The bandwidth is sometimes referred to as 2:1 VSWR bandwidth.

2.2.4.2 Radiation pattern measurement

In radiation pattern, the radiation properties of an antenna are graphically represented as a function of space co-ordinates. The radiation pattern assumes a three dimensional nature. But because of practical limitations in taking the three dimensional plot, two principal plane patterns are taken for directional antenna and three patterns (*xy, xz,* and *yz*) taken for omnidirectional patterns. All the far field measurements are taken inside an anechoic chamber. The antenna is placed on the antenna holder of turn table and connects to port of the network analyzer. The pattern is measured at a distance $d > \frac{2D^2}{\lambda}$, where λ is the operating wavelength, and D is the largest dimension of the antenna and

As shown in Figure 2.6(b), the AUT is connected to Port 1 and the standard horn is connected to Port 2. The height and polarization of both antennas are aligned for maximum transmission (S21) between them. The network analyzer is kept to measure transmission coefficient mode with the frequency range within the -10dB return loss bandwidth. A THRU calibration is performed to calibrate the S21 data to 0dB for every frequency point in the band. The number of frequency points is set according to requirement. The start angle, stop angle and step angle of the motor is also configured with the help of '*Crema Soft*'. In order to suppress spurious reflections from the nearby objects, the time domain gating facility of the analyzer is used. The antenna is positioned to home which automatically sets the current position as 0°. The *Crema Soft* software now invoked to take the radiation pattern and reads the normalized S21data for the specified frequency band, for each angular position of the AUT and stores it as a CSV file. This is used to plot the 2-D radiation pattern at the required frequency.

2.2.4.3 Antenna Gain

Gain of the antenna is measured by taking ratio of the intensity of strongest radiation of antenna in direction to that of a standard reference antenna. Here both antennas are fed with same input power. The gain transfer method is used to determine the gain of the antenna under test (AUT) using a standard gain antenna [1, 6]. The measurement setup is shown in Figure 2.6. Initially standard antenna with known gain is connected to port -2 for bore-sight radiation and the THRU calibration is done for the frequency range of interest. This is the reference gain for the AUT. Then standard antenna is replaced by the AUT and the change in transmission coefficient is recorded. This is relative gain of the antenna.

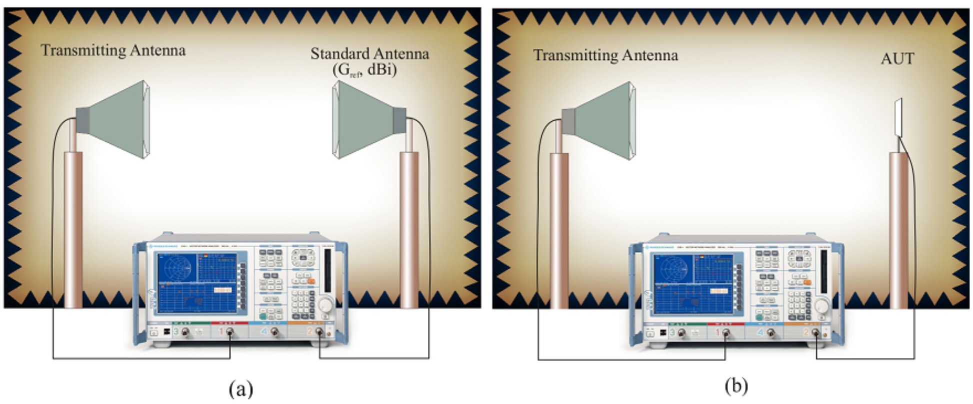

Figure 2.6: Antenna gain measurement set up

The absolute gain is calculated by adding this relative gain to the original gain of standard antenna obtained from gain chart.

$$G(dBi) = G_{ref}\,(dBi) + |S_{21}|_{AUT} \qquad (2.8)$$

2.2.4.4 Radiation Efficiency

Radiation efficiency is one of the main characteristic of an antenna and it tells how efficiently or effectively a radiator will radiate electromagnetic energy which is fed into it. Conventionally, Wheeler cap method is used to measure the efficiency of a resonant antenna [7, 8]. In wheeler cap method the input resistance of the antenna with a conducting cap enclosing the antenna and one without the conducting cap is measured using E8362B PNA. Efficiency of antenna is calculated using the equation:

$$Efficiency, \eta = \frac{R_{no\_cap} - R_{cap}}{R_{no\_cap}} \qquad (2.9)$$

Where, R_{no_cap} denotes the input resistance without the cap and R_{cap} the resistance with the cap.

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Chapter 3

RADIATION CHARACTERISTICS OF ASYMMETRIC COPLANAR STRIP ANTENNA

This chapter presents an analysis of radiation characteristics of an asymmetric coplanar strip antenna (ACPS). Simulation studies are performed to predict the reflection and radiation behavior of ACPS antenna and suitability of pattern reconfiguration are analyzed. The predicted results are validated experimentally by fabricating and testing a prototype of antenna. A dual band antenna with frequency tunability and pattern agility is also presented. Reflection and radiation characteristics of the antenna followed by an analysis on radiation pattern tilting are also discussed.

3.1 Introduction

The revolutionary growth in wireless communication systems demand for the design of antenna system that can integrate multiple functions into a single module to obtain low cost, simple and compact size antenna. These multifunctional antennas would provide functions like multiple bands, reconfiguration and filtering. Reconfigurability is achieved by a change in antenna physical structure, surface current distribution, feeding network and radiating edges. Several techniques were introduced to design antennas with reconfigurable functionality.

Compact reconfigurable antennas have recently received great attentions. The antenna feeding mechanism is an important factor during the design and development of compact antenna systems. Usually the feed structures consume most of the overall antenna size. Printed uniplanar excitation techniques like Coplanar waveguide (CPW), Coplanar strips (CPS) have gained attention of antenna researchers due to its attractive features like wider bandwidth, better impedance matching, and easy integration with microwave monolithic integrated circuits [1-2].

CPS is a planar analogy of parallel pair transmission line and is considered as a balanced transmission line. Coplanar strips offer much more flexibility during the design of microwave circuits and in the mounting of planar microwave circuits in series as well as parallel. A coplanar strip line in which the two strips do not have same width is called asymmetric coplanar strip.

An asymmetric CPS (ACPS) is more desirable to use due to its flexibility to adjust the characteristic impedance by changing the width of one of the strips while keeping the width of other strip and slot width fixed[1].

This chapter presents an investigation on the radiation performance of an asymmetric coplanar strip antenna. The antenna consists of signal strip and ground strip. From a parametric study, design equations are obtained and effects of various parameters in controlling the pattern direction are also analyzed. An experimental study using switches is also conducted to confirm the pattern steer ability of the antenna. Finally a simple dual band pattern agile antenna is also presented.

3.2 Asymmetric Coplanar Strip Antenna

Compact antennas can be efficiently designed using an asymmetric coplanar strip (ACPS) feed. An ACPS can be easily converted into antennas by geometrical modifications. Asymmetric coplanar strip (ACPS) line is analogous to the coplanar wave guide feed except that the ACPS feed has a single lateral ground strip. ACPS has all the benefits of CPS along with compactness. Thus compact antennas can be effectively designed using asymmetric coplanar feed lines.

ACPS has many advantages like simple structure, ease of fabrication and require comparatively lesser area than conventional CPW/ CPS feed structure. Through geometrical modifications ACPS can be easily converted into an antenna [3]. An analysis of radiation characteristics of an asymmetric coplanar strip antenna is discussed in this section. Reflection characteristics, radiation pattern and parameters which influence the pattern are discussed. Both simulation and experimental validation are also presented and discussed.

3.2.1 Antenna Design and Operation

Geometry of the proposed asymmetric coplanar strip antenna is shown in Figure 3.1. The antenna consists of a strip of length l_s and width w_s printed on a FR4 substrate of dielectric constant ε_r = 4.4 and height h = 1.6 mm. The length of the strip is selected as quarter wavelength of the design frequency. A rectangular ground plane with dimension l_g x w_g is printed on the substrate separated from signal strip by a gap g.

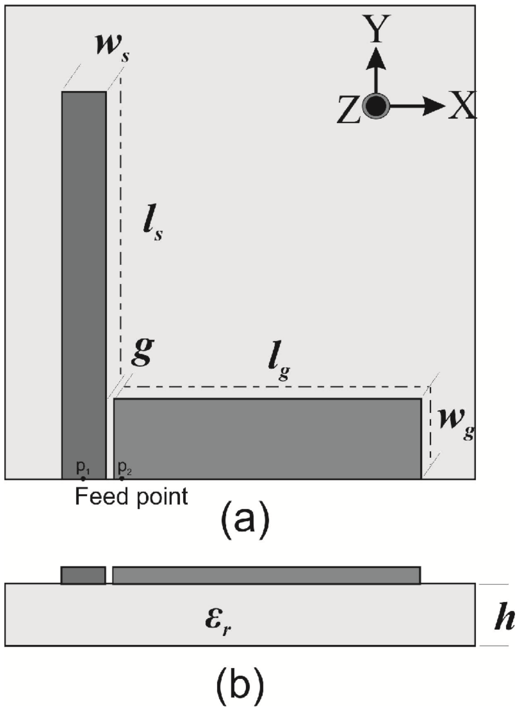


Figure 3.1: Geometry of the asymmetric coplanar strip antenna
(a) Top View (b) Side view

Width of signal strip w_s and gap g are optimized to achieve characteristic impedance of 50 Ω. The antenna dimensions are optimized using commercially available simulation software CST microwave studio.

3.2.2 Reflection characteristics

The antenna structure was simulated using the time domain solver in CST Microwave studio® and prototypes have been fabricated and measured the results using HP8510C Vector Network Analyzer (VNA). Figure 3.2 shows the simulated and measured reflection characteristics of the asymmetric coplanar strip (ACPS) fed antenna.

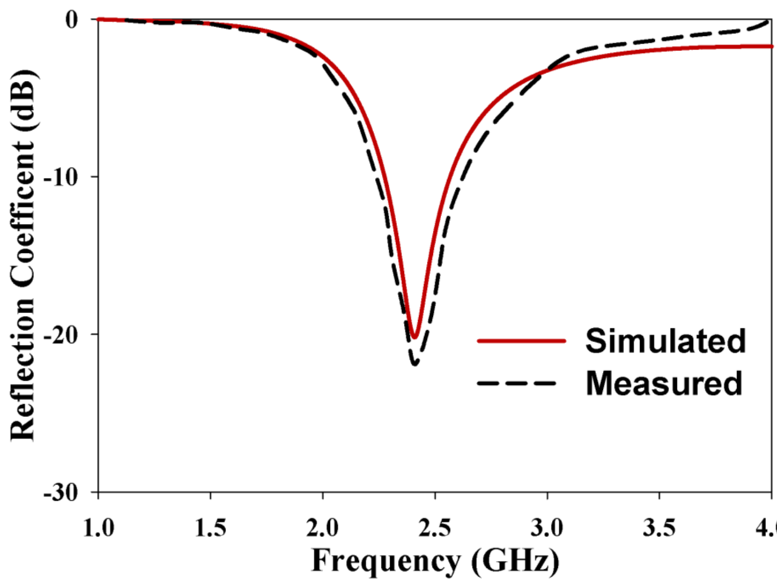


Figure 3.2 Simulated and measured reflection coefficient of the ACPS antenna (l_s = 21 mm, l_g = 23 mm, w_g = 5mm and w_d = 3mm, g=0.3mm, ε_r =4.4, h = 1.6mm)

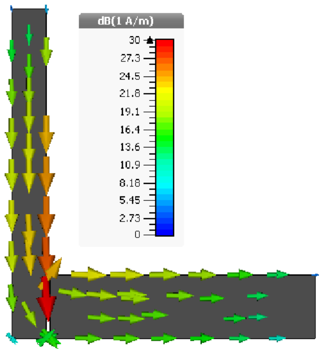


Figure 3.3: The surface current plot of the ACPS antenna at 2.4 GHz

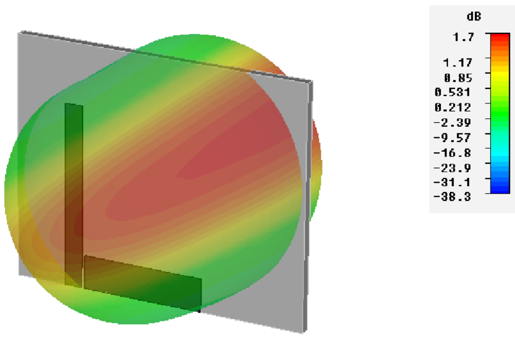


Figure 3.4: Three dimensional radiation pattern of ACPS Antenna at 2.4 GHz

The antenna exhibits a single resonance at 2.41 GHz with good impedance matching. It is clear from the figure that the reflection coefficient remains below -10dB from 2.195 GHz - 2.624 GHz. The -10dB impedance bandwidth of the antenna is nearly 17.8%. Both the simulated and measured results match almost well. Figure 3.3 shows the simulated surface current distribution of the antenna. A strong current is observed along the vertical and horizontal strip. It is clear from the figure that the resonance is due to the half wave length variation of field along the length $l_s + l_g$. The three dimensional radiation pattern of the antenna is shown in Figure 3.4. It is observed that the radiation pattern of the ACPS fed antenna is tilted. This tilt is due to the resultant current in the vertical and horizontal arm.

Parametric studies are conducted to examine the effect of various design values and are given in Figure 3.5 – 3.8. It is observed that the variation in the width of ground strip w_g and gap g affect only the matching of the antenna. In the variation study with l_s and l_g, it is observed that the resonant frequency of the antenna mainly depends on the length of l_s and l_g.

The resonant frequency shifts to the lower side of the spectrum with increase in length of l_s. The length of the ground plane l_g also significantly affects the resonant frequency and matching conditions of the antenna. As the length l_g increases the resonant frequency shifts towards lower frequencies and shifts towards higher frequencies as l_g decreases. It is clear from the current distribution of the antenna that there is a quarter wave variation in the strip l_s and a similar variation along the strip l_g. But the current variation in the ground plane is only along the edge, which therefore doesn't perturb much in the asymmetric coplanar strip line characteristics. The antenna acts moreover like a dipole.

Thus it can be concluded from the parametric studies that the resonant frequency corresponds to nearly half of the guided wavelength corresponding to the total length of $l_s + l_g$ of the antenna.

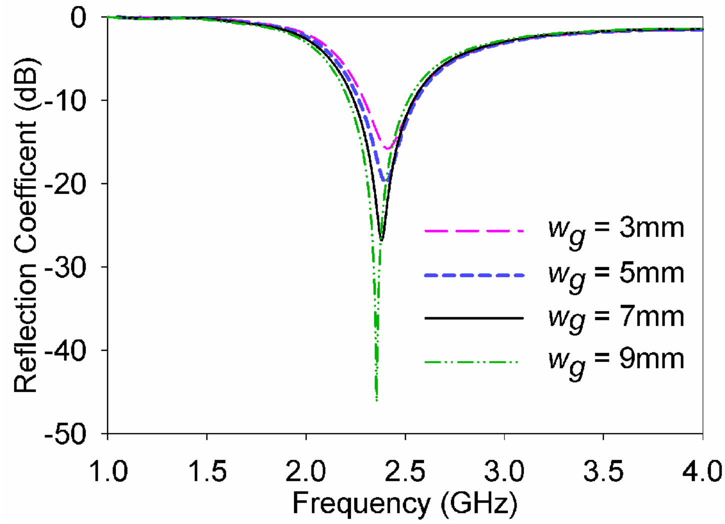


Figure 3.5: Effect of variation of w_g on reflection characteristics

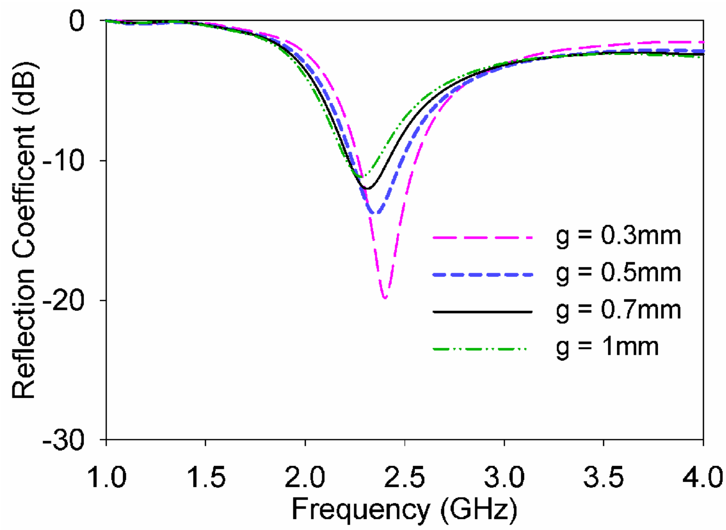


Figure 3.6: Effect of variation of gap *g* on reflection characteristics

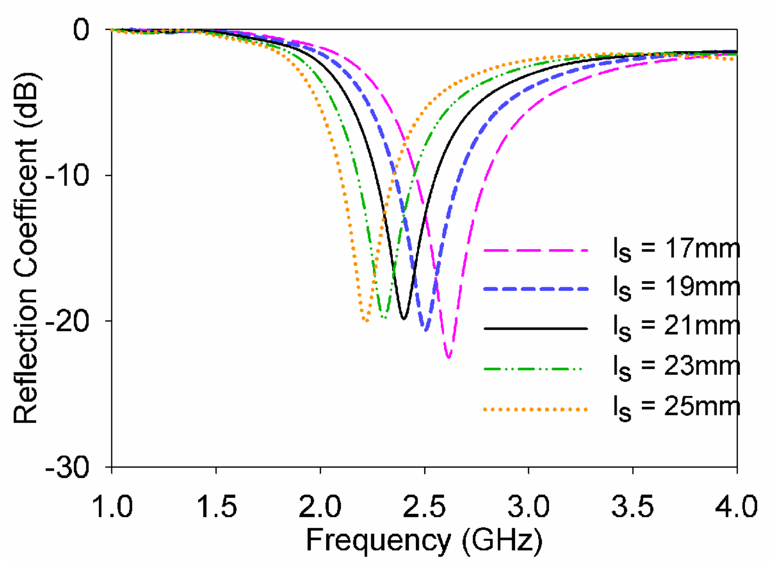


Figure 3.7: Effect of variation of l_s on reflection characteristics (l_g=23 mm)

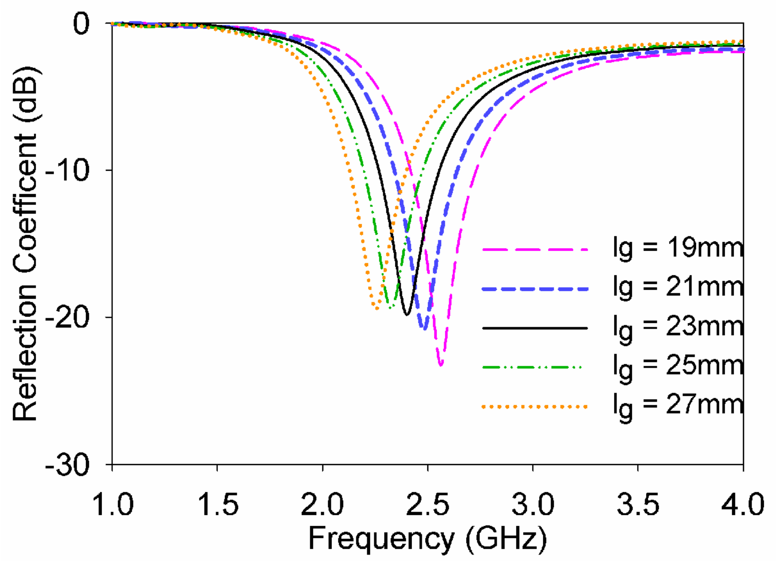


Figure 3.8: Effect of variation of l_g on reflection characteristics (l_s=21 mm)

Thus it can be conclude that the total length of the antenna determines the resonant frequency of the antenna which can be expressed as,

$$f_{GHz} = 0.5\frac{300}{L\sqrt{\varepsilon_{\text{eff}}}} \qquad \text{where } L = l_m + l_g \qquad \varepsilon_{\text{eff}} \cong \frac{\varepsilon_r+1+1}{3}$$

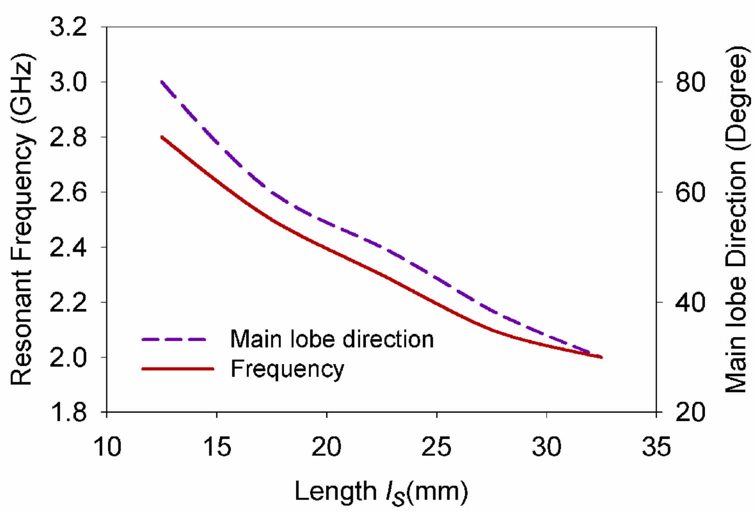
3.2.3 Radiation Properties

The radiation pattern of the antenna at resonant frequency in Figure 3.4 is similar to that of a dipole, but with a tilt. The current distribution in Figure 3.3 shows that the nearly equal X and Y directed currents are responsible for the tilt in the radiation pattern. To understand the reason for tilt in main lobe direction of radiation pattern, an analysis is carried out to find the effect of various design parameters on radiation characteristics. Table 3.1 shows the variation in frequency and shift in the main lobe direction of the antenna against changes in l_s and l_g parameters. Figure 3.9 and 3.10 shows the effect of the variation of l_s and l_g on the main lobe direction. So it is clear from the figure that increasing the length of the strip changes both the frequency and the direction of main lobe.

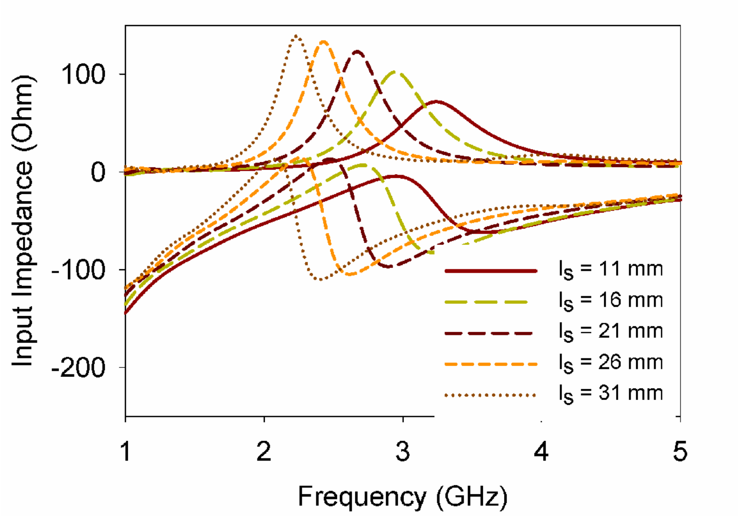
When the strip length l_s increases it is observed that the main lobe direction move towards x-axis, that is tilt angle decreases. It is evident from the input impedance plot that when the length of l_s and l_g increases, reactance becomes more inductive and moreover bandwidth decreases. Again when l_g increases the main lobe direction moves towards y-axis. This property can be utilized to steer the beam towards the desired direction.

l_s (mm)	l_g (mm)	Resonant Frequency (GHz)	Bandwidth (MHz)	Main lobe direction (Degree)	Gain (dBi)
11	23	3.04	433	70	2.2
16	23	2.60	365	55	1.9
21	23	2.41	298	45	1.8
26	23	2.17	245	35	1.8
31	23	2.01	217	30	1.7
21	13	2.82	330	20	2.1
21	18	2.62	340	30	1.8
21	23	2.41	298	45	1.8
21	28	2.22	277	55	1.6
21	33	2.06	267	60	1.6

Table 3.1: Effect of strip length on frequency and main lobe direction of ACPS antenna

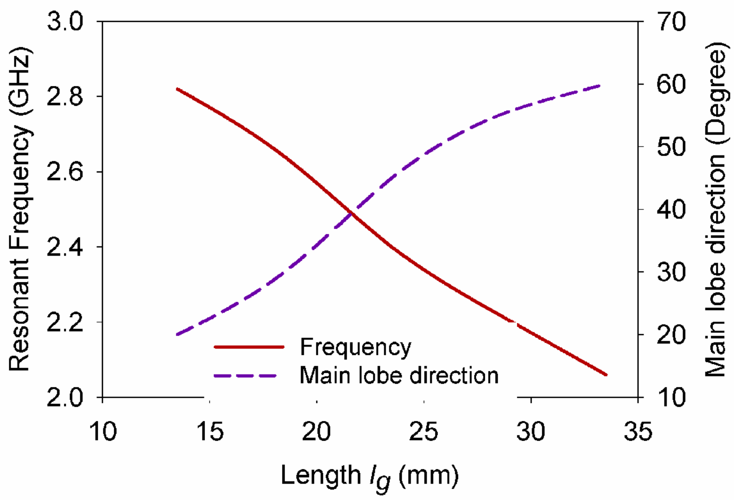


(a)

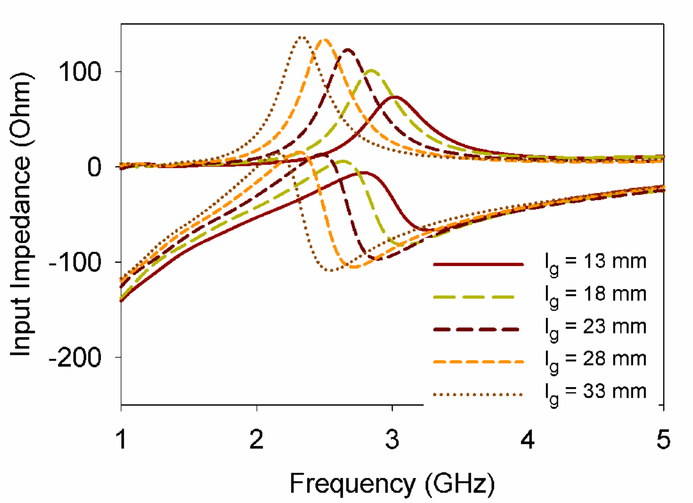


(b)

Figure: 3.9 Variation of (a) main lobe direction (b) input impedance against l_s



(a)



(b)

Figure: 3.10 Effect of l_g (a) main lobe direction (b) input impedance

3.2.4 Optimization

To further evaluate the beam steering capability of ACPS at 2.4 GHz studies are conducted keeping the total length of radiating arm $L= l_s + l_g$ = constant. Table 3.2 shows the summary of different conditions set for the study. Figure 3.11 shows the radiation performance of antenna for different combination of l_g and l_s keeping total length constant. It has been observed that the current density is more predominant in the longer arm than in smaller one. The asymmetry in the length of the vertical and horizontal radiating strips unbalances the current distribution and causes tilt in the pattern. Whenever the current in one arm dominates, the electric field due to that arm dominates, so the field pattern tilts.

Condition	l_s *(mm)*	l_g *(mm)*	$l=l_s+l_g$ *(mm)*	Resonant frequency (GHz)		Main lobe Direction (Degree) Simulation
				Computed	Simulated	
Antenna 1	17.5	28.5	46	2.44	2.44	65
Antenna 2	21.5	23.5	46	2.4	2.4	45
Antenna 3	27.5	18.5	46	2.38	2.34	25

Table 3.2: Different conditions set for ACPS antenna

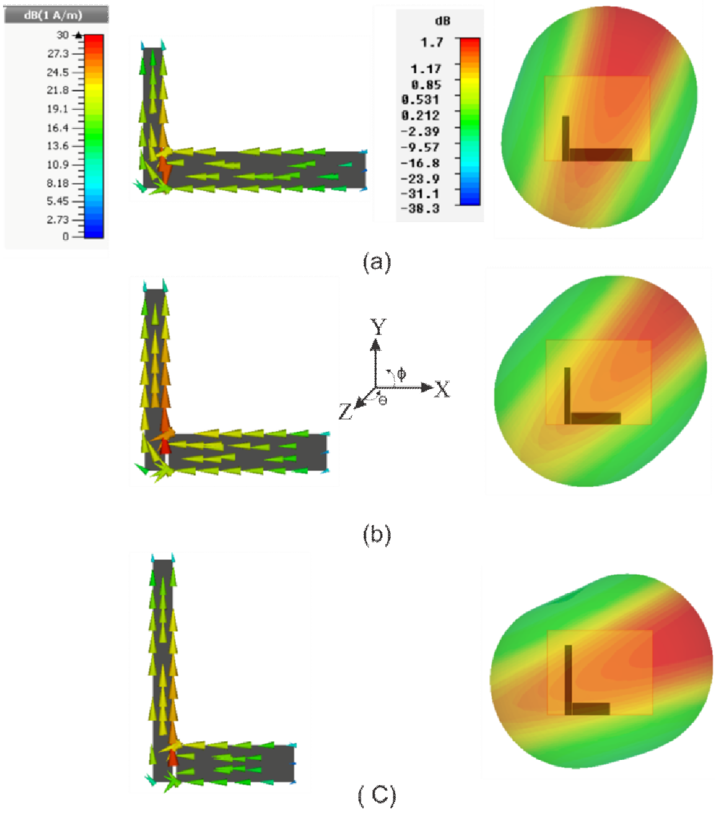


Figure 3.11 Radiation performance during different combination of l_g and l_s

(a) Antenna 1 (b) Antenna 2 (c) Antenna 3

The total field pattern is due to the superposition of the field patterns of two radiating arms. In case of Antenna 1, the length of horizontal arm is longer than vertical arm then the field of longer arm dominates; that is x directed current dominates than the y directed current. Hence the total field is due to the resultant of the field due to horizontal and vertical strip. Thus the pattern tilts more towards y axis $\varphi = 65°$. In Antenna 2, the length of horizontal and vertical strips are almost equal, then the current distribution is almost equal, then the both the components of field vector are also equal, this leads to direct the main lobe at $\varphi = 45°$. Similarly in in Antenna 3, the field components of vertical arm dominates at far field hence the direction of main lobe moves towards *x*-axis that is, at $\varphi = 25°$. So it can be conclude that the direction of far field pattern depends on the length of arm. Table 3.3 shows the computed and optimized dimensions of the antenna with different permittivity.

Parameters	**Antenna-1 Rogers 5880**	**Antenna-2 Rogers RO-4003**	**Antenna -3 FR4 epoxy**	**Antenna -4 Rogers RO 3006**
l_s	27	24	22.5	20
l_g	28	25	23.5	21
w_g	5.5	5.5	5.5	5.5
g	0.2	0.24	0.3	0.5
ε_r	2.2	3.38	4.4	6.15
h	1.575	1.524	1.6	1.28
f_1	2.49	2.415	2.4	2.45
Main lobe direction	45	45	45	45

Table 3.3: ACPS antenna simulated on with different substrate material

3.2.5 Experimental results

In order to demonstrate the pattern steering ability of the antenna in this work, a prototype of the antenna operates in 2.4 GHz was fabricated and measured. The configuration of the pattern reconfigurable ACPS antenna including switch is presented in Figure 3.12. In this study copper strip are used for proof of concept, the ON/OFF states are simulated with presence or absence of metal strip of area 0.5x0.5 mm^2. Switches are placed at specific locations along the horizontal and vertical strips in order to steer the beam towards desired direction.

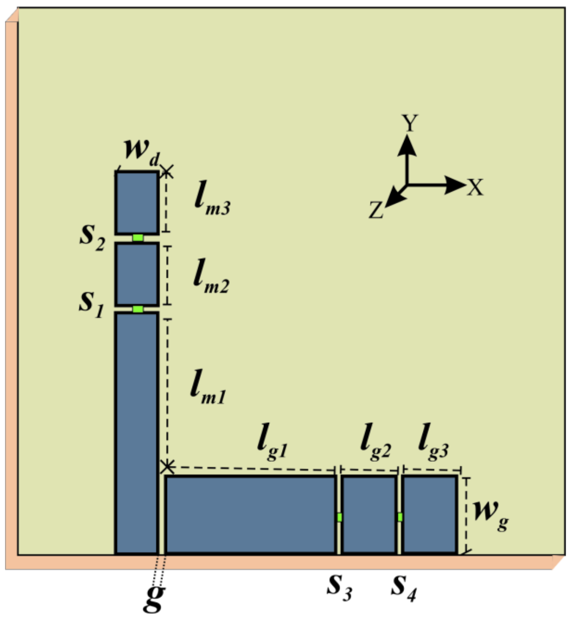


Figure 3.12: Geometry of the beam steering antenna

l_{m1} = 14, l_{m2} = 8, l_{m3} = 8, l_{g1} = 15, l_{g2} = 8, l_{g3} = 8, g = 0.3, ε_r = 4.4, w_g = 5, h = 1.6, w_d = 3 (all units in mm)

State	*S1*	*S2*	*S3*	*S4*	Resonant frequency (GHz)		Main lobe Direction (Degree) Measured
					Simulated	Measured	
State 1	OFF	OFF	ON	ON	2.41	2.43	78
State 2	OFF	ON	ON	OFF	2.4	2.41	55
State 3	ON	ON	OFF	OFF	2.37	2.4	32

Table 3.4: Different switching states of ACPS beam steering antenna

Even though many combinations of switching conditions are possible only three states which operate near the desired resonant frequency are listed in Table 3.4. Measured reflection characteristics of the antenna in Figure 3.13 demonstrate that all three states share a common bandwidth from 2.225 to 2.545 GHz.

Both the measured and simulated radiation patterns of the antenna at 2.41 GHz in the *x-y*, *x-z* and *y-z* planes during different states are shown in Figure 3.14. The measured results agree well with simulated results. It is observed that the direction of main lobe of radiation pattern can be steered by changing the length of vertical or horizontal arms by selecting the corresponding switches. From figure it can be seen that the pattern reconfigurability is easily observed from the *x-y* plane and the main beam of the antenna can scan in the first quadrant of *x-y* plane.

When the antenna is in state 1, the horizontal arm is longer than vertical arm and the measured beam maximum is at $\varphi = 78°$ and the 3-dB beam width covers the azimuth range from $\varphi = 45°$ to $\varphi = 115°$.

In state 2, lengths of both arms are equal then measured beam maximum points to $\varphi = 48°$ with 3-dB beam width covers from $\varphi = -5°$ to $\varphi = 92°$. In state 3, vertical arm is longer than horizontal arm then main lobe maximum points to $\varphi = 22°$, that is the main beam tilts more towards the *x*-axis. It is observed that *x*-*z* and *y*-*z* planes toggles when the antenna switches from state 1 to state 3.

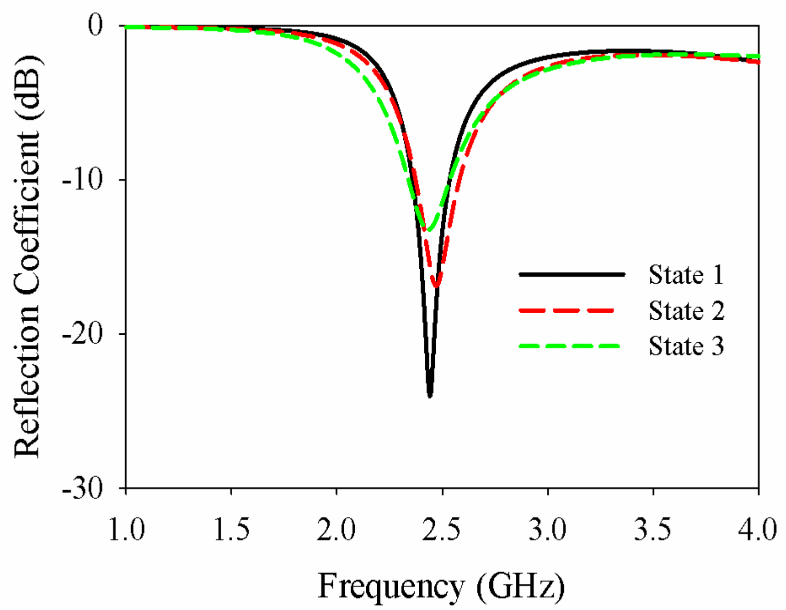


Figure 3.13: Measured reflection characteristics at different states

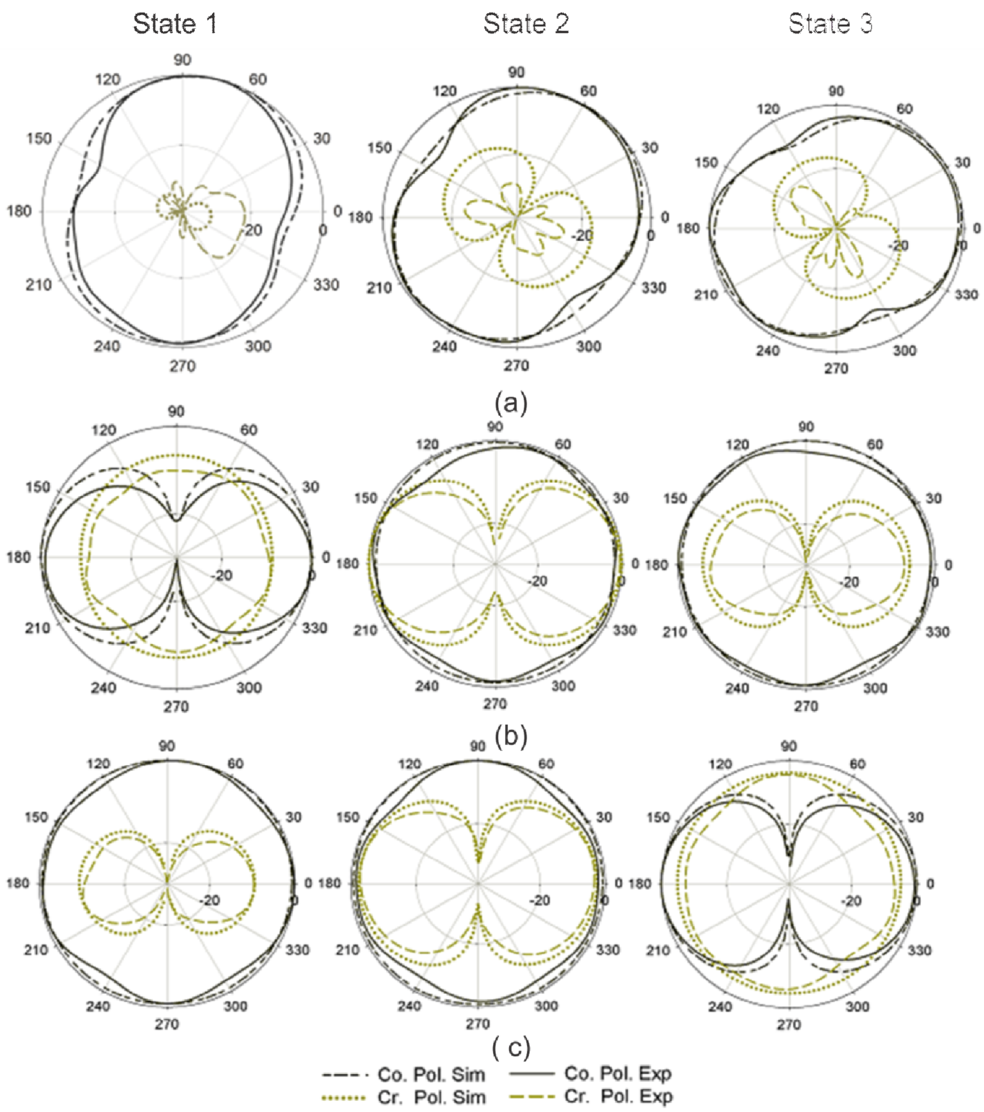


Figure 3.14 Radiation pattern during state 1, state 2, state 3

(a) *xy-plane* (b) *xz-plane* (c) *yz-plane*

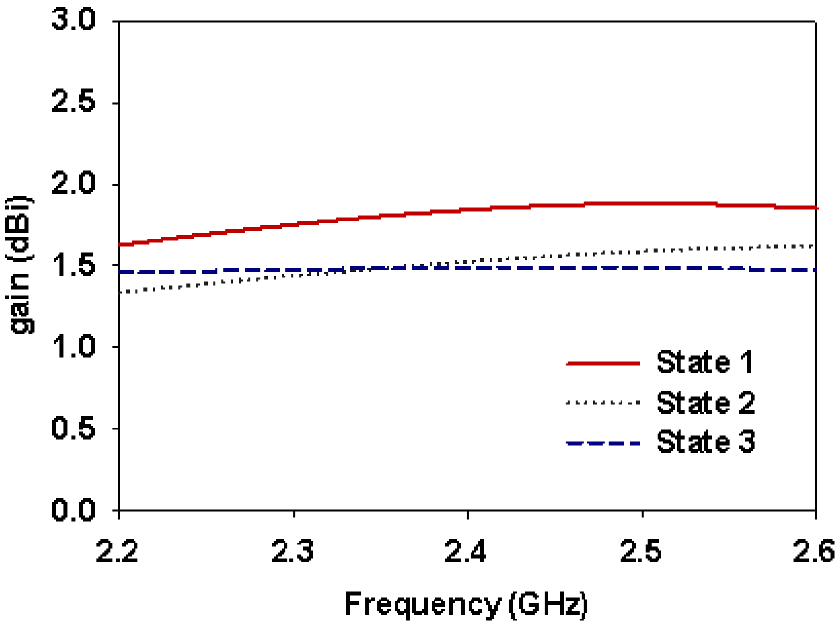


Figure 3.15 Measured gain of the antenna during different staes

The measured gain of the antenna is shown in Figure 3.15 and it is reasonable in the operating band. The antenna offers peak gain of 1.6 dBi at 2.41 GHz with an average gain of 1.4 dBi in the frequency band during the different states. So it can be concluded that the radiation pattern cab be successfully reconfigured by using switching diodes. The radiation efficiency of the antenna are 76%, 82%, and 78% in state 1, state 2and state 3 respectively.

3.3 Development of dual band antenna with pattern agility

A compact dual band antenna with pattern agility is presented in this section. The proposed antenna utilizes a simple asymmetric coplanar strip feed in conjunction with two radiating strips. These unequal parallel strips on an asymmetric coplanar strip brought two differently directed radiation patterns. The antenna operates around 1.8 and 2.4 GHz covering DCS and WLAN bands [4]. A detailed analysis of reflection and radiation characteristics is discussed in this section.

3.3.1 Antenna Geometry and Design

The geometry of the proposed ACPS fed antenna for a dual-band operation is shown in Figure 3.16. The proposed antenna consists of two parallel stubs and is printed on a substrate of relative permittivity ε_r =4.4 and height h =1.6 mm. The antenna is excited using 50Ω symmetric coplanar strip feed. The dimensions of lateral ground plane l_g and w_g are optimized to get the proper matching. The two dissimilar length radiating strips are centered and connected at an ACPS transmission line. The left strip has a length l_1 and width w_s, and the right strip has a length l_2 and width w_s; the two radiating strips are separated by a gap s = 0.4 mm. The total width (w_s+w_s+s) of the stubs including the separation is made equal to the width of the ACPS feed line. The length l_1 and l_2 are optimized to excite two resonant frequency bands.

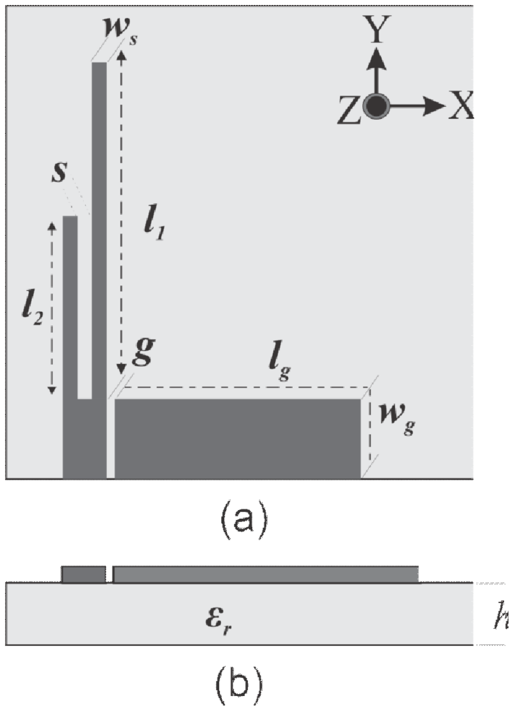


Figure 3.16: Geometry of the proposed antenna (a) top view (b) side view

3.3.2 Reflection characteristics

Fig. 3.17 shows the reflection coefficient of the proposed ACPS fed dual band antenna. It is observed that the antenna resonates at 1.81 GHz and 2.42 GHz with good matching. The antenna exhibits 2:1 VSWR bandwidth at 1725–1905 MHz and 2350–2512 MHz in the 1.8 and 2.4 GHz bands, respectively. Here the lower resonance is by the length of longer strip l_1, whereas the second resonant frequency is controlled by the length of short strip l_2. That is a dual frequency band operation can be obtained.

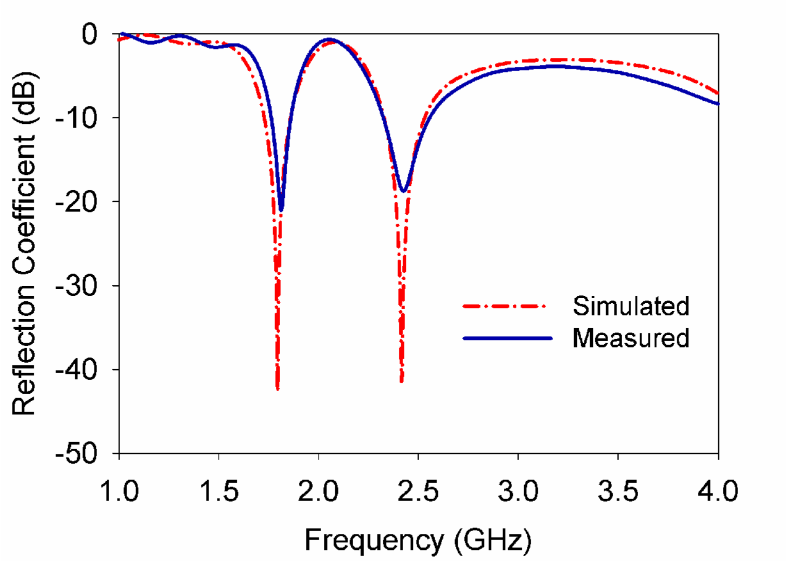
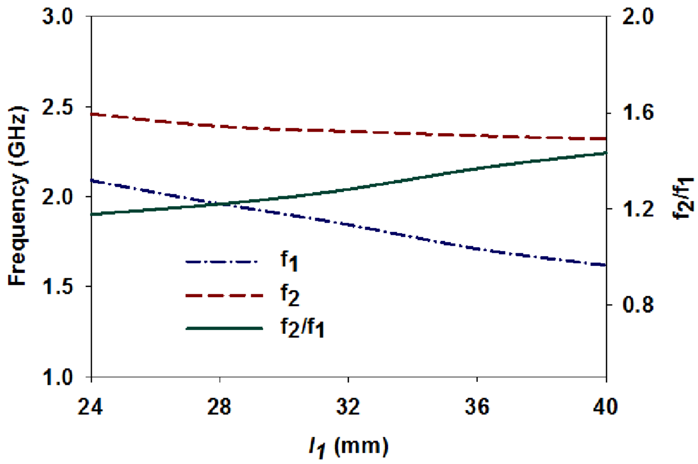


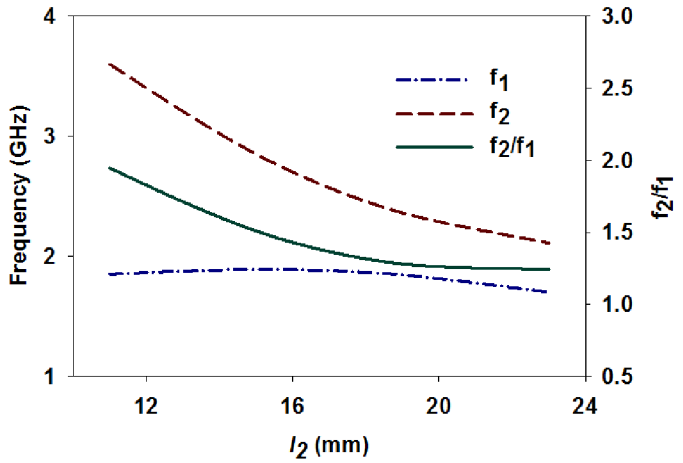
Figure 3.17: Reflection characteristics of dual band antenna

(l_1 = 32 mm, l_2 = 19 mm l_g = 21 mm, w_g = 5.5 mm and w_s = 1.3mm, g=0.3mm)

When the lengths of two stubs are equal, antenna resonates only at one frequency band. While antenna with two unequal stubs, it resonates around two frequency bands. As expected the resonance is due to excitation of current along two paths, one along l_1+l_g which corresponds to nearly $\lambda_g/2$ at 1.8 GHz and second along l_2+l_g corresponds to nearly equal to $\lambda_g/2$ at 2.4 GHz.



(a)



(b)

Figure 3.18: Effect of design parameters on frequency (a) l_1 (b) l_2

(l_g = 21 mm, w_g = 5.5 mm and w_s = 1.3mm, g=0.3mm)

In order to validate this argument exhaustive parametric studies are conducted. The effect of radiating arms l_1 and l_2 are studied. When length l_1 is varied keeping l_2 constant it is observed that different dual frequency operation can be achieved. Moreover the first resonance is affected to a great extent. Similarly when the length l_2 is varied keeping l_1 and l_g constant the second resonance has been significantly affected. The performance of the proposed antenna against different length of l_1 and l_2 are given in Figure 3.18. Excellent dual frequency design with frequency tunable with a ratio of 1.17 to 1.45 is obtained for changes in l_1 and 1.2 to 1.8 for various l_2 is also observed.

3.3.3 Radiation Characteristics

The measured far field radiation pattern of the antenna is shown in Figure 3.19. As expected, the direction of main lobe of the beam is slightly tilted and the direction of the main lobe is different for the both resonant frequencies. The main lobe direction changes from $\varphi = 22°$ at 1.8 GHz to $\varphi = 35°$ at 2.4 GHz. Similar change is noted in polarization angle too. Both resonant frequencies show a high cross polar level *y-z* plane and *x-z* plane. The measured gain for the typical antenna is 1.4 dBi and 1.35 dBi at 1.8 GHz and 2.4 GHz, respectively as given in figure 3.20. Corresponding efficiencies are 73 and 83%, respectively.

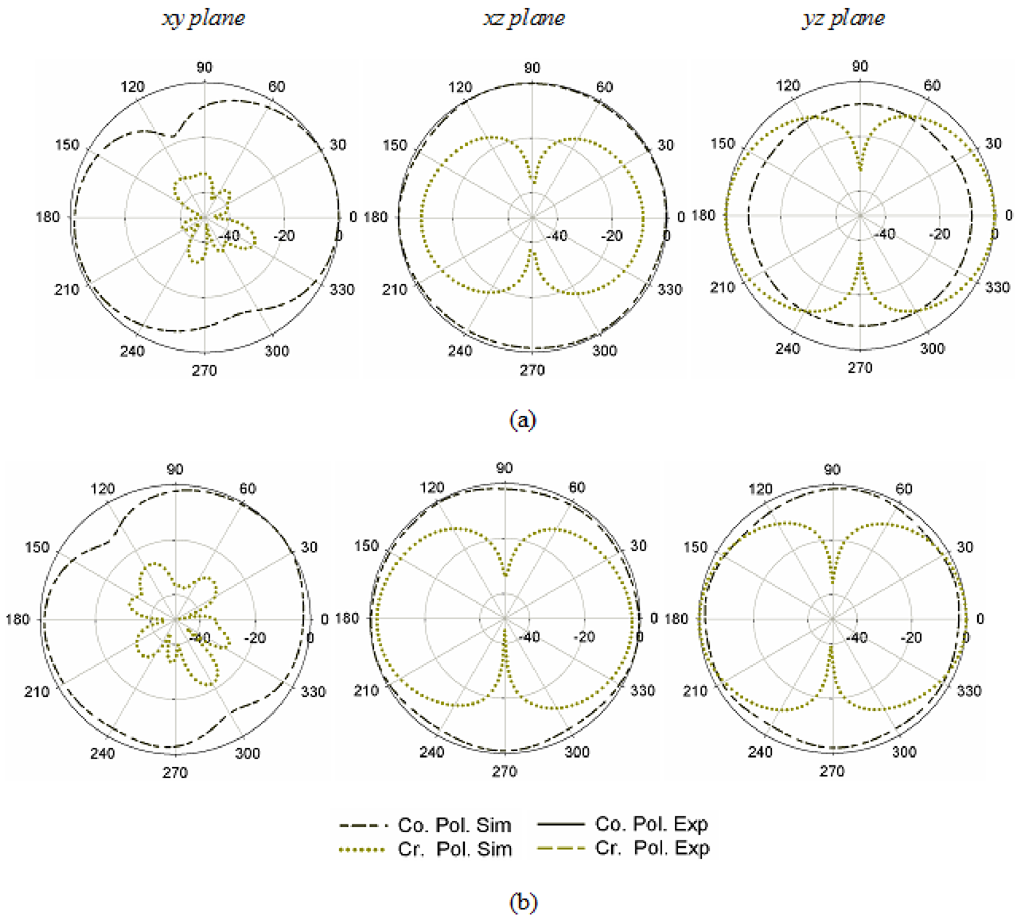


Figure 3.19: Radiation pattern (a) 1.8 GHz (b) 2.4 GHz

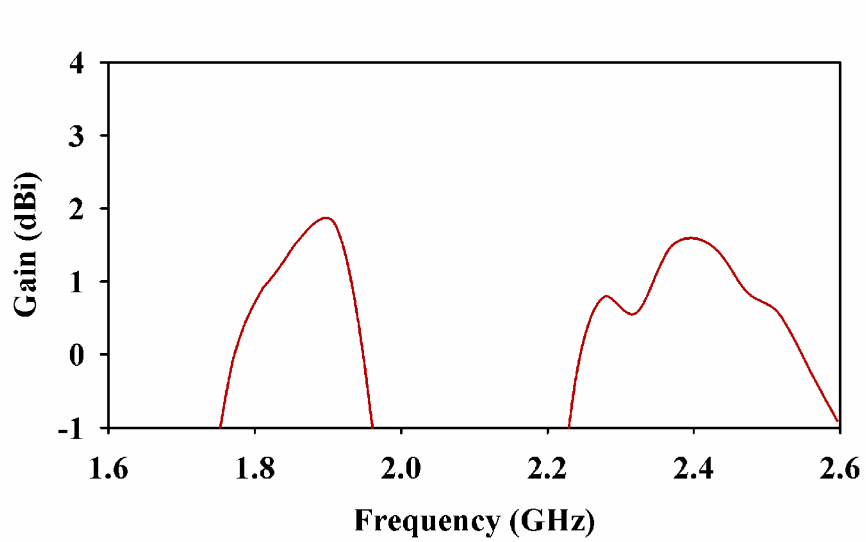


Figure 3.20: Gain of the antenna

3.4 Chapter Summary

An investigation on the radiation behavior of an asymmetric coplanar strip antenna is presented. Effects of various design parameters in controlling the pattern direction are analyzed. Experimental study using switches (copper plate) are also conducted to confirm the pattern steering capability of the antenna. Based on these inferences; an asymmetric coplanar strip fed dual band antenna is developed. The antenna has simple structure and easy to design. The antenna is so compact and is suitable for various wireless communication systems. The operating frequency bands of the antenna can be tuned by varying the length of one of the strips. The direction of main lobe of the beam is different for the both resonant frequencies.

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Chapter 4

DEVELOPMENT OF FREQUENCY AGILE AND PATTERN RECONFIGURABLE ANTENNA

This chapter presents a frequency agile and pattern reconfigurable antenna. The antenna is excited by an asymmetric coplanar strip. The folding of radiating strip is utilized to reconfigure both the pattern and frequency. Reconfiguration is done by activating or deactivating the switches. Two prototypes are presented. In the first case vertical strip is folded and in the second case horizontal strip is folded to steer the radiation pattern. The proposed structures are compact and easy to integrate with microwave circuits. Simulation and measured results shows that the antenna offers good radiation performance.

4.1 Introduction

With the fast growing wireless communication systems, there is a significant interest in providing compact reconfigurable antennas. Beam steering capability along with compactness opens up new avenues for the integration of antenna into portable devices. The major difficulty during the design of compact low profile antenna is that; the resistance and gain of the antenna get reduced when antenna size is reduced. Folding technique is extensively used to increase the impedance of the compact antenna design problems [1].

A single antenna which can cover multiple frequency bands and has an ability to switch its pattern in different directions seems to be promising solution for the design of modern wireless devices. These antennas would not cover all frequency bands at the same time, but with a dynamic switching it can achieve frequency agility.

This chapter proposes a folded strip frequency agile and pattern reconfigurable antenna. The antenna uses an asymmetric coplanar strip feeding. The radiating arm of the antenna is bent in the form of an inverted L strip [2, 3]. The bending of radiating strip is utilized to get the required radiation pattern and impedance. Reconfiguration is done by activating or deactivating the switches. Two types of bending are done to steer the beam into two directions; that is bending vertical arm or bending horizontal arm. Investigation of a frequency agile antenna with pattern reconfigurability is the main discussion of this chapter.

4.2 Asymmetric Coplanar Strip fed folded arm antenna

In order to design compact antenna the signal strip is folded towards the direction of ground plane. This section deals with study and analysis of reflection and radiation characteristics of folded antenna and check the suitability of pattern reconfigurability of antenna.

4.2.1 Antenna Geometry

The geometry of the proposed asymmetric coplanar strip fed folded arm antenna is shown in Figure 4.1. The antenna consists of an inverted L strip and an ACPS feed line printed on a FR4 substrate of thickness h and relative permittivity ε_r. The signal strip width w_d and gap g are selected for 50Ω impedance using standard design equations. The length of the radiating strip $l_1+l_g+l_2$ is taken as half of guided wavelength. The length of horizontal strip l_2 is kept nearly equal to ground strip length l_g. The optimized design parameters of the antenna to operate in 2.4 GHz band are given in figure.

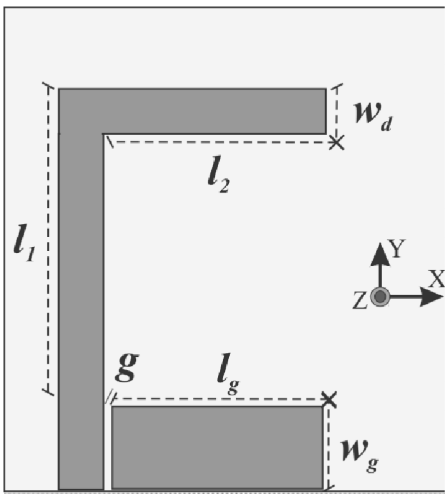


Figure 4.1: Geometry of the folded arm antenna

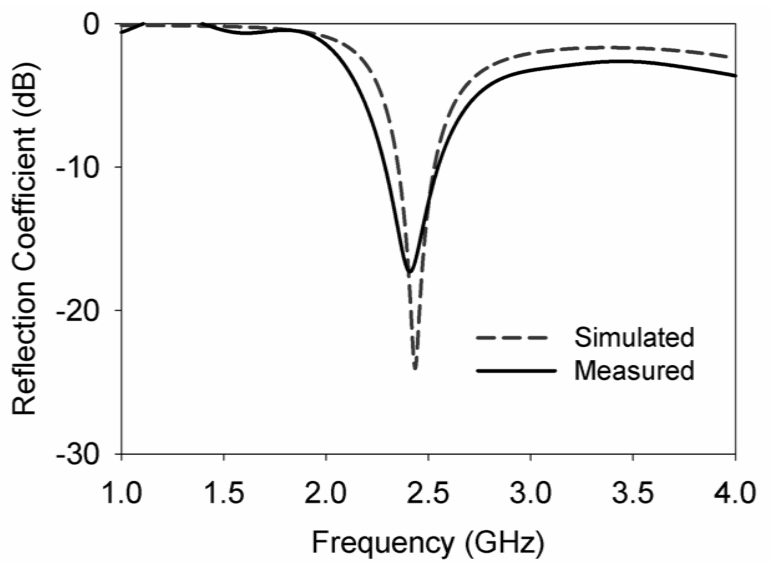
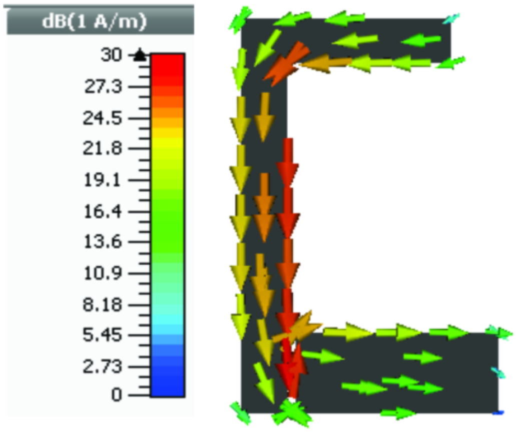


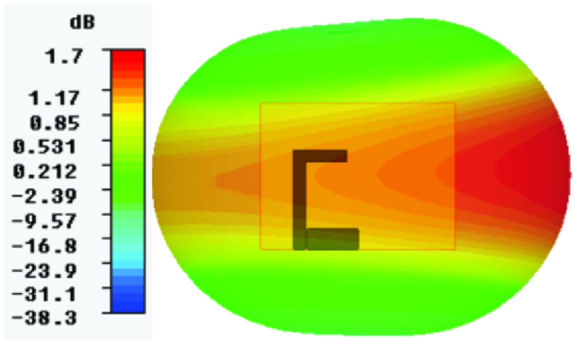
Figure 4.2: Reflection characteristics of the folded arm antenna (l_1 = 21mm, l_g = 11mm, l_2 = 11mm, w_g = 5mm and w_d = 3mm, g = 0.3mm, ε_r =4.4, h = 1.6mm)

4.2.2 Simulation Results

The antenna shows a resonance at 2.4 GHz with bandwidth of 390 MHz from 2.15 to 2.54 GHz as in Figure 4.2. The measured and simulated reflection characteristics are in good agreement. The surface current distribution in Figure 4.3(a) confirms that the resonance in 2.4 GHz is due to a half wave variation along the length $l_1+l_g+l_2$. The 3-D radiation pattern of the proposed antenna is shown in Figure 4.3(b). The pattern is again similar to dipole with non-directional *xz* plane and directional *x-y* plane pattern. From the radiation characteristics it is understood that the antenna is linearly polarized along the *y* axis. The tilt in the radiation pattern as in the previous chapter was not present in the folded strip antenna.



(a)



(b)

Figure 4.3: (a) Surface current distribution (b) 3D radiation pattern at 2.4 GHz

To investigate the reflection and radiation characteristics of the antenna parametric study is performed by varying the structural parameters. The resonant frequency and direction of radiation pattern main lobe are studied.

4.2.2.1 Effect of vertical strip length l_1

Effect of vertical strip length l_1 on the resonance, main lobe direction and input impedance keeping all other parameters constant are given in Figure 4.4 - 4.6. As the vertical strip length l_1 increases 17 mm to 25mm it is found that the resonant frequency decreases due to increase in effective resonant length and the direction of main lobe is almost remains constant. The folding of strip significantly affects the input impedance of the antenna. The reactance of the unfolded antenna is capacitive while that of folding is becoming more inductive. But better matching is obtained when the ratio of l_2 to l_1, is maintained at 0.52. The matching deteriorates when the horizontal strip becomes too closer to the ground plane. So it is concluded that l_1 determines the degree of coupling between horizontal arm and ground. Optimum value of l_1 is taken as 0.25 times of guided wavelength.

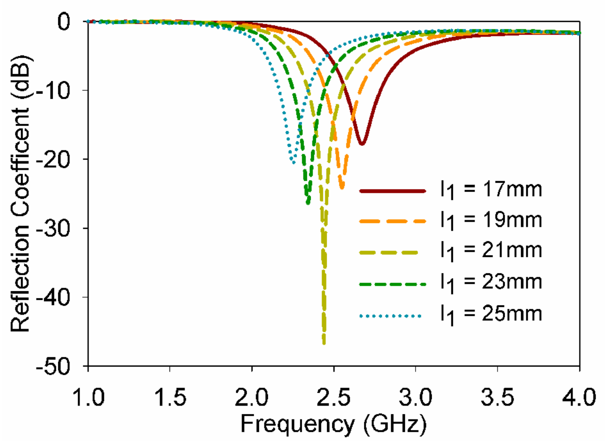


Figure 4.4: Effect of variation of l_1 on resonant frequency

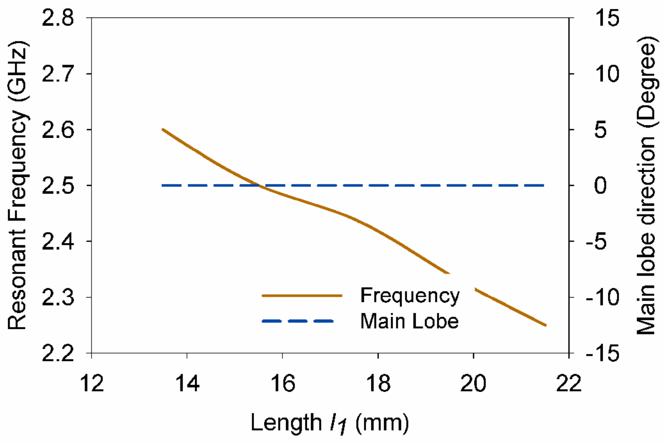


Figure 4.5: Effect of variation of l_1 on main lobe direction

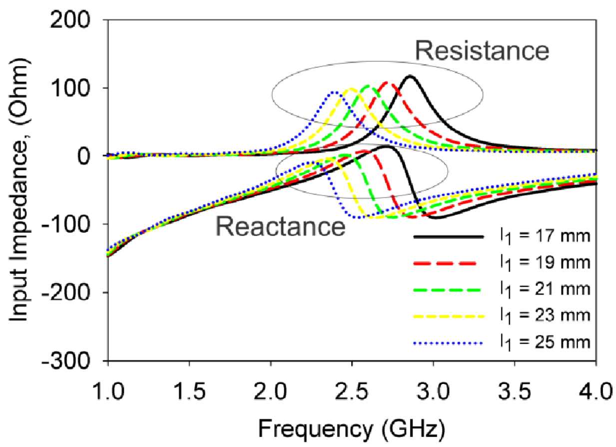


Figure 4.6: Effect of variation of l_1 on input impedance

4.2.2.2 Effect of folding strip length l_2

The influence of l_2 on the reflection and radiation characteristics is shown in Figure 4.7-4.9. The strip length l_2 is varied from 7mm to 15mm keeping all other parameters constant.

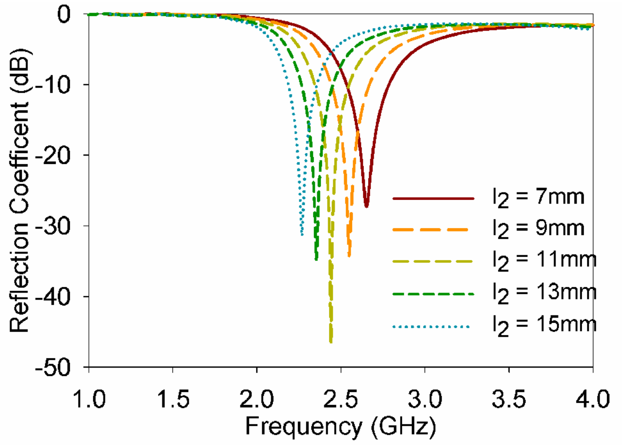


Figure 4.7: Effect of variation of l_2 on resonant frequency

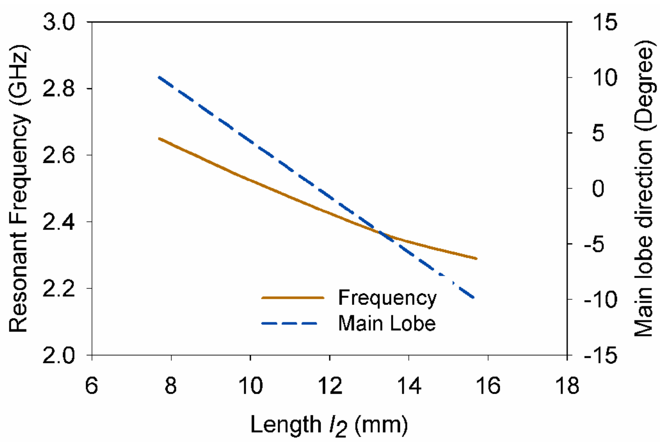


Figure 4.8: Effect of variation of l_2 on main lobe direction

It is evident from the graph that, when the strip length l_2 increases then the effective resonant length increases and there by shifts the resonant frequency from 2.7 GHz to 2.2 GHz. The direction of main lobe is at zero degree when the value of l_2 is at an optimum value of 11 mm.

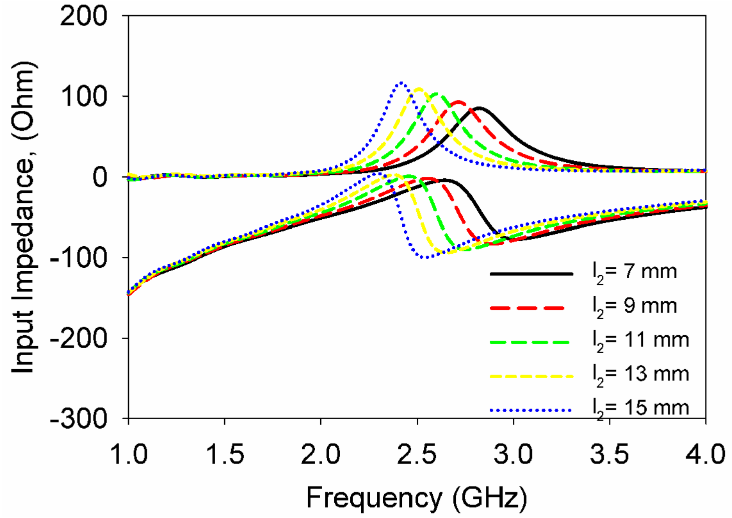


Figure 4.9: Effect of variation of l_2 input impedance

When the value of l_2 decreases from the optimum value the direction of main lobe deviates towards positive direction. The beam direction deviates towards negative direction when the value of l_2 changes from 11 mm to 15 mm. Thus when the value of l_2 is almost equal to l_g, the direction of main lobe is again at zero degree. It is also observed that when the value of l_2 increases the reactance part is more inductive. For the present design, the value of l_2 is taken nearly equal to 0.13 λg.

4.2.2.3 Effect of strip length l_g

A variation study is performed with l_g, keeping all other parameters constant. The simulated reflection characteristics and main lobe direction as a function of l_g are shown in Figure 4.10 - 4.12. As the value of l_g increases the resonant frequency shifts towards the lower side of the spectrum.

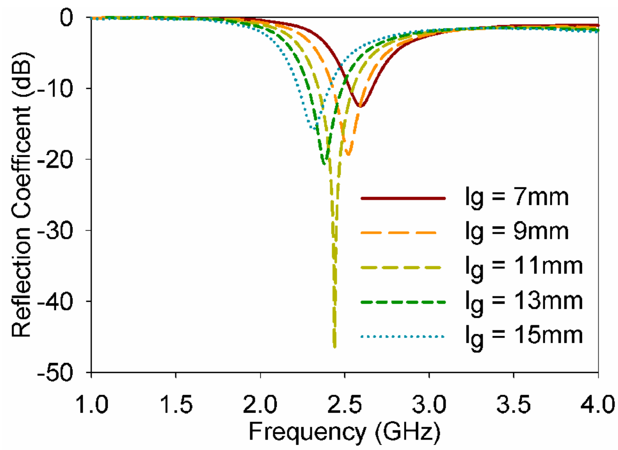


Figure 4.10: Effect of ground length l_g on resonant frequency

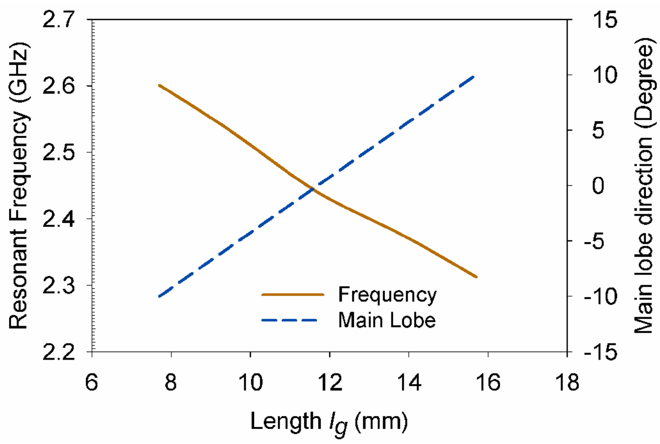


Figure 4.11: Effect of ground length l_g on main lobe direction

Zero tilt-angle is observed for an optimum value of l_g. When the value of l_g increases from the optimal value the main lobe shift towards the positive direction and when the value of l_g decreases, the main lobe deviates towards negative direction.

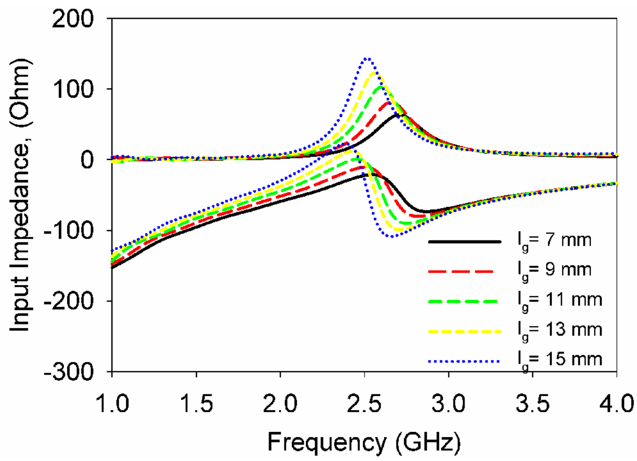


Figure 4.12: Effect of ground length l_g on input impedance

4.2.3 Design Procedure

From the investigations on parametric variations of the asymmetric coplanar strip fed folded arm antenna, it can be concluded that folded arm ACPS can be effectively utilized for the design of reconfigurable antenna. From the exhaustive parametric studies; design guidelines are derived for the design of reconfigurable antenna.

4.2.3.1 Design procedure for frequency agile antenna

- Select a suitable substrate with permittivity ε_r and height *h*. The width of ACPS feed line *wd* and *g* should be selected to get the 50Ω characteristic impedance.
- Since the fields are not fully confined into the substrate alone, effective

dielectric constant has to be used in calculations.

$\varepsilon_{eff} \cong \frac{\varepsilon r+1+1}{3}$ where εr is the dielectric constant of the substrate

- Calculate the dimension of vertical strip length from the following formula.

$$l_1 \approx 0.26\ \lambda g$$

- Calculate the length of top loaded horizontal strip using the given equation

$$l_2 \approx 0.13\ \lambda g$$

- Calculate the length and width of ground strip from the given relation

$$l_g \approx 0.13\ \lambda g$$

- Finally the total length of all parameters should satisfy the given equation

$$l_1 + l_g + l_2 \approx 0.5\ \lambda g$$

Where λg is the guided wavelength, $\lambda g = \lambda / \varepsilon_{eff}$

4.2.4 Development of pattern reconfigurable ACPS antenna.

From the previous discussions it is evident that main lobe direction of radiation pattern can be effectively controlled by varying the length of strips l_g and l_2. Based on this observation different combinations of l_g and l_2 are tested keeping the total resonating length constant. In the present study utilizes an antenna which operates at 2.4 GHz band. The Table 4.1 summarizes different combinations of strip length.

Condition	l_1 (mm)	l_2 (mm)	l_g (mm)	Resonant frequency (GHz) Simulated	Main lobe Direction (Degree) Simulation
Antenna 1	21	6	18	2.48	20
Antenna 2	21	12	12	2.44	0
Antenna 3	21	15	9	2.412	-20

Table 4.1: Description of different folded arm antenna

It is obvious from the table that some combinations of l_g and l_2 the resonant frequency is almost constant but the direction of main lobe beam is pointed towards different directions. Direction of main lobe swings between $\pm 20°$. Thus the tilt in the radiation pattern can be effectively controlled by varying the length of l_g or l_2.

Figure 4.13 (a)-(c) illustrates radiation pattern of different antenna configurations. It is observed that a half wavelength variation of field on the length $l_1+l_g+l_2$ causes radiation. In antenna 1, the main lobe direction and pattern pointed towards $\varphi = +20°$. This is mainly due to the flow of feeble surface current through top loaded strip l_2, which is opposite to the direction of current along horizontal ground strip l_g. So the uneven distribution of these current in these parallel asymmetrical arm causes disturbances in the radiation pattern. Since the radiation pattern at far field is resultant of the fields due to l_1, l_2 and l_g the pattern gets tilted.

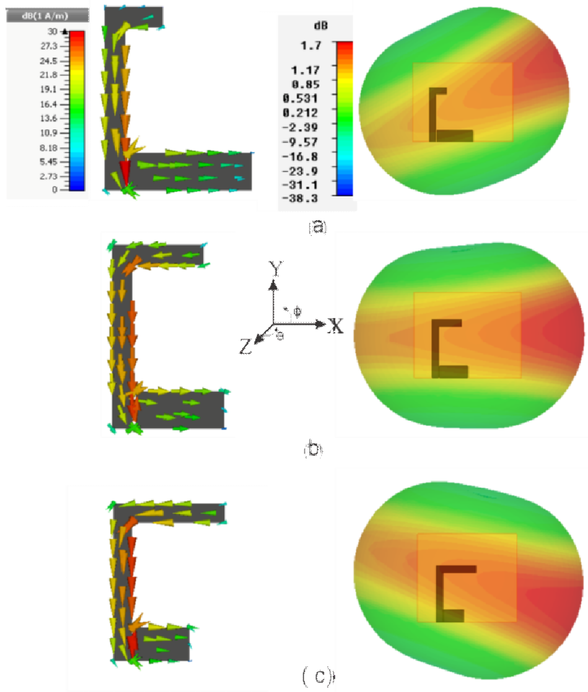


Figure 4.13 Radiation pattern (a) Antenna 1 (b) Antenna 2 (c) Antenna 3

When the lengths of horizontal strips are almost equal as in Antenna 2, the field variation along l_g and l_2 are equal and opposite and their effects cancel in the far field, resulted in a broadside pattern. Here the direction of main lobe is at $\varphi = 0°$. When the value of l_2 increases and the value of l_g decreases, domination of the field due to l_1 and l_2 causes the total radiation pattern pointed towards $\varphi = -20°$. Thus a folded arm ACPS too is a suitable candidate for the development of pattern reconfiguration and it can be exploited for the development of beam steering antenna.

4.2.5 Measurement Results

A prototype of the folded strip antenna was fabricated on a FR4 substrate of permittivitty ε_r = 4.4 and h = 1.6 mm with the optimized parameters is shown in Figure 4.14. The effective resonating length can be varied by using four switches.

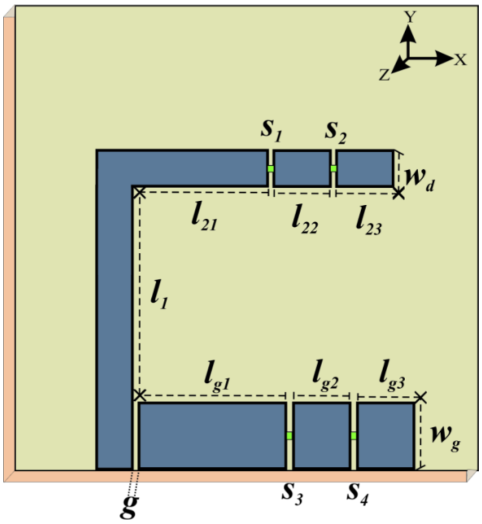


Figure 4.14: Geometry of Antenna with switches

l_{g1} = 8, l_{g2} = 4, l_{g3}= 4, l_{21}= 8, l_{22} = 4, l_{23} = 4, l_l = 21, g = 0.3,

ε_r= 4.4, w_g = 5.5, h = 1.6, w_d = 3 (all units in mm)

The antenna was operated with different switching conditions as stated in Table 4.2. The simulated and measured reflection coefficients of the fold arm ACPS antenna operated in 2.4 GHz band on different switching conditions are in good agreement as shown in Figure 4.15 - 4.16.

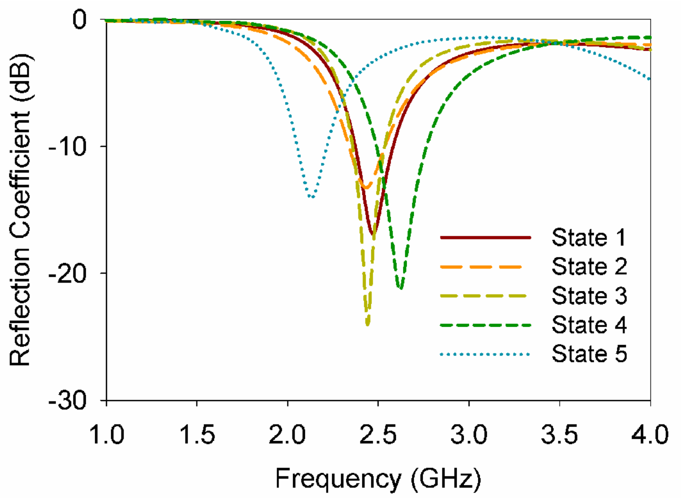


Figure 4.15: Simulated reflection characteristics for different switching states

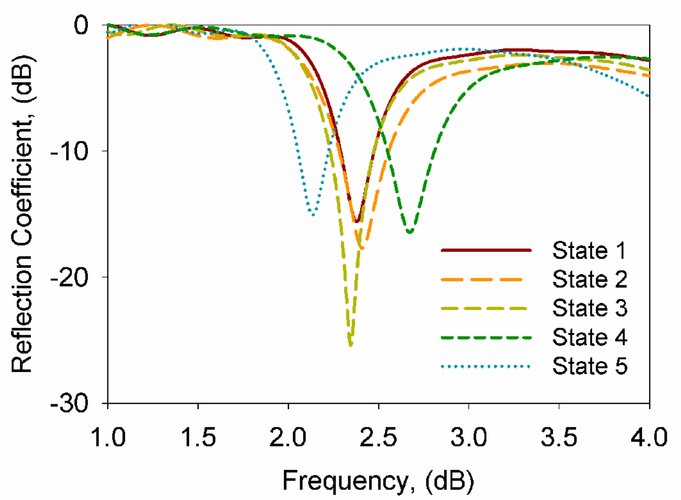
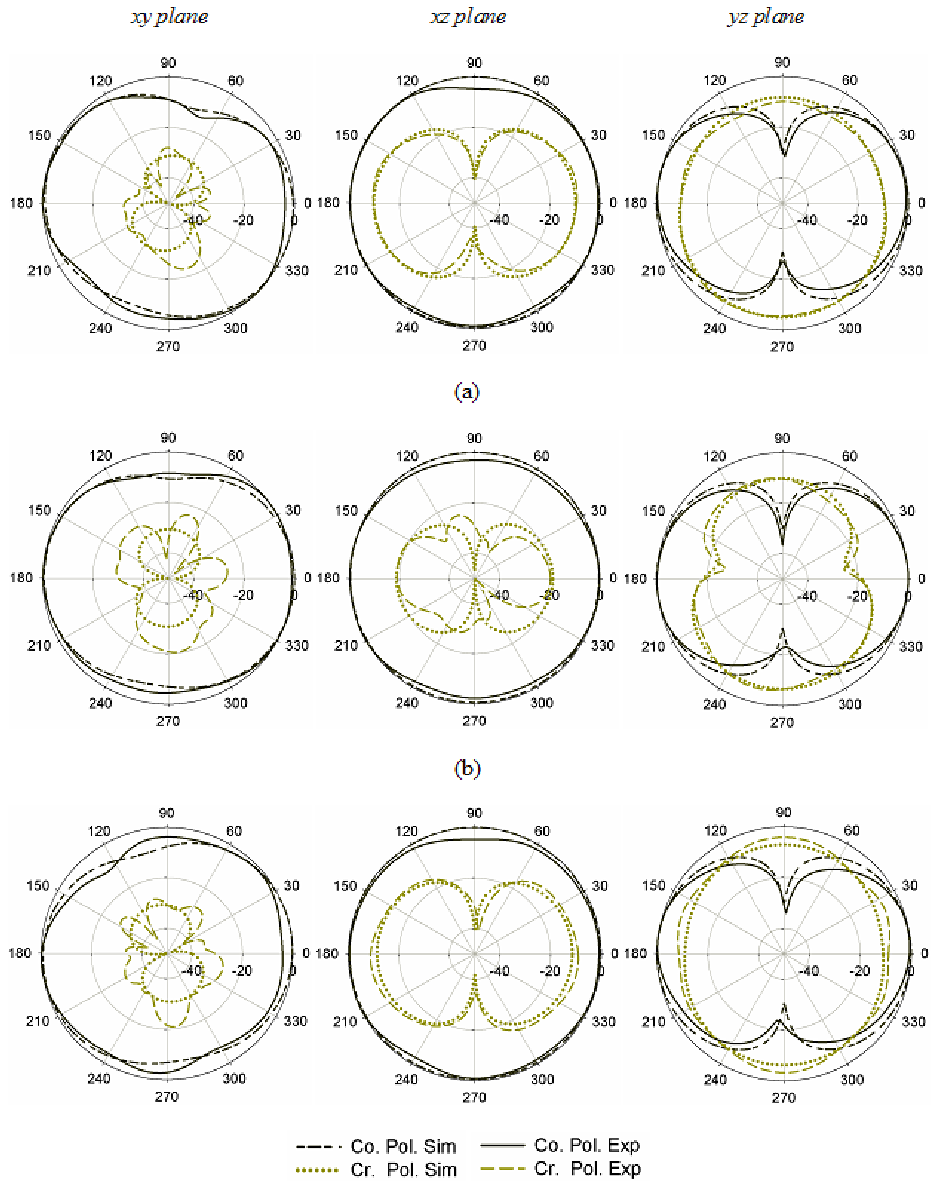


Figure 4.16: Measured reflection characteristics for different switching states

State	*S1*	*S2*	*S3*	*S4*	Resonant frequency (GHz)		Main lobe Direction (Degree) Measured
					Simulated	Measured	
State 1	ON	ON	OFF	OFF	2.47	2.38	-32
State 2	ON	OFF	ON	OFF	2.42	2.41	0
State 3	OFF	OFF	ON	ON	2.44	2.35	36
State 4	OFF	OFF	OFF	OFF	2. 62	2.675	0
State 5	ON	ON	ON	ON	2.13	2.135	0

Table 4.2: Different switching states of folded antenna

Radiation patterns of the antenna in *x-y, y-z,* and *x-z* planes during state 1 state 2 and state 3 are simulated and measured and are shown in Figure 4.17. Patterns are normalized with respect to the maximum value of the corresponding plane. It is found that the antenna produces a non directional pattern in H plane (*x-z* plane) and directional pattern in E plane (*x-y* plane). A higher cross polar level is observed in *x-z* and *y-z* plane. This is due to the asymmetry of the structure. The radiation pattern in the xy plane shows that the antenna can direct its E-plane radiation towards $\varphi = -32°, \varphi = 0°$ and $\varphi = +36°$ during state 1, state 2 and state 3 respectively. The radiation patterns in other plane are similar for different states.



(c)

Figure 4.17: Radiation characteristics during (a) state 1 (b) state 2 (c) state 3

The polarization angle of the antenna also changes in different states. The measured gains of the antenna for different states are shown in figure 4.18. The gain is almost same during different states. Measured radiation efficiency is better.

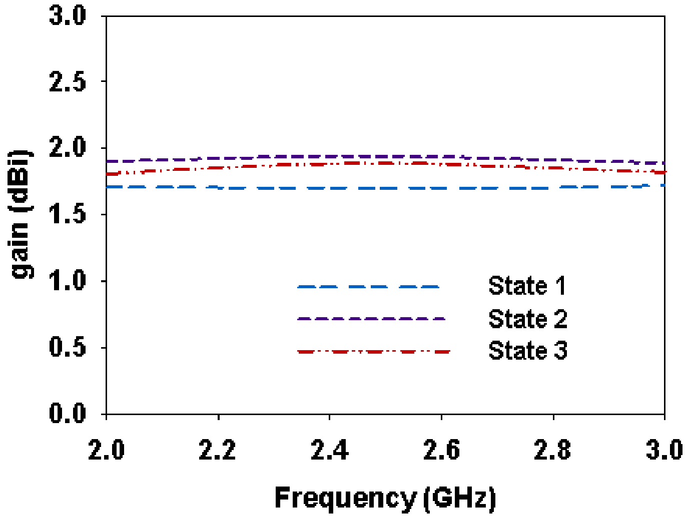


Figure 4.18: Gain of the antenna with different states

4.3 Asymmetric Coplanar Strip Fed Folded ground Antenna

A folded ground strip antenna is presented in this section. The ground strip of the antenna is folded to get the required radiation pattern and impedance. Analysis of radiation pattern and beam steering capability is examined. Simulated and Experimental results are presented in this section.

4.3.1 Antenna Geometry

The geometry of the proposed asymmetric coplanar strip fed folded ground antenna is shown in Figure 4.19. The ground strip of the antenna is folded to achieve compactness and pattern steer ability. The structure of the antenna is etched on a FR4 substrate of thickness h=1.6 mm and relative permittivity ε_r = 4.4. The detailed structural parameters are given in figure.

The reflection characteristic of the proposed antenna is shown in Figure 4.20. The antenna shows resonance at frequency 2.41 GHz with 2:1 VSWR bandwidth of 10.7% from 2.28 to 2.54 GHz.

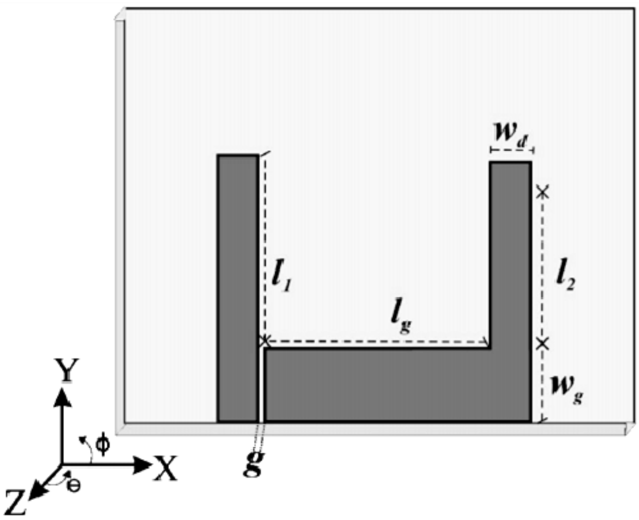


Figure 4.19: Geometry of folded ground antenna

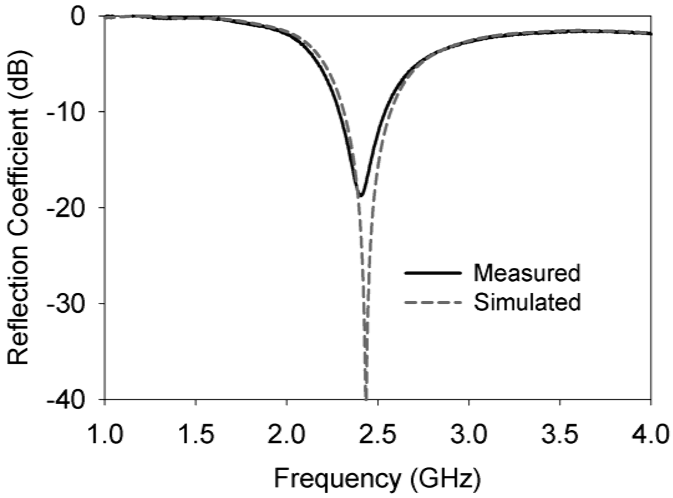


Figure 4.20: simulated and measured **r**eflection characteristics (l_g = 22mm, l_1 = 11mm, l_2 = 10mm, w_g = 5mm and w_d = 3mm, g = 0.3mm, ε_r =4.4, h = 1.6mm)

It is clear from the simulated surface current distribution shown in Figure 4.21 that the resonance is due to the half wavelength long variation of surface current present in the l_1+l_2+l_g. The 3-D radiation pattern of the folded ground is given in Figure 4.22. To understand the performance and characteristics of the antenna, parametric studies are conducted.

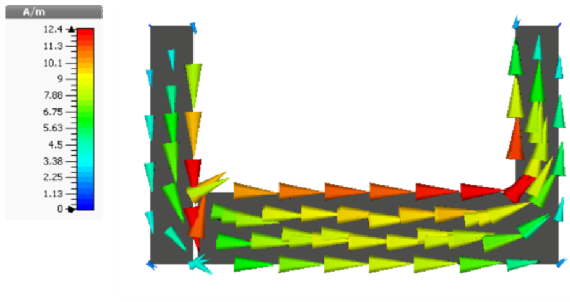
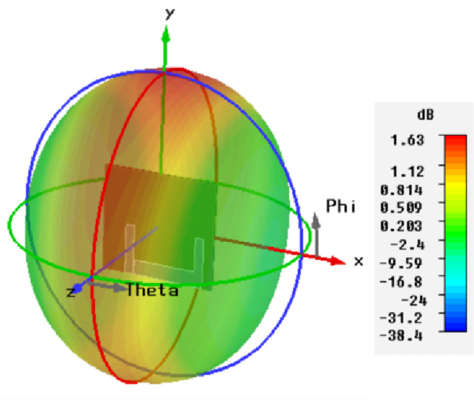


Figure 4.21: Surface current on folded ground antenna at 2.4 GHz



(b)

Figure 4.22: 3D radiation pattern of folded ground antenna at 2.4 GHz

The effect of vertical signal strip l_1 on reflection coefficient, input impedance and main lobe direction are shown in Figure 4.23 - 4.24. When l_1 is increased the resonant frequency decreases and the pattern tilt angle also decreases. The pattern is oriented at $\varphi = 90°$ in the azimuth plane for an optimum value of l_1.

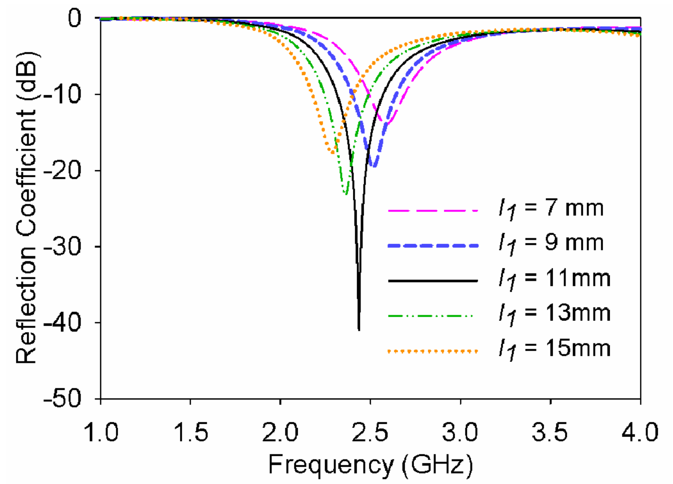


Figure 4.23: Effect of variation of l_1 on resonant frequency

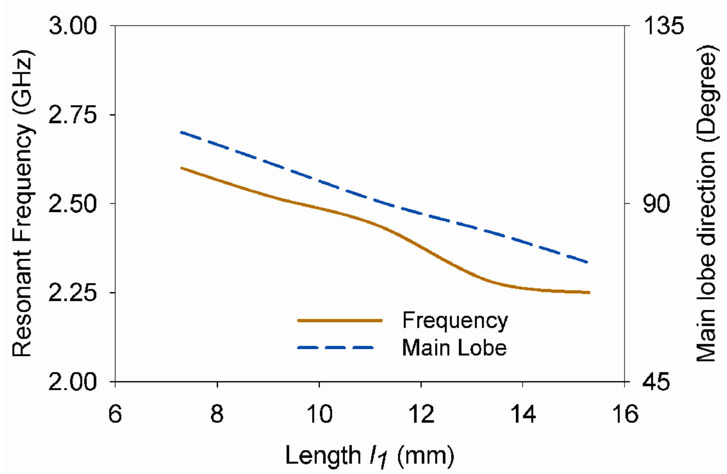


Figure 4.24: Effect of variation of l_1 on main lobe direction

The influence of l_2 on the reflection characteristics, input impedance and direction of main lobe are given in Figure 4.25 - 4.26. The length of strip l_2 is varied keeping all other parameters constant. It is clear from the figure that as strip length l_2 increases the resonant frequency shifts towards lower side of the spectrum. The direction of main lobe is at $\varphi = 90°$ when the value of l_2 is set at an optimum value. When the value changes from the optimum value the main lobe direction deviates from $\varphi = 90°$. As in previous section here also when the value of l_2 is equal to l_1 pattern tilt angle is nearly equal to 90 degree.

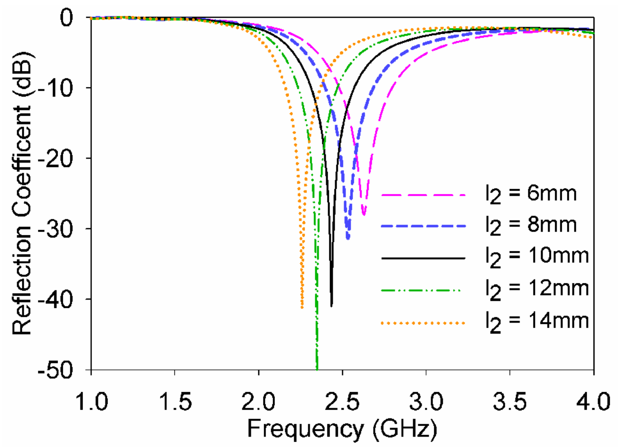


Figure 4.25: Effect of variation of l_2 on resonant frequency

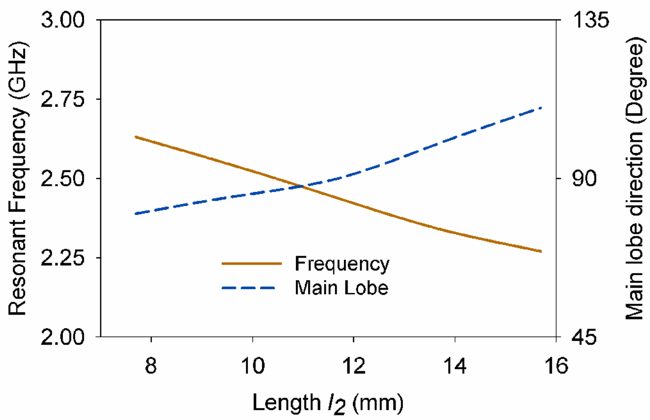


Figure 4.26: Effect of variation of l_2 on main lobe direction

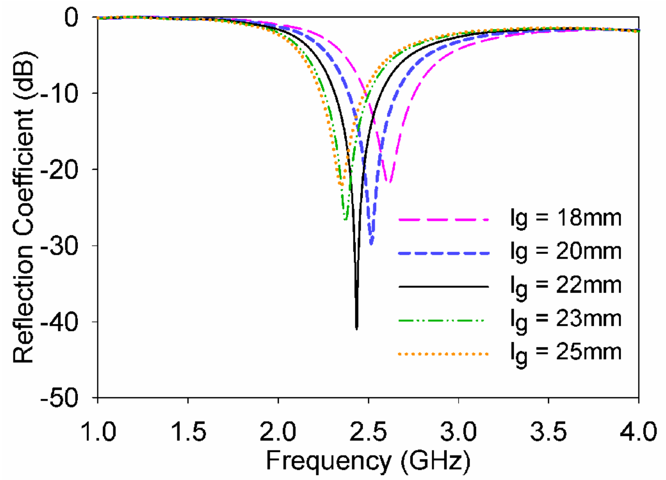


Figure 4.27: Effect of variation of l_g on resonant frequency

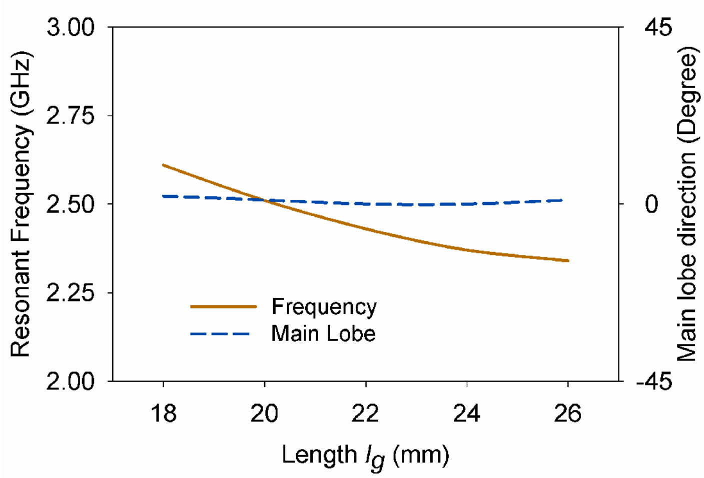


Figure 4.28: Effect of variation of l_g on main lobe direction

Figure 4.27 and 4.28 shows the variations in reflection and radiation characteristics of folded ground ACPS against l_g. It is observed that as length l_g increases the resonant frequency decreases and the direction of main lobe almost remains constant. The matching deteriorates when the two vertical strips becomes too closer. So these properties of folded ground ACPS can be effectively used to design a reconfigurable antenna.

From the above parametric analysis, following design equations are derived for the proposed folded ground antenna.

$$l_1 + l_g + l_2 = 0.62\ \lambda g$$

$$l_g = 0.24\ \lambda g$$

$$l_2 = 0.15\ \lambda g$$

$$l_1 = 0.16\ \lambda g$$

Condition	l_g *(mm)*	l_2 *(mm)*	l_1 *(mm)*	Resonant frequency (GHz)		Main lobe Direction (Degree)
				Computed	Simulated	Simulation
Antenna 1	17	6	18	2.478	2.48	60
Antenna 2	17	12	12	2.456	2.44	90
Antenna 3	17	18	6	2.436	2.412	110

Table 4.3: Description of folded Antenna optimized for 2.4 GHz

4.3.2 Optimization

From the design equations derived in the previous section geometrical parameters for a pattern steering antenna which operates in 2.4 GHz band are tabulated in the Table 4.3. It is observed that main lobe of the radiation pattern can be steered with respect to the ratio of l_1 and l_2.

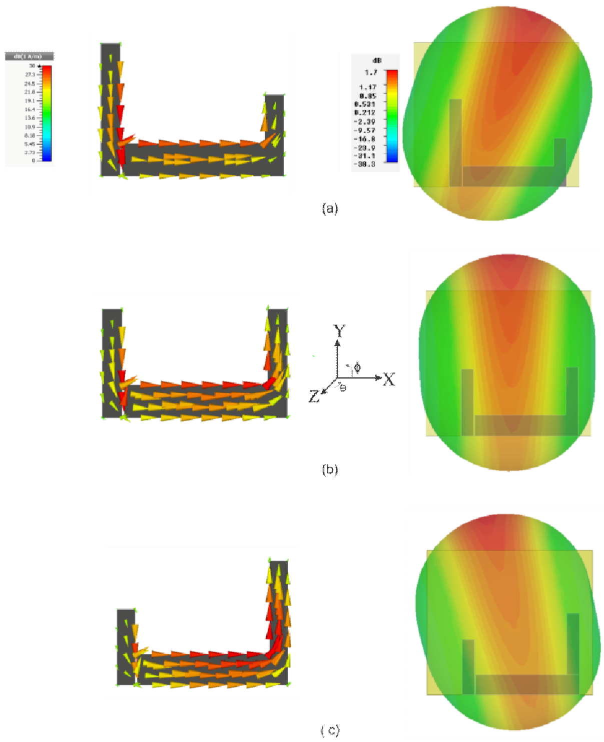


Figure 4.29: Radiation performance (a) antenna1 (b) antenna 2 (c) antenna 3

When the value of l_1 =12 mm and l_2 = 12 mm the direction of maximum radiation is found to be towards $\varphi_{max} = +90°$ in the azimuth plane with gain of

1.62 dBi at 2.4 GHz. For antenna 1 and 3 the simulated maximum beam radiations are at $60°$ and $110°$ for 2.4 GHZ respectively. Figure 4.29 shows the surface current distribution and 3D radiation pattern for the different antenna. It is clear from the graph that the y-directed current in the l_1 and l_2 are in opposite directions and cancel each other in the far fields. Hence the major current path is oriented along X direction, that is, the antenna gets X polarized. Thus the folded ground strip antenna produces a steerable *x* directed pattern. Thus a combination of folded arm and folded ground can be useful in the design of a pattern reconfigurable antenna.

State	*S1*	*S2*	*S3*	*S4*	Resonant frequency (GHz)		Main lobe Direction (Degree)
					Simulated	Measured	
State 1	ON	ON	OFF	OFF	2.4	2.355	79
State 2	ON	OFF	ON	OFF	2.41	2.385	92
State 3	OFF	OFF	ON	ON	2.45	2.41	109
State 4	OFF	OFF	OFF	OFF	2. 7	2.675	90
State 5	ON	ON	ON	ON	2.1	2.132	90

Table 4.4: Summary of switching conditions of folded ground antenna

4.3.3 Experimental Result

A prototype of the proposed antenna was built using substrate of FR4 (ε_r = 4.4, h = 1.6 mm) and measured. The antenna utilizes four switches (metal short is used for demonstration) which can be turned on/off. Switches are located at different places so as to enable different frequency band.

Table 4.4 shows the different swiching conditions. The resonant frequency of the antenna can be changed by turning on/off the switches. The optimized parameters of the antenna are given in figure 4.30. Measured reflection coefficient of the folded ground antenna are given in Figure 4.31.

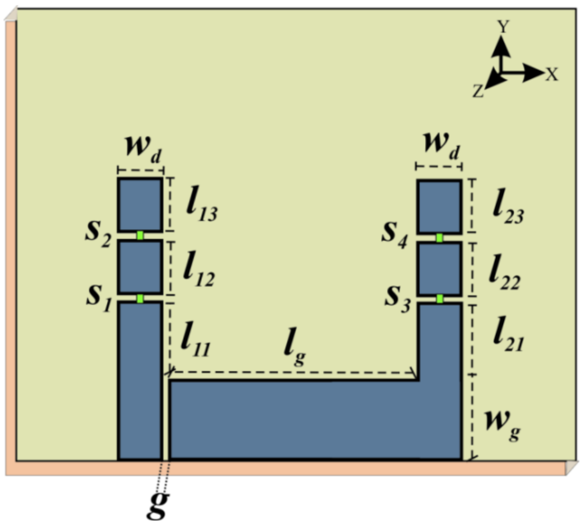


Figure 4.30: Geometry of Antenna with switches
l_{11} = 8, l_{12} = 4, l_{13} = 4, l_{21} = 8, l_{22} = 4, l_{23} = 4, l_g = 21, g = 0.5, ε_r = 4.4, w_g = 5.5, h = 1.6, w_d = 3 (all units in mm)

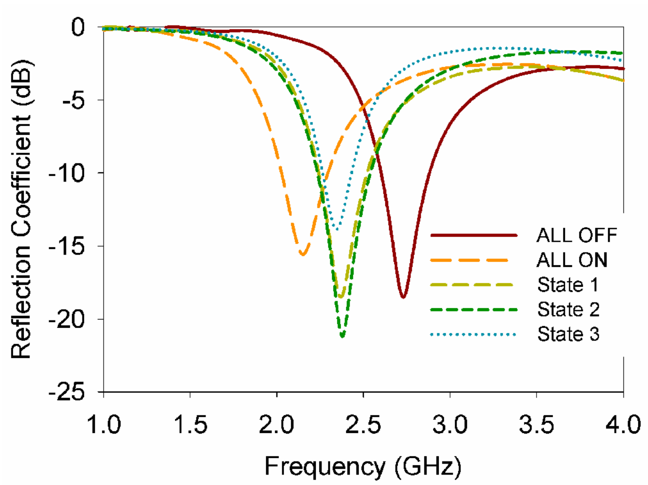


Figure 4.31: Measured reflection characteristics with switches

The proposed antenna is designed to operate at 2.41 GHz with three different radiation patterns in azimuthal plane (*xy* plane), whose maximum of main lobe points towards 70°, 90° and 110° respectively. The radiation pattern can be altered in the xy-plane by controlling the states of the switches. The antenna is capable of switching between different states.

The measured and simulated radiation pattern of the antenna in *x-y, x-z* and *y-z* plane at 2.4 GHz band are shown in Figure 4.32. The antenna produces a radiation patterns are similar to half wavelength dipole with a maximum directivity along y axis. It is noted that all of the patterns are very similar except that of azimuth plane. It shows a slight shift of direction of maximum radiation with

$\varphi = 79°, 92°$ and $109\ °$ during state 1 state 2 and state 3 respectively. The antenna exhibts higher cross polarization levels due to feable current variation in the parasitic strips. The halfpower beam width of the antenna is $88°, 92°$ and $110°$ during state 1, state 2 and state 3 along *x-y* plane respectively. The polarization of the antenna changes with swtiching condition but is almost along *x* axis with some deviation.

The gain of antenna has been simulated and measured in different states. Figure 4.33 shows the measured gain. The maximum gain of the antenna in the operating band during state 1 is 1.5dBi while for state 2 and state 3 is 1.6dBi and 1.5dBi respectively. The efficency of the antenna is 72% .

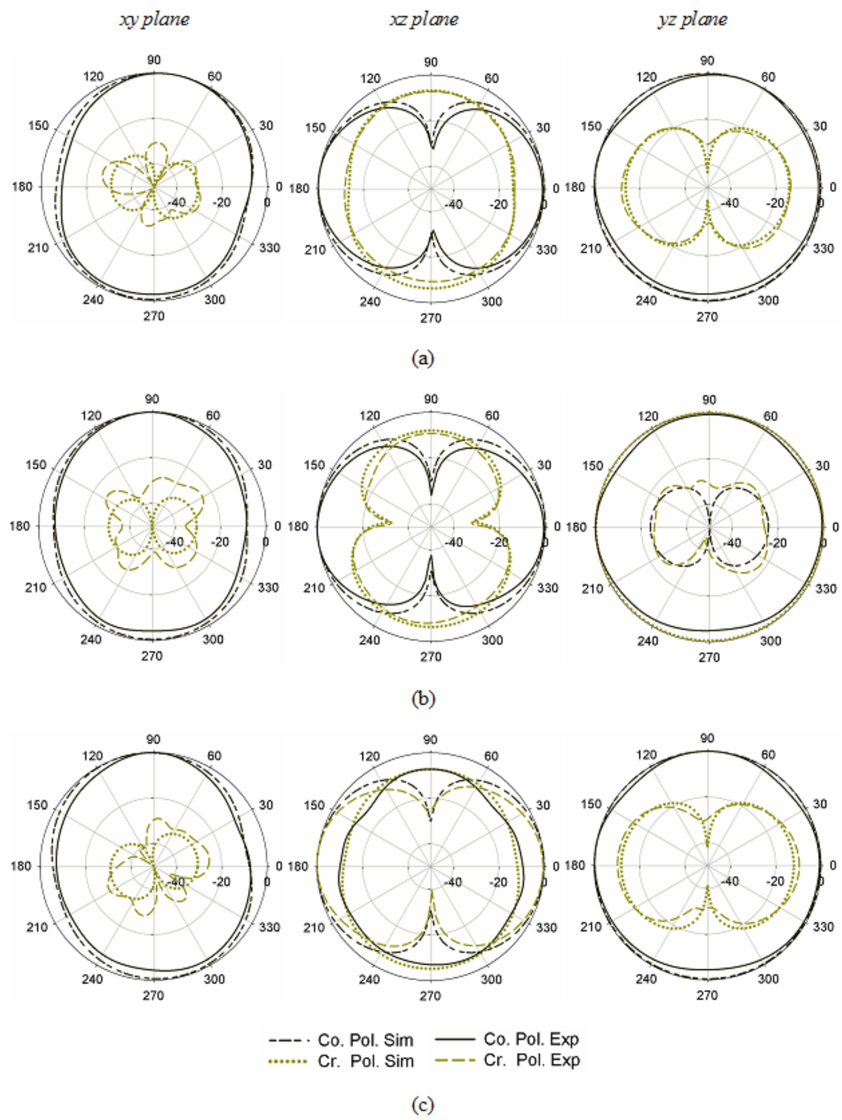


Figure 4.32: Measured and simulated radiation pattern at 2.4 GHz (a) State 1 (b) state 2 (c) state 3

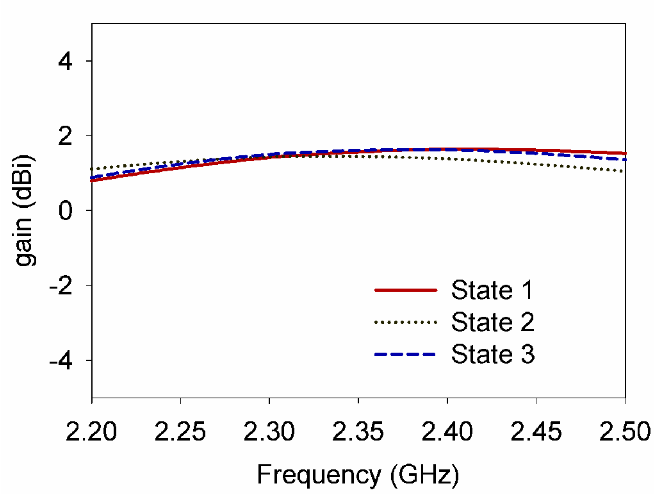


Figure 4.33: Measured gian of the antenna in different states

4.4 Chapter Summary

A frequency agile and pattern reconfigurable antenna is presented. The frequency and pattern can be reconfigured by activating switches. Prototypes of antenna were fabricated and tested. Folding of radiating strips is effectively utilized. Analysis of radiation pattern and beam steering capability is examined and observed that antenna radiation pattern can be steered at some extent. Simulated and Experimental results are presented. The proposed antenna shows excellent radiation characteristics and reasonable gain. The antenna is suitable for modern wireless communication systems.

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Chapter 5

ACPS PATTERN AND POLARIZATION RECONFIGURABLE ANTENNA

Development of a pattern and polarization reconfigurable antenna using asymmetric coplanar strip antenna (ACPS) is presented in this chapter. The two radiating arms of the antenna are turned according to the required pattern. Simulation studies are performed to predict the reflection and radiation behavior of ACPS antenna. Suitability of pattern reconfigurations are also analyzed. The predicted results are validated experimentally by fabricating and testing the prototype of antenna. The performances of the proposed antenna such as reflection characteristics, radiation characteristics are also presented.

5.1 Introduction

The rapid growth of electronics and wireless communication systems demands for smart antenna systems that are able to change its operating characteristics according to the environment. Pattern reconfigurable antennas are becoming an essential part of modern smart wireless networks. A pattern reconfigurable antenna is considered as a possible candidate for smart antenna design, where it can direct its signals towards the intended user and hence to provide larger coverage by steering the beams directions [1]. A pattern reconfigurable antenna has the potential to reduce the interference by altering the null positions [2].

In this chapter the design and development of a simple pattern and polarization reconfigurable antenna using an asymmetric coplanar strip is presented. The antenna is capable of switching its pattern between two orthogonal directions according to the switching conditions. The antenna exhibits good reflection and radiation characteristics in the operating band. The antenna can be used in modern wireless devices. The structures were simulated using the transient solver (time domain solver) in CST Microwave Studio ® [3].

5.2 Asymmetric Coplanar Strip Fed Pattern and Polarization reconfigurable Antenna

A simple asymmetric coplanar strip (ACPS) fed pattern reconfigurable antenna capable of switching the pattern between the two orthogonal planes is presented. The antenna consists of two radiating arms which are placed orthogonally on an asymmetric coplanar strip feed line. In order to alter the radiation pattern three switches are placed at proper locations. The proposed antenna operates at 2.41 GHz for WLAN (2.4–2.485 GHz). The proposed antenna has a simple structure with an overall dimension of 40 x 27 mm^2 and can be designed easily. The performances of the proposed antenna such as reflection characteristics, radiation characteristics are also presented [4].

5.2.1 Antenna Geometry

The geometry of the proposed pattern reconfigurable antenna is shown in Figure 5.1. The antenna consists of a vertically oriented inverted L shaped arm and a horizontally oriented arm printed on a FR4 substrate of dielectric constant 4.4 and height h =1.6 mm. The length of radiating arms $L_3+L_4+L_g$ and L_1+L_2 is approximately half wavelength long at the resonant frequency. The gap g and W_g are optimized so as to get improved matching. The antenna is excited using an asymmetric coplanar strip. The width W_f and gap G are derived using standard design equation for 50 Ω impedance.

The two radiating arms are placed orthogonally on the feeding strip. The antenna can be made to radiate at two orthogonal polarizations by exciting either of the radiating arms. Thus the radiation pattern can be switched between *y-z* and *x-z* planes. The radiation pattern is controlled by three switches S1, S2 and S3 installed in the gap between the strips in order to change the total resonating length. In the present study switches are simulated with the presence and absence of a copper pad with an area of 0.5x0.5 mm^2. The horizontal radiating arm can be extended or shortened by using switch S3 in order to get the required frequency of operation. The resonant length $L_g+L_3+L_4$ and L_1+L_2 are designed to yield resonance at 2.4 GHz.

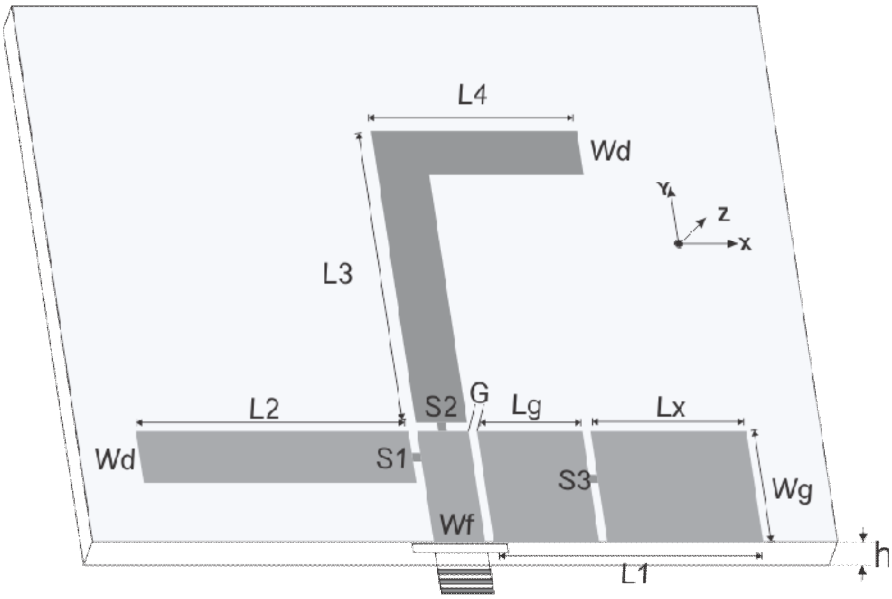


Figure 5.1. Geometry of the proposed reconfigurable antenna

5.2.2 Simulation Results and Discussion

In order to demonstrate the reconfiguration mechanism of the ACPS reconfigurable antenna a model of the designed antenna is simulated. The optimized parameters of this antenna are $L_1 = L_2 = 0.27\lambda g$, $L_g = 0.1\lambda g$, $L_3 = 0.23\lambda g$, $L_4 = 0.12\lambda g$ where λg is the guided wavelength in the substrate. By closing and opening different switches, antenna can be forced to operate in different states. Hence the length and direction of current flow can be altered there by reconfiguration of frequency and pattern can be achieved. Performance of antenna for different states are summarized in Table 5.1.

State	S1	S2	S3	Frequency	Bandwidth	Beam Direction
State 1	ON	OFF	ON	2.406	2.232-2.66	90
State 2	OFF	ON	OFF	2.412	2.312-2.544	0
State 3	ON	ON	ON	2.244	2.068-2.552	70

Table 5.1: Different switching states of pattern reconfigurable antenna

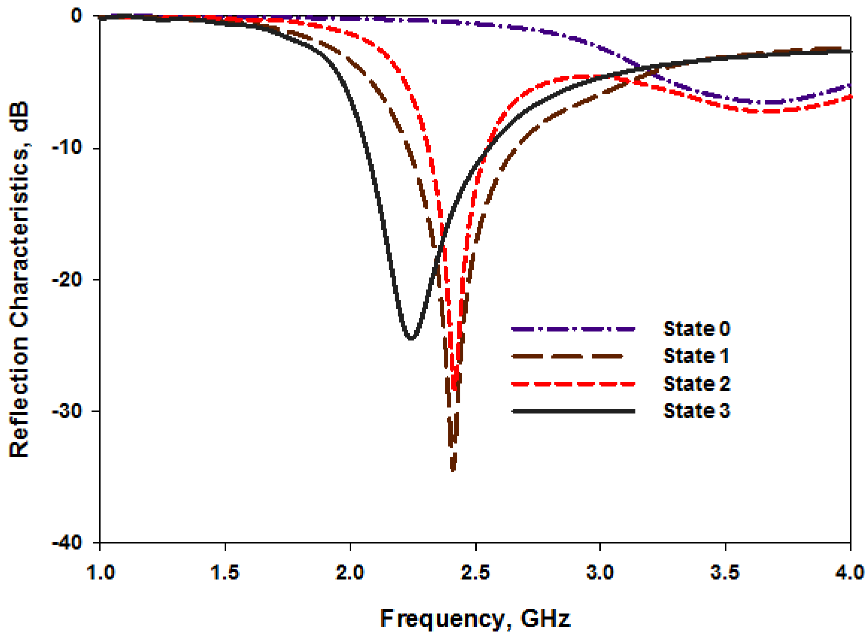


Figure 5.2: Simulated reflection characteristics of the antenna

L_1=21 mm, L_2=21 mm, L_3=20 mm, L_4=12 mm, L_g=8 mm, L_x=12.5mm, W_g=6.5mm, W_d =3 mm, W_f=3 mm, G = 0.3mm, h=1.6mm, ε_r= 4.4.

In State 0, all the switches are open. No evidence of resonance is seen during this state. In state 1 switch S2 is open and all other switches are closed. Then the antenna operates like dipole antenna. The resonance is observed due to a half wave variation of current through the length L_1+L_2. During state 2, at which switch S2 is closed and all other switches are open, then a half wave variation is observed along the length $L_g+L_3+L_4$ just like a folded arm discussed in the chapter 4. In state 3 all switches are closed. Thus by operating switches in different ways, the main beam of the antenna can be directed towards different directions.

The simulated reflection characteristics of the reconfigurable antenna for different states are presented in Figure 5.2. The antenna exhibits a 2:1 VSWR bandwidth of 18.5% and 10.5% centered at 2.41 GHz during state 1 and state 2 respectively. This is wide enough to cover the 2.4 GHz IEEE 802.11 WLAN band. It is observed that both simulated and measured reflection characteristics match well. When state 3 is excited, the resonance frequency shifts to lower frequencies as shown. The simulated operating frequency is centered at 2.24 GHz with impedance bandwidth from 2.12 to 2.57 GHz. Moreover it results in wide bandwidth.

The surface current distribution on the proposed antenna during state 1 and state 2 are shown in figure 5.3 and 5.4 respectively. When the antenna is in state 1 a large surface current distribution is observed along the horizontal arm, L_1+L_2 which corresponds to 0.55λg at 2.41 GHz. During the state 2 the current dominates at vertical arm and half wave variation can be observed along the length L_g+ L_3+L_4.

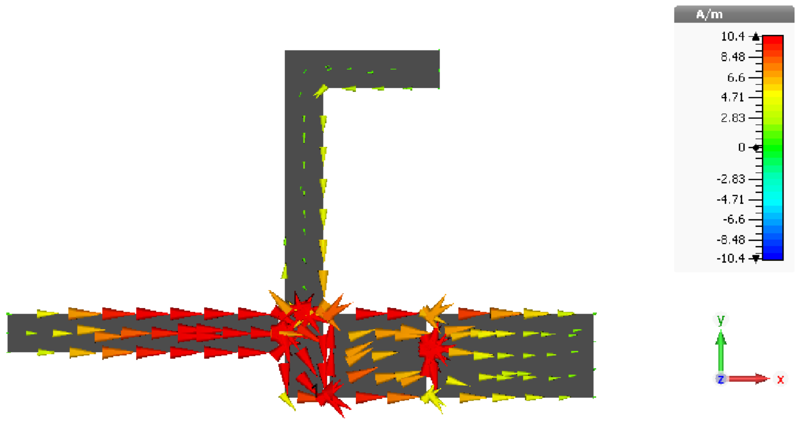


Figure 5.3: Surface current distribution during state 1

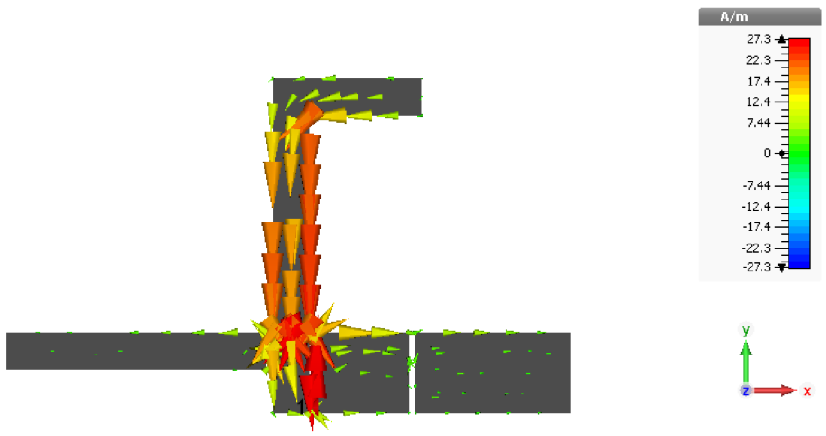


Figure 5.4: Surface current distribution during state 2

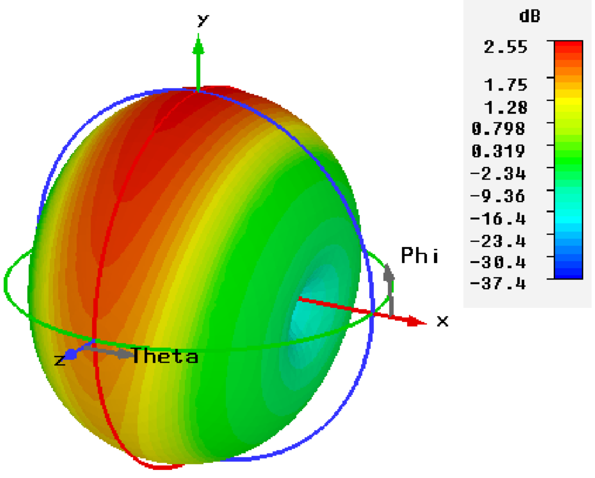


Figure 5.5: 3D radiation pattern during state 1

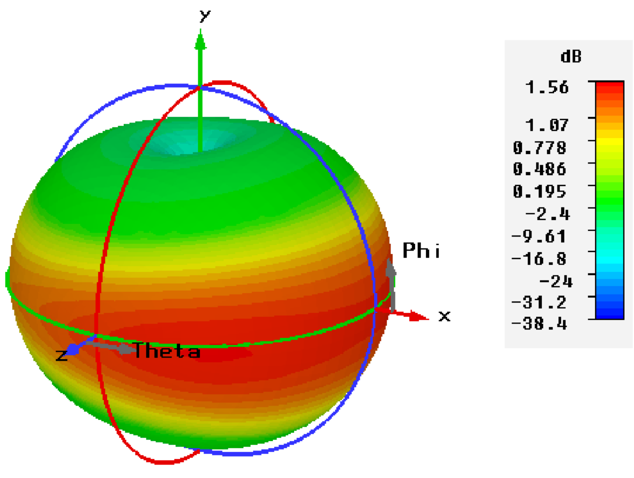


Figure 5.6: 3D radiation pattern during state 2

The simulated 3D radiation patterns of the antenna corresponding to state 1 and state 2 are shown in Figure 5.5 and Figure 5.6 respectively. During state 1 horizontal arm is excited and an x-axis directed pattern equivalent to a dipole is obtained, which provides equal power along y-z plane and a null along x axis. In state 2 vertical arm is excited and a y-axis directed pattern is observed, in which the x-z plane displays equal power and a null along y- axis. In this case, the inverted L resonates like a dipole. The X directed current along the ground plane L_g and the strip L_4 are in opposite direction and are expected to cancel each other in the far field. Thus the current along L_3 dominates and radiates with polarization along Y direction. So state 2 produces a y-axis directed pattern, in which the x-z plane displays equal power and a null along y- axis.

5.2.3 Experimental Results

Prototypes of antennas are constructed to validate the results obtained during the simulations. Figure 5.7 shows measured reflection characteristics. The measured reflection coefficient was compared with simulated results in Figure 5.2. The simulated and measured reflection coefficient agrees reasonably well.

The antenna exhibits measured bandwidth from 2.12 -2.54 GHz during state 1 and state 2. The -10dB bandwidth span around 2.4 GHz as expected. The measured value of impedance bandwidth is slightly higher than that of simulated result. This may be due to the change in loss tangent of actual substrate and tolerance in fabrication.

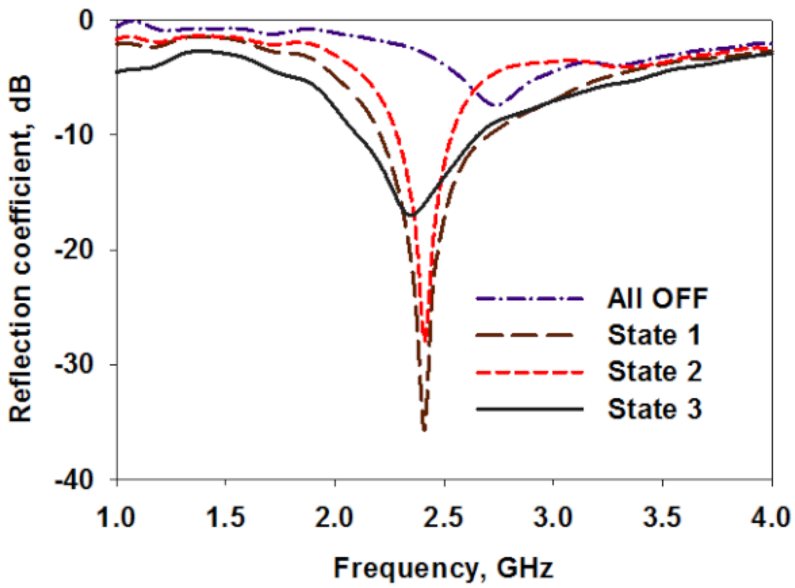
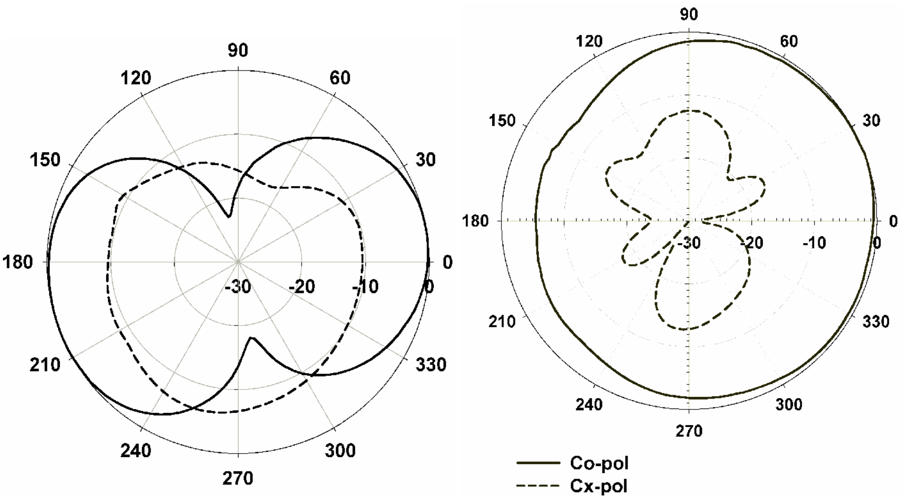


Figure 5.7: Measured Reflection characteristics of the antenna

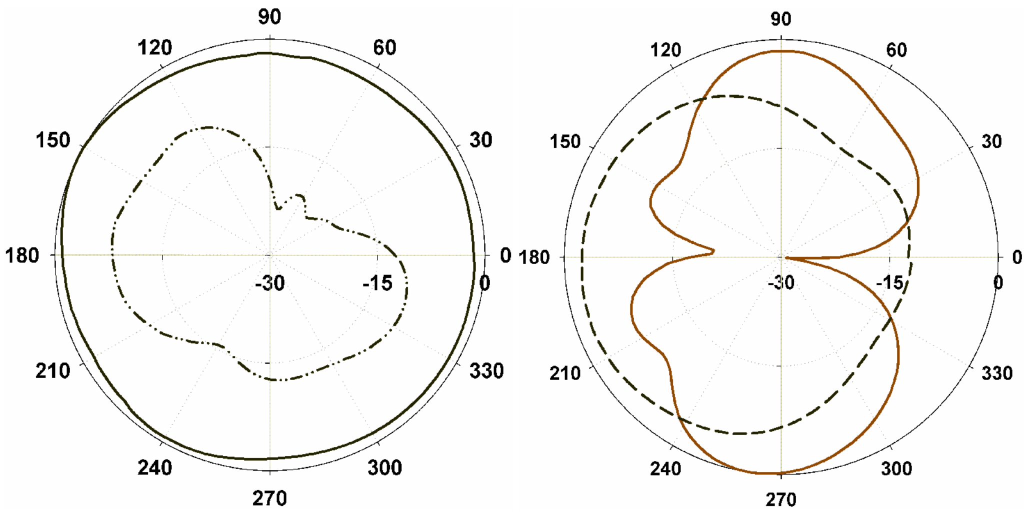
The measured radiation pattern of the proposed antenna is given in Figure 5.8-5.10. Both *x* directed and *y* directed pattern are non directive in the H-plane during state 1 and state 2 respectively. A stable near figure of eight pattern is obtained in the E plane.

It is observed from the measured results that the maximum of main lobe is at 87^0 and -32^0 during state 1 and state 2 respectively. The half power beam width of 62^0 and 86^0 are also obtained during state 1 and state 2.



XZ plane YZ plane

Figure 5.8: Measured radiation characteristics of the antenna state 1



(a) (b)

Figure 5.9: Measured radiation characteristics of the antenna state 2
(a) XZ plane (b) YZ plane

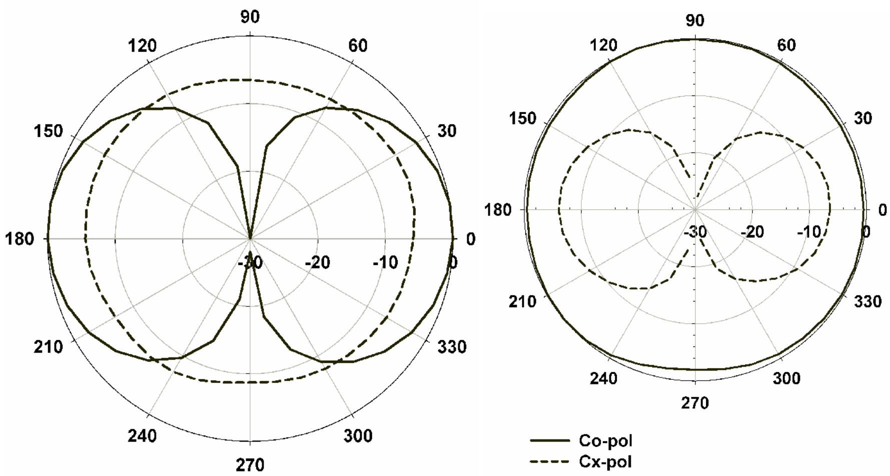


Figure 5.10: Measured radiation characteristics of the antenna state 3

(a) XZ plane (b) YZ plane

It is also noted that the polarization of the antenna in State 1, is along the *x*-axis, and in State 2, the polarization of the antenna is along *y*-axis. So, the polarization of the antenna can be reconfigured between x and y axis by activating the switch.

The measured average gain of the antenna obtained in the 2.4 GHz band is 1.6dBi and is shown in figure 5.11. The discrepancy in measured results can be mostly attributed to the measurement environment and the tolerances in the manufacturing process. The proposed pattern reconfigurable antenna can be used in mobile and wireless applications. The antenna is polarized along the *x* axis for the first state and along the *y* axis for the second state.

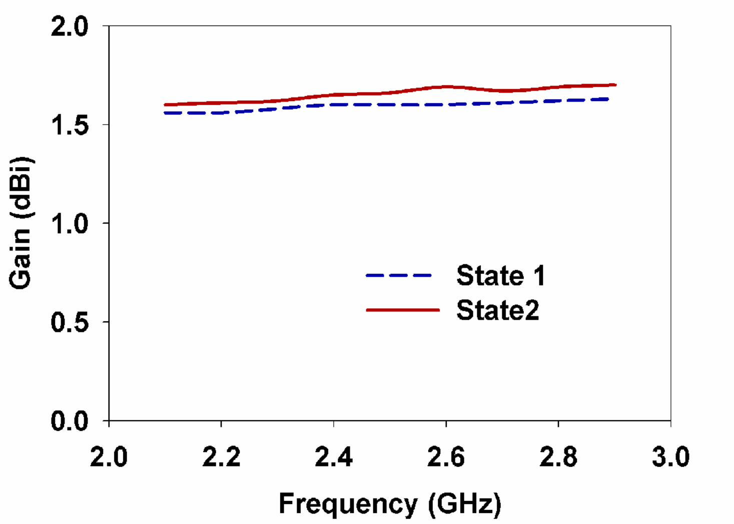


Figure 5.11: Measured gain during state 1 and state2

5.3 Chapter Summary

An asymmetric coplanar strip fed pattern and polarization reconfigurable antenna has been presented. The main beam direction of antenna can easily steered by structural modification of the antenna. The antenna has two radiating arms which are placed orthogonally on an ACPS feeding strip. The beam direction can be steered using three switches. By properly switching, the antenna can be used for the reconfiguration of both pattern and polarization. A prototype of the antenna operating at 2.4GHz is fabricated and analyzed the characteristics at different states. The antenna exhibits good radiation characteristics in the bands of operation suitable for 2.4-GHz band applications.

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Chapter 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Summary and Conclusions

This thesis investigates the radiation characteristics of an asymmetric coplanar strip antenna and assessed its suitability for pattern reconfiguration. Different asymmetric coplanar strip antenna designs have been examined and methods have been proposed to achieve pattern reconfiguration. Detailed analyses of antenna operations are presented through simulation and experimental studies.

Novel reconfigurable antenna designs have been proposed. These include single band, dual band, folded arm and folded ground antenna. The study reveals that by properly activating the switches the electrical behavior and direction of current flow of the antenna can be changed and thereby altering the electromagnetic fields. The ability to steer the radiation pattern at any frequency and to control the main lobe direction have lot of applications in controlling the noise and electronic jamming problems.

A detailed look on the radiation behavior of an asymmetric coplanar strip antenna is presented in chapter 3. Due to the asymmetry in the structure a tilt in the radiation pattern is observed. Various parameters are optimized to steer the main beam direction of radiation pattern. The reconfiguration is experimentally realized by inserting ideal switches. An antenna which operates on 2.4 GHz is realized and its main lobe direction can steer from $\varphi = 22°$ to $\varphi = 78°$. Based on these inferences an asymmetric coplanar strip fed dual band antenna is developed with pattern reconfigurability. The operating frequency bands of the antenna can be tuned by varying the length of one of the strips. The direction of main lobe is different for the both resonant frequencies. The antenna has simple structure and is easy to design. The antenna is also compact and suitable for various wireless communication systems.

A frequency agile and pattern reconfigurable antenna is presented in chapter 4. The radiating arm of the antenna is bent in the form of an inverted L strip. The bending of radiating strip is utilized to get the required radiation pattern and impedance. Reconfiguration is done by activating or deactivating the switches. Two types of bending is done to steer the beam into two directions; that is bending vertical arm or bending horizontal arm. The folded arm can steer the beam between $\varphi = \pm 20°$ keeping the frequency of operation constant. The effects of various parameters are also analyzed. Prototypes of antenna were fabricated and tested. The proposed antenna shows excellent radiation characteristics and reasonable gain.

An asymmetric coplanar strip fed pattern and polarization reconfigurable antenna has been presented in chapter 5. The main beam direction of antenna can easily be steered by structural modification. The antenna has two radiating arms which are placed orthogonally on an ACPS feeding strip. The beam direction can be steered using three switches. By properly switching, the antenna can be used for the reconfiguration of both pattern and polarization. Prototypes of the antenna operating at 2.4GHz were fabricated and analyzed the characteristics at different states.

6.2 Suggestions for Future Work

The main objective of this research work is to investigate the radiation pattern of asymmetric coplanar strip antenna and how it can be utilized to develop a pattern reconfigurable antenna using simple and efficient tuning mechanisms. This has been achieved. However, some suggestions are proposed for future work.

All the reconfigurable antennas in this thesis have been demonstrated by inserting ideal switches (copper strips of dimension 0.5x0.5 mm^2). Future work may focus on the electronic reconfiguring of radiation pattern by using linear switching devices like RF MEMS or non linear switching devices like PIN diode. A study to address the undesirable responses of non linear devices such as insertion loss, gain suppression and generation of spurious frequency components is also desirable.

More research is needed to develop highly directive pattern reconfigurable asymmetric coplanar strip antennas. Effective use of reflector or directors to enhance directivity and gain can be employed. Possibility of ACPS array is also suggested.

Appendix 1

A COMPACT ASYMMETRIC COPLANAR STRIP FED DUAL-BAND ANTENNA FOR DCS/WLAN APPLICATIONS

A compact asymmetric coplanar strip (ACPS) fed dual-band antenna suitable for DCS/WLAN applications is presented. Dual-band operation is achieved by modifying the signal strip of the ACPS monopole. Parametric studies indicate that operating frequencies of the antenna are determined by the dimensions of the strip monopole. Measurements on the optimized antenna printed on an FR4 substrate with er=4.4 and height h=1.6 mm indicate good radiation characteristics with moderate gain.

1. INTRODUCTION

The revolutionary growth in wireless technology demands the integration of different radio modules into a limited equipment space. As a result, the associated antennas are desired to be low profile, single fed, and light weight. The coplanar waveguide (CPW) fed antenna appears more promising due to their many attractive features like wider bandwidth, better impedance matching, uniplanar structure, and easy integration with micro-wave monolithic integrated circuits.

Numerous investigations have been made to study CPW fed dual-band antennas, like attached sleeves along with switches to obtain frequency agility[1], meandered CPW feed for broad band operation [2], strip line monopole with three bended strips exciting multiple bands [3]. A CPW fed dual-frequency monopole antenna composed of two monopoles connected in parallel at the feed point is reported in Ref. 4. By varying the length of the monopoles the operating frequencies are tuned with frequency ratios ranging from 1.3 to 1.6. Broadband operation is achieved by increasing the width of monopole. However, the entire antenna occupies a large ground plane and hence is bulky.

A compact uniplanar antenna with a meandered radiating structure using an asymmetric coplanar strip (ACPS) is reported in Ref. 5 and its compact size is achieved by virtue of single lateral ground strip instead of twin lateral ground strips in the CPW feed. Here, the resonant frequencies are dependent on various lengths of radiating structure, which increases the complexity of the antenna design.

In this letter, a simple compact ACPS dual-band antenna with operating bands around 1.8 and 2.4 GHz covering DCS and WLAN bands, is presented. The antenna exhibits all the benefits of CPW fed antenna along with the advantage of a more compact design [6].

2. ANTENNA GEOMETRY

The geometry of the proposed ACPS fed antenna for a dual-band operation is shown in Figure A1.1. The antenna is printed on a substrate of relative permittivity er = 4.4 and height h =1.6 mm. A slit of width S = 0.4 mm is introduced on the signal strip of the ACPS monopole to create two unequal signal strips having lengths L1 = 32 mm and L2 = 19 mm each having width Wd = 1.3 mm. The dimensions of lateral ground plane Lg and Wg are optimized at 5.5 and 21 mm and the gap width G = 0.5 mm to get good impedance matching.

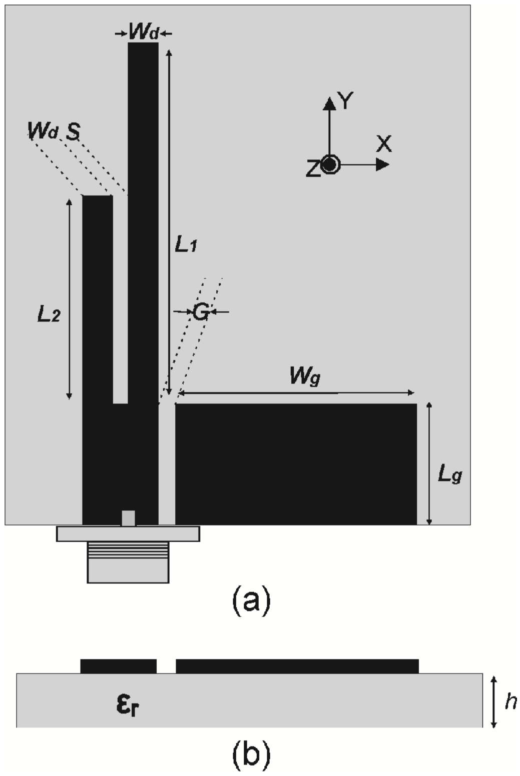


Figure A1.1: Geometry of antenna (a) top view (b) side view.

L1 =32 mm, L2 = 19 mm, Wd =1.3 mm, Lg =5.5 mm, Wg = 21 mm, S=0.4 mm, G=0.5 mm, h=1.6 mm, $\varepsilon r = 4.4$

3. RESULTS AND DISCUSSION

The simulation studies of the antenna are carried out using Ansoft HFSS and are experimentally validated using HP8510C vector network analyzer. The simulated and measured reflection characteristics of the ACPS fed monopole antenna are shown in Figure A1.2. It is observed that the antenna resonates at 1.81 and 2.42 GHz with good matching. From exhaustive parametric studies shown in Figure A1.3, it is found that the first resonance can be tuned by varying L1, whereas the second resonant frequency is influenced by the length

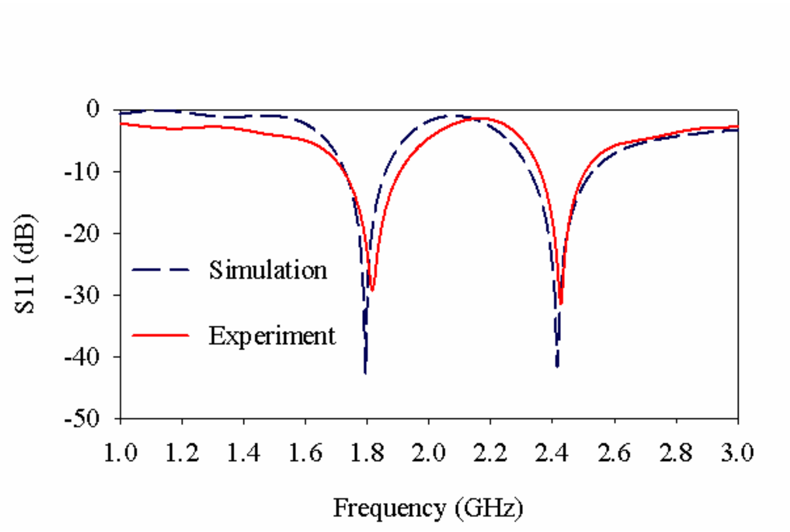
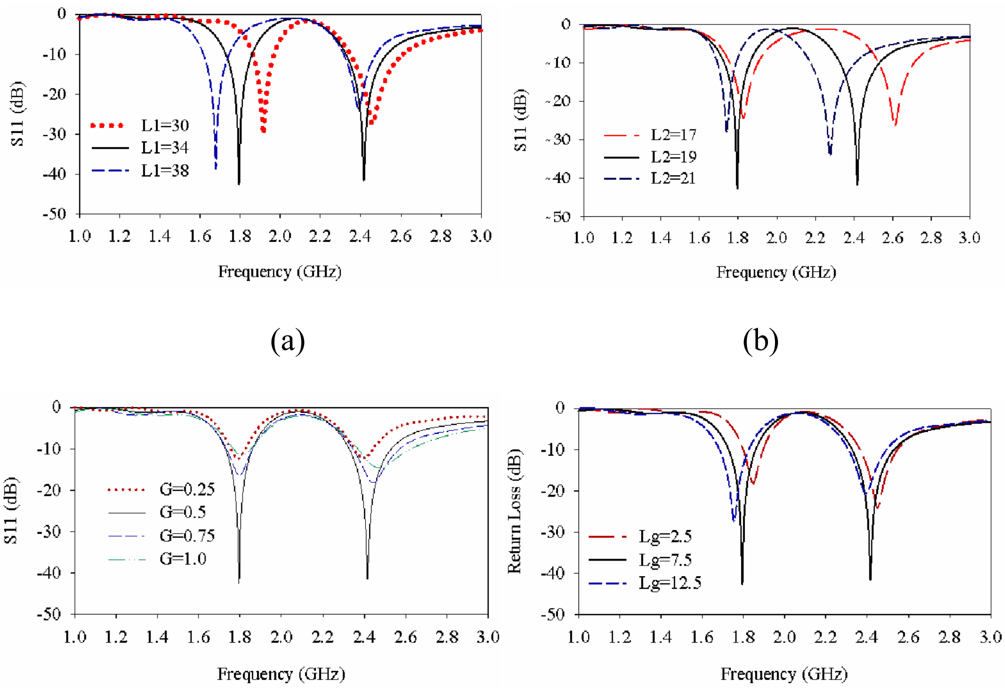


Figure A1.2: Reflection characteristics of the antenna

of short monopole strip L2. The antenna exhibits 2:1 VSWR bandwidth at 1725–1905 MHz and 2350–2512 MHz in the 1.8 and 2.4 GHz bands, respectively. This proposed antenna covers DCS/2.4 GHz WLAN communication bands.

The experimental radiation patterns of the proposed antenna at frequencies 1.81 and 2.42 GHz in the x-z and y-z planes are plotted in Figure 4. The patterns are nearly omnidirectional. The average gain of the antenna is 1.08 dBi in the first band and 1.21 dBi in the second band, respectively. Corresponding efficiencies are 73 and 83%, respectively. The proposed configuration has an area reduction of about 62% with respect to the CPW fed counterpart [4] resonating at the same frequency.

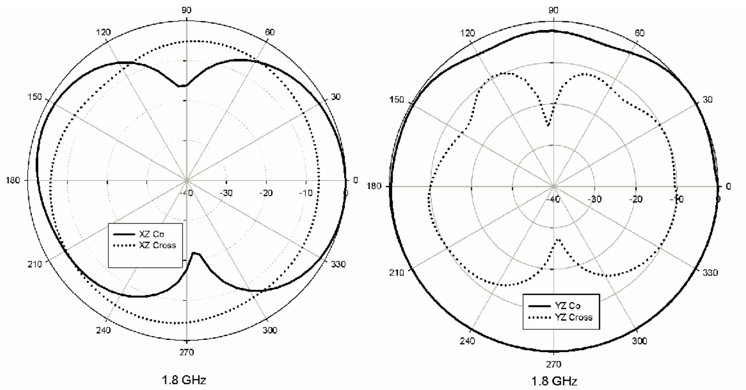


(c) **(d)**

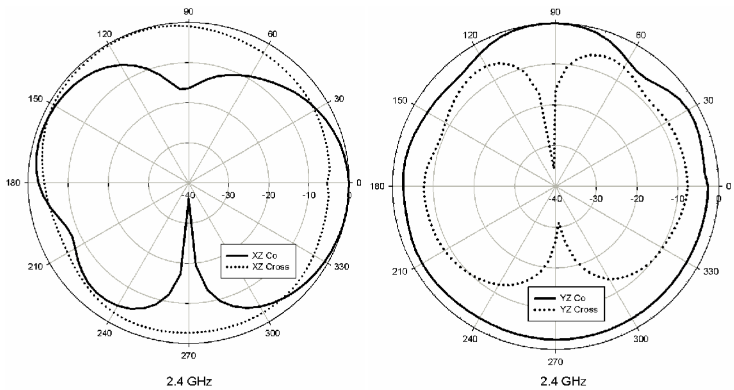
Figure A1.3: Simulated reflection characteristics of antenna keeping all other parameters constant (a) strip L1 (b) strip L2 (c) gap G (d) ground strip Lg

4. CONCLUSION

In this letter, a compact ACPS fed monopole antenna has been proposed. Dual-frequency operation is achieved by two closely spaced monopoles of unequal lengths. The antenna design with optimized dimensions is fabricated and measured. The simulated and measured results show good agreement. The antenna is compact and is suitable for DCS/2.4 GHz WLAN applications.



(a)



(b)

Figure A1.4: Radiation patterns of the antenna at (a) 1.8 GHz and (b) 2.4 GHz

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1. **P Ashkarali**, S Sreenath, R Sujith, R Dinesh, DD Krishna, and CK Aanandan "A compact asymmetric coplanar strip fed dual-band antenna for DCS/WLAN applications"Microwave and Optical Technology Letters 54 (4), 1087-1089
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Objective:

To pursue research activities in the field of printed antennas, reconfigurable antennas and dielectric resonator antenna and to perform my duties with dedication and integrity.

Education:

- Ph. D. in Microwave Electronics - Cochin University of Science and Technology (Currently Doing)
- M.Sc Electronics - Cochin University of Science and Technology (2003) Score: CGPA 8.24 First class with Distinction.
- B.Sc Computer Science with Electronics - University of Calicut (2001) Score: 86% First class with Distinction

Awards Obtained:

- UGC Research Fellowship for Science Meritorious Students
- UGC NET in June -2006

Research Experience:

Worked as a part time Research scholar in Centre for Research in Electro Magnetics and Antennas, Dept. of Electronics, Cochin University of Science and Technology from 13rd September 2007 to till date

Work Experience:

1. Working as Assistant Professor in Electronics at Govt. Arts and Science College Tanur, Malappuram from 03-06-2015 onwards.
2. Worked as Assistant Professor in Electronics at Govt. College, Mananthavady Wayanad from 03-10-2011 to 02-06-2015.
3. Worked as Assistant Professor in Electronics at Sree narayana Guru College Chelannur, Kozhikode from 01-01-2011 to 02-10-2011.

Publications:

International Journal	: 4
National Conference	: 3

Computer Proficiency:

1. C, C^{++}, MATLAB, Assembly Level Programming,
2. Antenna Designing software like Ansoft HFSS, CST Microwave Studio.

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