PATTERN RECONFIGURABLE MIMO ANTENNA

A Project report submitted in partial fulfilment of the requirements for

the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(UGC AUTONOMOUS)

(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*

Sangivalasa, Bheemili mandal, visakhapatnam dist.(A.P)

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CERTIFICATE

This is to certify that the project report entitled "**PATTERN RECONFIGURABLE MIMO ANTENNA**" submitted by **D.Venusree (317126512131), B.Aakash (317126512128), B.J.C.Meghana (317126512127), P.V.S.Manidhar (317126512156)** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

Due to the fast development of wireless communication technology, reconfigurable antennas with multiple-input and multiple-output (MIMO) in modern wireless applications with high-data rate have drawn very close attention from researchers. The multiple radio channels through multiple input multiple output (MIMO) technology result in high throughput in wireless communication. MIMO is a technique where multiple antennas are used at both the transmitter and the receiver to increase the link reliability and the spectral efficiency. By placing multiple antenna elements at the transmitter and receiver ends of the wireless communication system, MIMO can not only improve the capacity of channel, but also reduce the effects of multi-path fading. The major problem faced by the MIMO systems is mutual coupling due to the electromagnetic interference between antenna elements. In this proposed project work, a reconfigurable MIMO antenna is designed. Microstrip patch is used, as it is a low profile, simple and broadside radiator. This pattern reconfigurable MIMO antenna is composed of two elements arranged opposite to each other, and two decoupling strips are introduced to improve the isolation. The pattern reconfigurable characteristic is obtained by changing the bias voltages of the PIN diodes embedded in the parasitic strips of the elements. Moreover, the proposed antenna has a low profile compared to the antenna with similar overlapped bandwidth. The implemented design is simulated using High Frequency Structure Simulator (HFSS) Software. The applications of this proposed antenna are satellite high performance aircraft, satellite and in missile applications.

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CHAPTER I

INTRODUCTION

INTRODUCTION

An Antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver. In transmission, a radio transmitter supplies an electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of a radio wave in order to produce an electric current at its terminals that is applied to a receiver to be amplified . Antennas are essential components of all radio equipment.

1.1 ANTENNA BASICS

1.1.1 Definition of Antenna

There are several definitions of antenna. They are as follows:

- An Antenna is a device that converts electronic signals to electromagnetic waves and vice versa effectively with minimum loss of signals.
- An Antenna is a transducer that converts radio frequency (RF) fields into alternating current or vice versa. There are both receiving and transmission antennas for sending or receiving radio transmissions.

1.1.2 Radiation Mechanism

The sole functionality of an antenna is power radiation or reception. The functioning of an antenna depends upon the radiation mechanism of a transmission line. When transmitting and receiving antenna is excited with an alternating voltage, then the initial move will be started by the balanced motion of charges in the antenna. Resonant oscillations are produced by the supplied energy.

Radiation mechanism in single-wire:

It is a fundamental single wire antenna. By the principle of radiation, the current must be time-varying. For a single wire antenna:

1. If the charge is stationary, no current is developed. So no radiation is observed.
2. If the charge is moving with uniform velocity, then

    i)No radiation occur for a straight wire which is infinity in extent

    ii) Radiation is possible only if the wire is curved; bent, discontinuous, terminated or truncated.

When a wire is energized using a source, the free electrons in wire are set into motion due to the force of electrical lines.

The charges will be accelerated at the source end while they are decelerated due to the reflection at the other end. As a result, radiation fields are created not only at the two ends but also along the remaining part of the wire.

If the pulses of charge travelling along the wire are narrow, then radiation is stronger with a wide frequency spectrum. But if the charge is oscillating, then the radiation of a single frequency is produced.

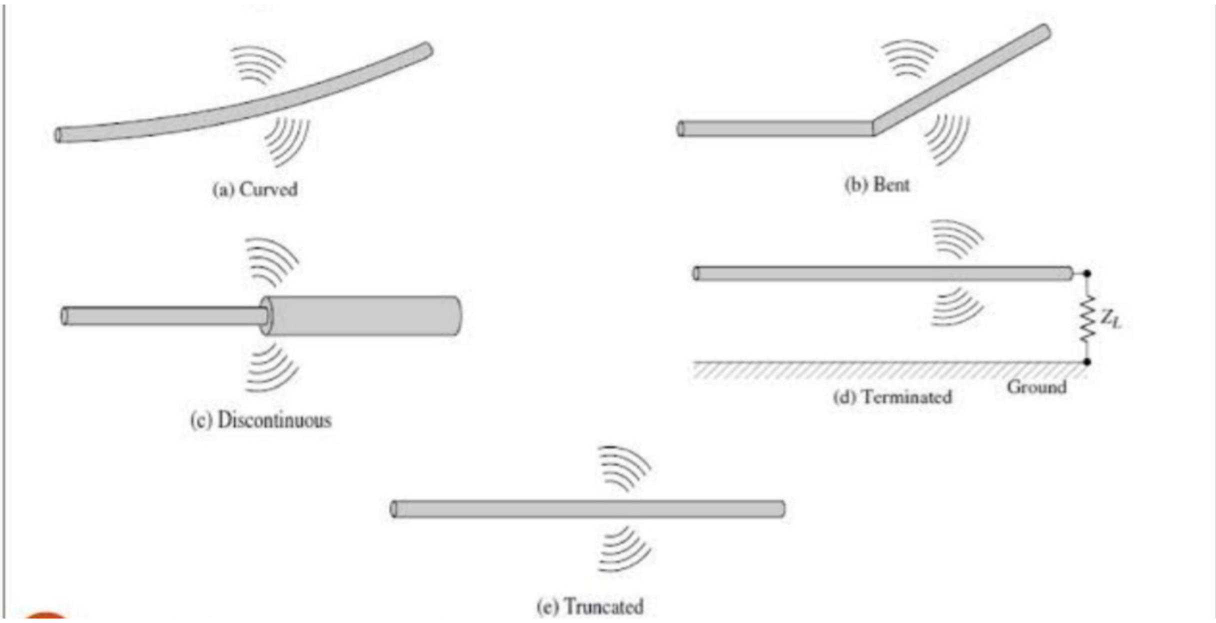


Fig.1.1. different wire configurations producing radiation

Radiation Mechanism in two wire:

Let us consider a voltage source connected to a two-conductor transmission line which is connected to an antenna. This is shown in Figure (a). Applying a voltage across the two conductor transmission line creates an electric field between the conductors. The electric field 7 has associated with it electric lines of force which are tangent to the electric field at each point and their strength is proportional to the electric field intensity. The electric lines of force have a tendency to act on the free electrons (easily detachable from the atoms) associated with each conductor and force them to be displaced. The movement of the charges creates a current that in turn creates magnetic field intensity. Associated with the magnetic field intensity are magnetic lines of force which are tangent to the magnetic field. We have accepted that electric field lines start on positive charges and end on negative charges. They also can start on a positive charge and end at infinity, start at infinity and end on a negative charge, or form closed loops neither starting or ending on any charge. Magnetic field lines always form closed loops encircling current-carrying conductors because physically there are no magnetic charges. In some mathematical formulations, it is often convenient to introduce equivalent magnetic charges and magnetic currents to draw a parallel between solutions involving electric and magnetic sources. The electric field lines drawn between the two conductors help to exhibit the Distribution of charge. If we assume that the voltage source is sinusoidal, we expect the electric field between the conductors to also be sinusoidal with a period equal to that of the applied source. The relative magnitude of the electric field intensity is indicated by the density (bunching) of the lines of force with the arrows showing the relative direction (positive or negative). The creation of time varying electric and magnetic fields between the conductors forms electromagnetic waves which travel along the transmission line, as shown in Figure 1.2(a). The electromagnetic waves enter the antenna and have associated with them electric charges and corresponding currents. If we remove part of b the antenna structure, as shown in Figure (b), free-space waves can be formed by ―connecting‖ the open ends of the electric lines (shown dashed). The free-space waves are also periodic but a constant phase point P0 moves outwardly with the speed of light and travels a distance of λ/2 (to P1) in the time of one-half of a period. It has been shown that close to the antenna the constant phase point P0 moves faster than the speed of light but approaches the speed of light at points far away from the antenna (analogous to phase velocity inside a rectangular waveguide).

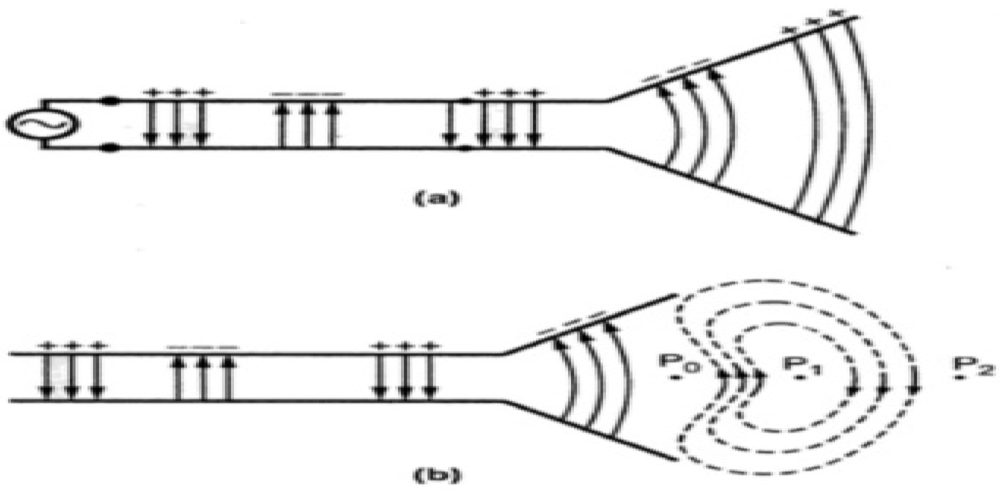


Fig.1.2 Radiation from two wire antenna

Radiation from a dipole:

Radiation from a Dipole Now let us attempt to explain the mechanism by which the electric lines of force are detached from the antenna to form the free-space waves. This will again be illustrated by an example of a small dipole antenna where the time of travel is negligible. This is only necessary to give a better physical interpretation of the detachment of the lines of force. Although a somewhat simplified mechanism, it does allow one to visualize the creation of the free-space waves. Figure(a) displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance λ/4. For this example, let us assume that the number of lines formed is three. During the next quarter of the period, the original three lines travel an additional λ/4 (a total of λ/2 from the initial point) and the charge density on the conductors begins to diminish. This can be thought of as being accomplished by introducing opposite charges which at the end of the first half of the period have neutralized the charges on the conductors. The lines of force created by the opposite charges are three and travel a distance λ/4 during the second quarter of the first half, and they are shown dashed in Figure (b). The end result is that there are three lines of force pointed upward in the first λ/4 distance and the same number of lines directed downward in the second λ/4. Since there is no net charge on the antenna, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops. This is shown in Figure(c). In the remaining second half of the period, the same procedure is followed but in the opposite direction. After that, the process is repeated and continues indefinitely and electric field patterns are formed.

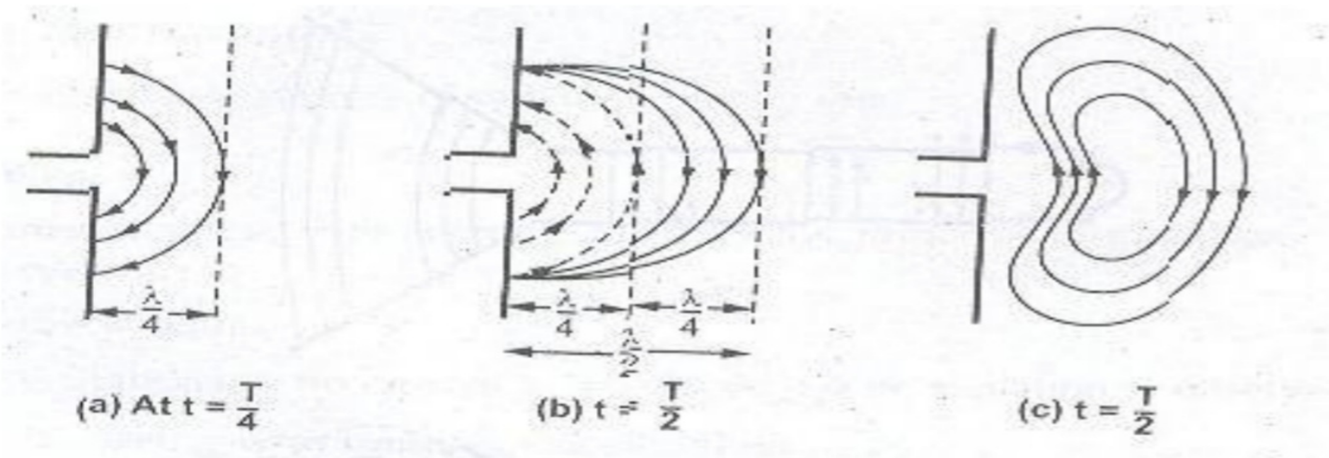


Fig.1.3 Formation of electric field line for short dipole

1.2 BASIC ANTENNA PARAMETERS

To describe the performance of antenna, definitions of various parameters are necessary. Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance. Like for cellular mobile communication a circular polarized antenna is requires with high gain and for satellite communication in downlink a high directive antenna is required. The parameter definitions of the antenna are from IEEE Standard Definitions of Terms and Antennas

1.2.1 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as “a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.

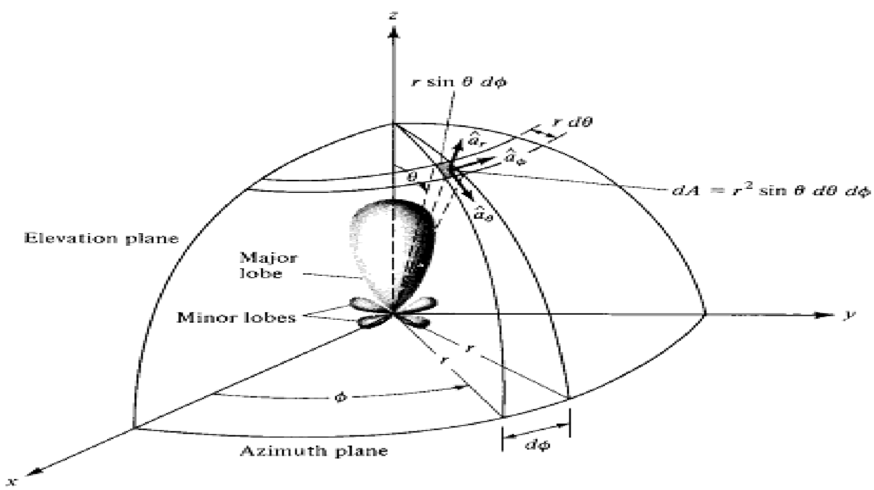


Fig.1.4 Radiation Pattern in 3D-Plane of an antenna

1.2.2 Beam width

The beam width of an antenna is very important figure of merit and often is used as a trade-off between it and the side lobe level; that is, as the beam width decreases, the side lobe increases and vice versa.

<u>Half-Power Beam Width (HPBW):</u> It is an angular width (in degrees), measured on the major lobe of an antenna radiation pattern at half-power points i.e the points at which the signal power is half that of its peak value. In other words, The Half Power Beam width (HPBW) is

the angular separation in which the magnitude of the radiation pattern decreases by 50% (or -3 dB) from the peak of the main beam.

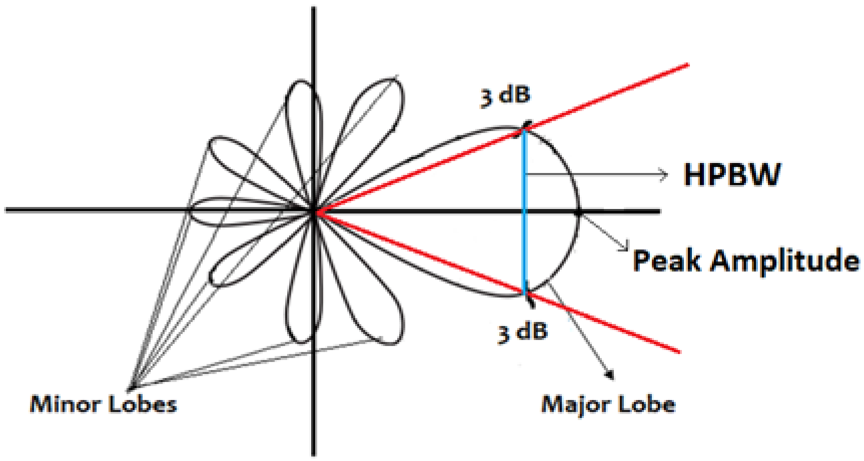


Fig.1.5 Half power Beam width

The 3 dB points on the major lobe of the antenna are the half power points. These points are at -3 dB from where the point of maximum amplitude. When a line is drawn between radiation pattern's origin and the half power points on the major lobe, on both the sides, the angle between those two vectors is termed as HPBW, half power beam width.

First-Null Beam Width (FNBW): Angular separation between the first nulls of the pattern.

1.2.3 Radiation Intensity

Radiation Intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle." In mathematical form it is expressed as

$$U = r^2 W_{rad}$$

Where U = radiation intensity (W/unit solid angle)

W_{rad} = radiation density (W/m^2)

1.2.4 Directivity

Directivity of an antenna shows that how much the antenna is able to radiate in a particular given direction. The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

$$\text{Directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}}$$

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

1.2.5 Return loss

Return loss is a measure of the effectiveness of power delivery from a transmission line to a load such as an antenna. If the power incident on the antenna-under-test (AUT) is P_{in} and the power reflected back to the source is P_{ref}, then the return loss can be defined as

$$\text{Return Loss} = 10\ \log_{10}\left(\frac{\mathrm{P_{in}}}{\mathrm{P_{ref}}}\right)\mathrm{dB}$$

1.2.6 VSWR

VSWR describes how much energy is reflected from the antenna because of impedance mismatching. A perfectly impedance antenna would have VSWR equal to one [1]. VSWR than 2:1(equivalent to a return loss of a -9.5dB) is considered to be acceptable for most wireless applications because the time delay of any reflections is typically small, thus providing small amounts of error within the receiver.

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

Where, Γ is voltage reflection coefficient at the input terminals of the antenna.

1.2.7 Gain

Antenna Gain is also referred as Power gain or simply Gain. This combines of antenna efficiency and directivity. For a transmitting antenna it shows how efficiently antenna is able to radiate the given power into space in a particular direction. While in case of receiving antenna it shows how well the antenna is to convert the received electromagnetic waves into electrical power. When it is calculated with efficiency and directivity D it is referred as Power Gain.

$$\text{Power Gain} = \mathrm{E_{antenna}}.\ \mathrm{D}$$

When the directivity with a particular direction is given it is known as Directive Gain.

1.2.8 Bandwidth

The bandwidth of an antenna expresses its ability to operate over a wide frequency range. It is often defined as the range over which the power gain is maintained to within 3dB of its maximum value, or the range over which the VSWR is no greater than 2:1, whichever is smaller. The bandwidth is usually given as a percentage of the nominal operating frequency. The radiation pattern of an antenna may change dramatically outside its specified operating bandwidth.

1.2.9 Effective Aperture

If an antenna is used to receive a wave with a power density S, it will produce a power in its terminating impedance of Pr watts. The constant of proportionality between Pr and S is Ae, the effective aperture of the antenna in square metres: Pr= AeS

For some antennas, such as horn or dish antennas, the aperture has an obvious physical interpretation, being almost the same as the physical area of the antenna, but the concept is just as valid for all antennas. The effective aperture may often be very much larger than the physical area, especially in the case of wire antennas. Note however, that the effective aperture will reduce as the efficiency of the antenna decreases.

The antenna gain G is related to the effective aperture as follows:

G= 4pi/(lamda)2Ae

The effective aperture is the ratio of the available power at the terminals of the antenna to the power flux density of a plane wave incident upon the antenna, which is polarization matched to the antenna. If there is no specific direction chosen, the direction of maximum radiation intensity is implied.

1.3 TYPES OF ANTENNAS

We have different type of antennas based on frequency range. They are as follows:

1.3.1 Low Frequency Antennas

Low Frequency (LF) is the designation for radio frequencies(RF) in the range of 30-300 kHz. Low Frequency radio waves exibit low signal attenuation, making them suitable for long-distance communications. Since the ground waves used in this band require vertical polarization, vertical antennas are used for transmission. Due to the long wavelengths in the band, nearly all LF antennas are electrically short, shorter than one quarter of the radiated wavelength, so their low radiation resistance makes them inefficient, requiring very low resistance grounds and conductors to avoid dissipating transmitter power. These electrically short antennas need loading coils at the base of the antenna to bring them into resonance. LF (longwave) broadcasting stations use mast antennas with heights of more than 150 meters or T-aerials. The mast antennas can be ground-fed insulated masts or upper-fed grounded masts. It is also possible to use cage antennas on grounded masts. LF transmitting antennas for high power transmitters require large amounts of space.

Advantages:

- Communicates best with items containing metal.
- Signals have better penetration

Disadvantages:

- Large antennas must be used and many frequencies are susceptible to atmospheric noise.
- Higher tag cost.
- Limited capability to read multiple tags.

Applications:

- Standard time signals
- Military
- Radio navigation signals
- Radio broadcasting

1.3.2 MF or HF Antennas

To communicate at longer ranges, you will normally need a satellite telephone or an MF/HF marine radiotelephone. MF/HF antennas typically cover the frequency range of 1.5 to 30 MHz (0.1 to 30 MHz receiving).This frequency band is highly popular among radio amateurs around the world. It exhibits very high ranges while through reflection (or: bending) at the ionosphere, even over-ranges are possible ("over-the-horizon"). Horizontally polarized long wire antenna is the most common type of antenna for GMDSS MF-HF. Combined Medium Frequency and High Frequency(MF/HF) radios can transmit over thousands of nautical miles as the signal can be 'bounced' off the ionosphere to overcome line of sight issues. This makes them an ideal tool for ocean going ships to communicate without the need to pay a service provider for 'airtime'.

Fig.1.6 Yagi Uda Anetnna

Fig.1.7 Loop Antenna

Applications:

- AM radio transmission
- Navigation systems for ships and aircrafts
- Aviation industry

1.3.3 Microwave Antenna

A microwave antenna is a physical transmission device used to broadcast microwave transmissions between two or more locations. The short wavelengths of microwaves allow omnidirectional antennas for portable devices to be made very small, from 1 to 20 centimeters long.

Microwave Frequency bands

Table.1.1 Microwave frequency bands

Band	Frequency Range (GHz)
L	1 to 2
S	2 to 4
C	4 to 8
X	8 to 10
Ku	12 to 18
K	18 to 26.5
Ka	26.5 to 40

Q	**30 to 50**
U	**40 to 60**
B	**50 to 75**
E	**60 to 90**
W	**75 to 110**
F	**90 to 140**
D	**110 to 170**

Uses:

- Radar
- Radio astronomy
- Communication intelligence
- Electronic warfare

Antenna Types

Horn Antenna:

It's also referred to as a microwave horn. A horn antenna is comprised of a waveguide, which has flared end walls on the outside forming a structure that looks like a megaphone. The horns are used widely as antennas microwave frequencies above 300 MHz and ultra-high frequencies. Horn antennas are used to approximate how much gain the other antennas have. They are used as directive and calibrating antennas for equipment such as microwave-radio meters, and automatic door openers. Some of the benefits of horn antennas are broad bandwidth, low-standing wave ratio, and moderate directivity. Horn antennas have a gain ranging up to 25db. They are used extensively at microwave frequency when you require moderate power gain.

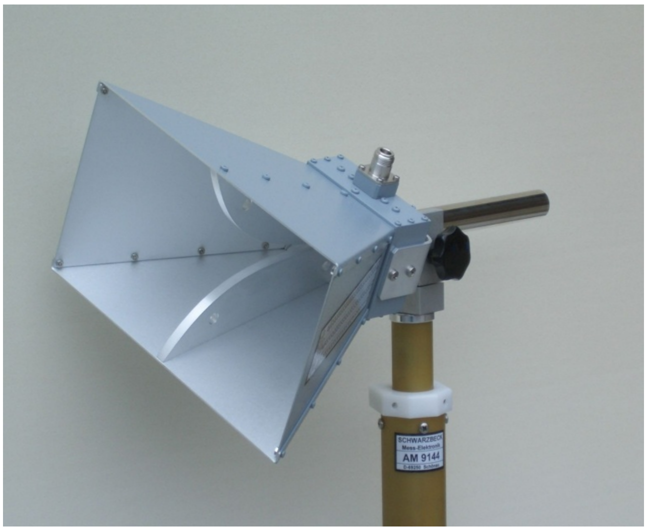


Fig.1.8 Horn antenna

Parabolic Antenna

This antenna uses a parabolic reflector. This is a parabolic-shaped and curved area that is used to direct the radio waves. The antenna is shaped like a dish thus it is referred to as a parabolic dish or dish antenna. One of the benefits of a parabolic antenna is that it has high directivity. Parabolic antennas are applied as radio telescopes and for point-to-point communication since they have high-end gain. Also, these antennas are used as radars. They require the transmission of a narrow beam wave of radio to some equipment such as airplanes and ships.

Fig.1.9 Parabolic antenna

Plasma Antenna

This is a kind of radio antenna that uses plasma rather than metal elements as a development device. Metal elements were used in antennas in the past years. Plasma antenna uses ionized gas for conduction.

The gas is ionized when reception or transmission occurs. The plasma antenna can operate up to 90GHz frequency range. Thus, they can be applied in reception and transmission of signals from radios.

Besides, the antenna has a cutoff of high frequency. It's able to receive and transmit signals of low and high-frequency and it does not interact with the signals with high frequency. Some of the areas where plasma antennas are applied include 4G and radar systems, RFID, electronic intelligence, and high-speed digital communications.

Fig.1.10 Plasma antenna

1.4 APPLICATIONS

1.4.1 Frequency Spectrum

Frequency spectrum of a signal is the range of frequencies contained by a signal.

The following table depicts the frequency bands and its uses –

Table.1.2 Frequency spectrum

Band Name	Frequency	Wavelength	Applications
Extremely Low Frequency (ELF)	30 Hz to 300 Hz	10,000 to 1,000 KM	Power line frequencies
Voice Frequency (VF)	300 Hz to 3 KHz	1,000 to 100 KM	Telephone

Band Name	Frequency	Wavelength	Applications
			Communications
Very Low Frequency (VLF)	3 KHz to 30 KHz	100 to 10 KM	Marine Communications
Low Frequency (LF)	30 KHz to 300 KHz	10 to 1 KM	Marine Communications
Medium Frequency (MF)	300 KHz to 3 MHz	1000 to 100 m	AM Broadcasting
High Frequency (HF)	3 MHz to 30 MHz	100 to 10 m	Long distance aircraft/ship Communications
Very High Frequency(VHF)	30 MHz to 300 MHz	10 to 1 m	FM Broadcasting
Ultra High Frequency (UHF)	300 MHz to 3 GHz	100 to 10 cm	Cellular Telephone
Super High Frequency (SHF)	3 GHz to 30 GHz	10 to 1 cm	Satellite Communications, Microwave links
Extremely High Frequency (EHF)	30 GHz to 300 GHz	10 to 1 mm	Wireless local loop
Infrared	300 GHz to 400 THz	1 mm to 770 nm	Consumer Electronics
Visible Light	400 THz to 900 THz	770 nm to 330 nm	Optical Communications

1.4.2 Microwave frequency applications

Microwave technology is extensively used for point-to-point telecommunications (i.e. non-broadcast uses). Microwaves are especially suitable for this use since they are more easily focused into narrower beams than radio waves, allowing frequency reuse; their comparatively higher frequencies allow broad bandwidth and high data transmission rates, and antenna sizes are smaller than at lower frequencies because antenna size is inversely proportional to the transmitted frequency. Microwaves are used in spacecraft communication, and much of the world's data, TV, and telephone communications are transmitted long distances by microwaves between ground stations and communications satellites. Microwaves are also employed in microwave ovens and in radar technology.

Communication

Fig.1.11 Satellite dish

A satellite dish on a residence, which receives satellite television over a K_u band 12–14 GHz microwave beam from a direct broadcast communications satellite in a geostationary orbit 35,700 kilometres (22,000 miles) above the Earth

Before the advent of fiber-optic transmission, most long-distance telephone calls were carried via networks of microwave radio relay links run by carriers such as AT&T Long Lines. Starting in the early 1950s, frequency-division multiplexing was used to send up to 5,400 telephone channels on each microwave radio channel, with as many as ten radio channels combined into one antenna for the *hop* to the next site, up to 70 km away.

Wireless LAN protocols, such as Bluetooth and the IEEE 802.11 specifications used for Wi-Fi, also use microwaves in the 2.4 GHz ISM band, although 802.11a uses ISM band and U-NII frequencies in the 5 GHz range. Licensed long-range (up to about 25 km) Wireless Internet Access services have been used for almost a decade in many countries in the 3.5–4.0 GHz range. The FCC recently carved out spectrum for carriers that wish to offer services in this range in the U.S. — with emphasis on 3.65 GHz. Dozens of service providers across the country are securing or have already received licenses from the FCC to operate in this band. The WIMAX service offerings that can be carried on the 3.65 GHz band will give business customers another option for connectivity.

Metropolitan area network (MAN) protocols, such as WiMAX (Worldwide Interoperability for Microwave Access) are based on standards such as IEEE 802.16, designed to operate between 2 and 11 GHz. Commercial implementations are in the 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz ranges.

Mobile Broadband Wireless Access (MBWA) protocols based on standards specifications such as IEEE 802.20 or ATIS/ANSI HC-SDMA (such as iBurst) operate between 1.6 and 2.3 GHz to give mobility and in-building penetration characteristics similar to mobile phones but with vastly greater spectral efficiency.

Some mobile phone networks, like GSM, use the low-microwave/high-UHF frequencies around 1.8 and 1.9 GHz in the Americas and elsewhere, respectively. DVB-SH and S-DMB use 1.452 to 1.492 GHz, while proprietary/incompatible satellite radio in the U.S. uses around 2.3 GHz for DARS.

Microwave radio is used in broadcasting and telecommunication transmissions because, due to their short wavelength, highly directional antennas are smaller and therefore more practical than they would be at longer wavelengths (lower frequencies). There is also more bandwidth in the microwave spectrum than in the rest of the radio spectrum; the usable bandwidth below 300 MHz is less than 300 MHz while many GHz can be used above 300 MHz. Typically, microwaves are used in television news to transmit a signal from a remote location to a television station from a specially equipped van. See broadcast auxiliary service (BAS), remote pickup unit (RPU), and studio/transmitter link (STL).

Most satellite communications systems operate in the C, X, K_a, or K_u bands of the microwave spectrum. These frequencies allow large bandwidth while avoiding the crowded UHF frequencies and staying below the atmospheric absorption of EHF frequencies. Satellite TV either operates in the C band for the traditional large dish fixed satellite service or K_u band for direct-broadcast satellite. Military communications run primarily over X or K_u-band links, with K_a band being used for Milstar.

Navigation

Global Navigation Satellite Systems (GNSS) including the Chinese Beidou, the American Global Positioning System (introduced in 1978) and the Russian GLONASS broadcast navigational signals in various bands between about 1.2 GHz and 1.6 GHz.

Radar

Fig.1.12 Parabolic Antenna

The parabolic antenna (lower curved surface) of an ASR-9 airport surveillance radar which radiates a narrow vertical fan-shaped beam of 2.7–2.9 GHz (S band) microwaves to locate aircraft in the airspace surrounding an airport.

Radar is a radiolocation technique in which a beam of radio waves emitted by a transmitter bounces off an object and returns to a receiver, allowing the location, range, speed, and other characteristics of the object to be determined. The short wavelength of microwaves causes large reflections from objects the size of motor vehicles, ships and aircraft. Also, at these wavelengths, the high gain antennas such as parabolic antennas which are required to produce the narrow beam widths needed to accurately locate objects are conveniently small, allowing them to be rapidly turned to scan for objects. Therefore, microwave frequencies are the main frequencies used in radar. Microwave radar is widely used for applications such as air traffic control, weather forecasting, navigation of ships, and speed limit enforcement. Long-distance radars use the lower microwave frequencies since at the upper end of the band atmospheric absorption limits the range, but millimeter waves are used for short-range radar such as collision avoidance systems.

Fig.1.13 Dish Antenna

Some of the dish antennas of the Atacama Large Millimeter Array (ALMA) a radio telescope located in northern Chile. It receives microwaves in the millimeter wave range, 31 – 1000 GHz.

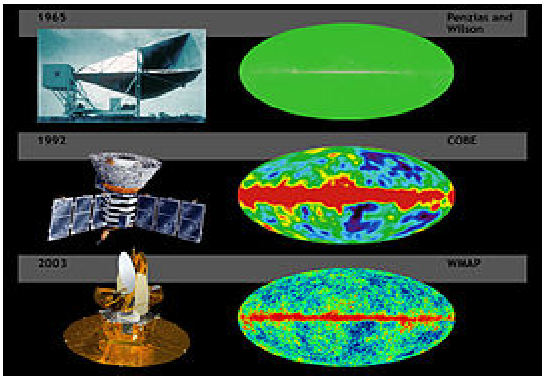


Fig.1.14 Maps of Cosmic microwave background radiation

Maps of the cosmic microwave background radiation (CMBR), showing the improved resolution which has been achieved with better microwave radio telescopes

Radio astronomy

Microwaves emitted by astronomical radio sources; planets, stars, galaxies, and nebulas are studied in radio astronomy with large dish antennas called radio telescopes. In addition to receiving naturally occurring microwave radiation, radio telescopes have been used in active radar experiments to bounce microwaves off planets in the solar system, to determine the distance to the Moon or map the invisible surface of Venus through cloud cover.

A recently completed microwave radio telescope is the Atacama Large Millimeter Array, located at more than 5,000 meters (16,597 ft) altitude in Chile, observes the universe in the millimeter and submillimetre wavelength ranges. The world's largest ground-based astronomy project to date, it consists of more than 66 dishes and was built in an international collaboration by Europe, North America, East Asia and Chile.

A major recent focus of microwave radio astronomy has been mapping the cosmic microwave background radiation (CMBR) discovered in 1964 by radio astronomers Arno Penzias and Robert Wilson. This faint background radiation, which fills the universe and is almost the same in all directions, is "relic radiation" from the Big Bang, and is one of the few sources of information about conditions in the early universe. Due to the expansion and thus cooling of the Universe, the originally high-energy radiation has been shifted into the microwave region of the radio spectrum. Sufficiently sensitive radio telescopes can detect the CMBR as a faint signal that is not associated with any star, galaxy, or other object.

Heating and power application

Fig.1.15 Microwave oven

A microwave oven passes microwave radiation at a frequency near 2.45 GHz (12 cm) through food, causing dielectric heating primarily by absorption of the energy in water. Microwave ovens became common kitchen appliances in Western countries in the late 1970s, following the development of less expensive cavity magnetrons. Water in the liquid state possesses many molecular interactions that broaden the absorption peak. In the vapor phase, isolated water molecules absorb at around 22 GHz, almost ten times the frequency of the microwave oven.

Many semiconductor processing techniques use microwaves to generate plasma for such purposes as reactive ion etching and plasma-enhanced chemical vapor deposition (PECVD).

Microwaves are used in stellarators and tokamak experimental fusion reactors to help break down the gas into a plasma, and heat it to very high temperatures. The frequency is tuned to the cyclotron resonance of the electrons in the magnetic field, anywhere between 2–200 GHz, hence it is often referred to as Electron Cyclotron Resonance Heating (ECRH). The upcoming ITER thermonuclear reactor will use up to 20 MW of 170 GHz microwaves.

Microwaves can be used to transmit power over long distances, and post-World War II research was done to examine possibilities. NASA worked in the 1970s and early 1980s to research the possibilities of using solar power satellite (SPS) systems with large solar arrays that would beam power down to the Earth's surface via microwaves.

Less-than-lethal weaponry exists that uses millimeter waves to heat a thin layer of human skin to an intolerable temperature so as to make the targeted person move away. A two-second burst of the 95 GHz focused beam heats the skin to a temperature of 54 °C (129 °F) at a depth of 0.4 millimetres (1⁄64 in). The United States Air Force and Marines are currently using this type of active denial system in fixed installations.

Spectroscopy

Microwave radiation is used in electron paramagnetic resonance (EPR or ESR) spectroscopy, typically in the X-band region (~9 GHz) in conjunction typically with magnetic fields of 0.3 T. This technique provides information on unpaired electrons in chemical systems, such as free radicals or transition metal ions such as Cu(II). Microwave radiation is also used to perform rotational spectroscopy and can be combined with electrochemistry as in microwave enhanced electrochemistry.

CHAPTER 2

MICROSTRIP PATCH ANTENNA

MICROSTRIP PATCH ANTENNA

Microstrip antenna was first introduced in the 1950s. This concept had to wait for about 20 years to be realized after the development of the printed circuit board (PCB) technology in the 1970s. Since then, microstrip antennas are the most common types of antennas with wide range of applications due to their apparent advantages of light weight, low profile, low cost, planar configuration, easy of conformal, superior portability, suitable for array with the ease of fabrication and integration with microwave monolithic integrate circuits (MMICs).They have been widely engaged for the civilian and military applications such as radio-frequency identification (RFID), broadcast radio, mobile systems, global positioning system (GPS), television, multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, missile guidance, and so on.

2.1 TYPES OF MICROSTRIP ANTENNA:

Microstrip patch antenna:

Microstrip patch antenna is one kind of microstrip antenna and it is most widely chosen among other kinds because of its different shapes. In microstrip patch antenna (MSPA), the patch is generally made of a conducting material such as copper or gold. The microstrip patch antenna can have any shape but, rectangular, circular, triangular and elliptical are some common shapes. The radiating patch and the feed lines are usually photoetched on the dielectric substrate. The basic geometry of a microstrip patch antenna (MPA) consists of a metallic patch which is either printed on a grounded substrate or suspended above a ground plane. The antenna is usually fed either by a coaxial probe or a stripline. In the coaxial case, the center conductor is directly connected to the patch and the outer conductor to the ground. In the stripline case, energy is coupled to the patch in several ways: by direct connection, by proximity coupling, and by aperture coupling. Microstrip patch antennas are of different types such as rectangular microstrip patch antenna, circular microstrip patch antenna, open circuit microstrip radiator, microstrip dipole antenna.

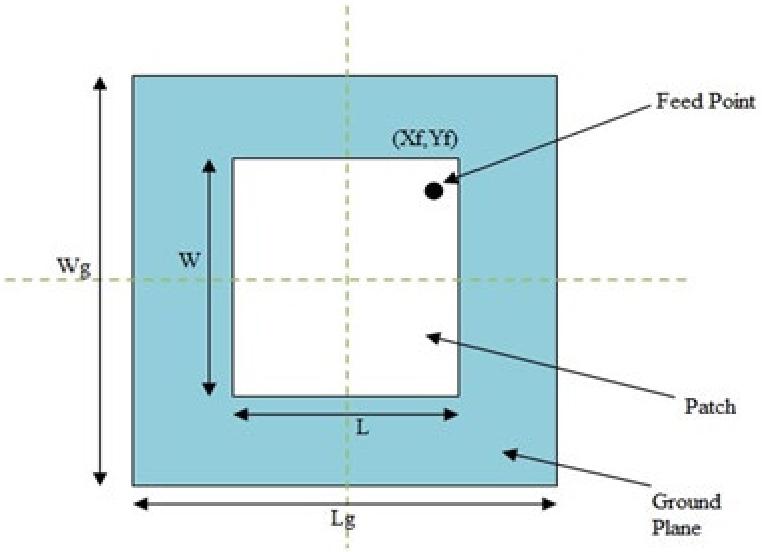


Fig.2.1 microstrip patch antenna

Where; L = Length of the patch

W = Width of the patch

t = Thickness of the substrate

h = Height of dielectric substrate

They are the original type of microstrip antenna described by Howell. The two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable.

Microstrip slot/travelling antenna:

The microstrip patch antenna has a slot either on ground or patch known as microstrip slot antenna. The slot antenna is just an opening created in conductor with a particular dimension such that it radiates electromagnetic waves or receives EM waves. Microstrip slot antenna is simple in structure. It consists of microstrip feed that couples electromagnetic waves through the slot above and slot radiates them. slot antennas are an about λ/2 elongated slot, cut in a conductive plate and excited in the centre. The impedance of the slot can be deduced by using folded slot. Microstrip slot antennas are used in broad range of applications from wireless and satellite communication system to medical system, primarily due to their miniaturization,simplicity, inexpensive, conformability, light weight, low profile, reproducibility and ease of integration with solid state device. By using high permittivity substrate and by different shape of slot we can enhance the gain of antenna The slot antennas can be fed by microstrip line , slot line and coplanar wave guides. Fractal patch antennas find application for wide band of frequency transmission and reception. Decoupling slots are used for dual band of operation and finds applications in WLAN.

2.2 FEEDING TECHNIQUES

We have to give input to microstrip patch antenna. Inorder to get impedance matching we have different feeding techniques. Feeding techniques are classified in two categories. The one is contacting and the other is non-contacting. There are four types of the feeding techniques and they are:

- Inset feed
- Probe feed
- Coupled feed
- Aperture feed

2.2.1 Inset Feed

Previously, the patch antenna was fed at the end as shown here. Since this typically yields a high input impedance, we would like to modify the feed. Since the current is low at the ends of a half-wave patch and increases in magnitude toward the center, the input impedance (Z=V/I) could be reduced if the patch was fed closer to the center. One method of doing this is by using an inset feed (a distance R from the end) as shown in Figure 2.2.

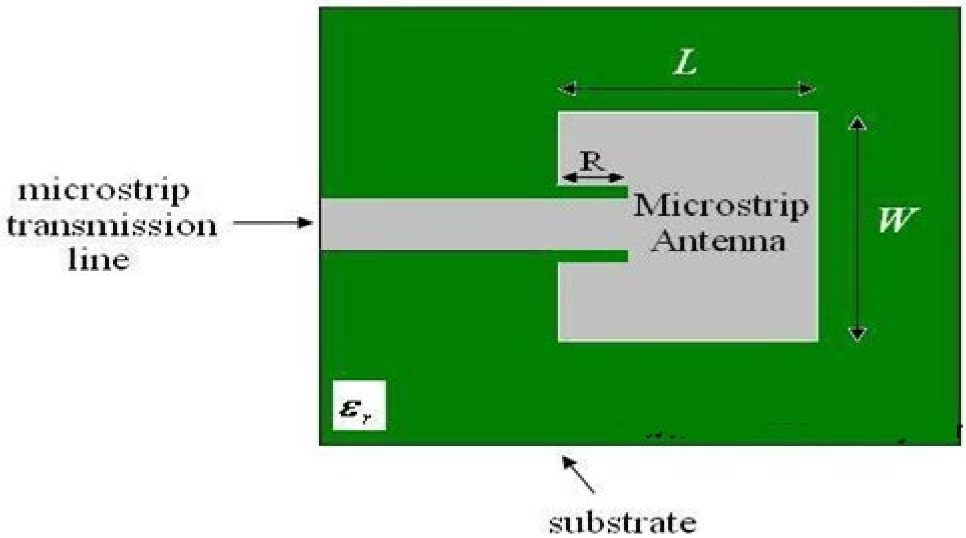


Fig. 2.2 Patch Antenna with an Inset Feed.

Since the current has a sinusoidal distribution, moving in a distance R from the end will increase the current by cos(pi*R/L) - this is just noting that the wavelength is 2*L, and so the phase difference is 2*pi*R/(2*L) = pi*R/L.

The voltage also decreases in magnitude by the same amount that the current increases. Hence, using Z=V/I, the input impedance scales as:

$$Z_{in}(R) = \cos^2\left(\frac{\pi R}{L}\right) Z_{in}(0)$$

In the above equation, Zin(0) is the input impedance if the patch was fed at the end. Hence, by feeding the patch antenna as shown, the input impedance can be decreased. As an example, if R=L/4, then cos(pi*R/L) = cos(pi/4), so that [cos(pi/4)]^2 = 1/2. Hence, a (1/8)-wavelength inset would decrease the input impedance by 50%. This method can be used to tune the input impedance to the desired value.

2.2.2 Feed with a Quarter-Wavelength Transmission Line

The microstrip antenna can also be matched to a transmission line of characteristic impedance Z0 by using a quarter-wavelength transmission line of characteristic impedance Z1 as shown in Figure 2.3.

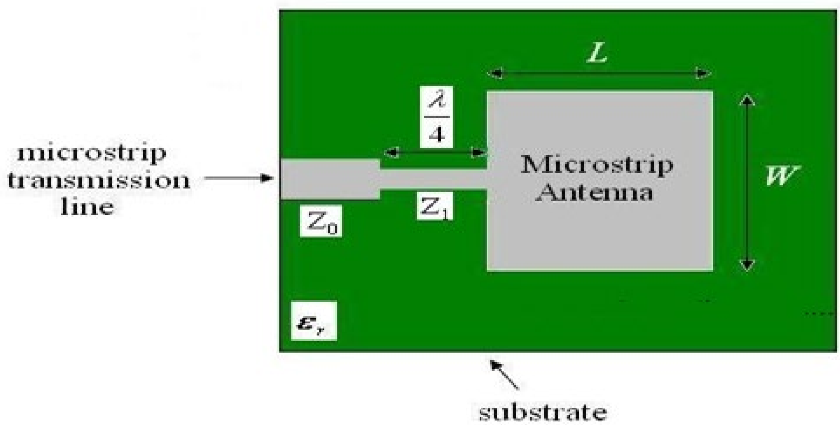


Fig.2.3 Patch antenna with a quarter-wavelength matching section.

$$Z_{in} = Z_0 = \frac{{Z_1}^2}{Z_A}$$

This input impedance Z_{in} can be altered by selection of the Z_1, so that $Z_{IN} = Z_0$ and the antenna is impedance matched. The parameter Z_1 can be altered by changing the width of the quarter-wavelength strip. The wider the strip is, the lower the characteristic impedance (Z_0) is for that section of line.

2.2.3 Coaxial Cable or Probe Feed

Microstrip antenna can also be fed from underneath via a probe as shown in Figure 2.4. The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is extended up to the patch antenna.

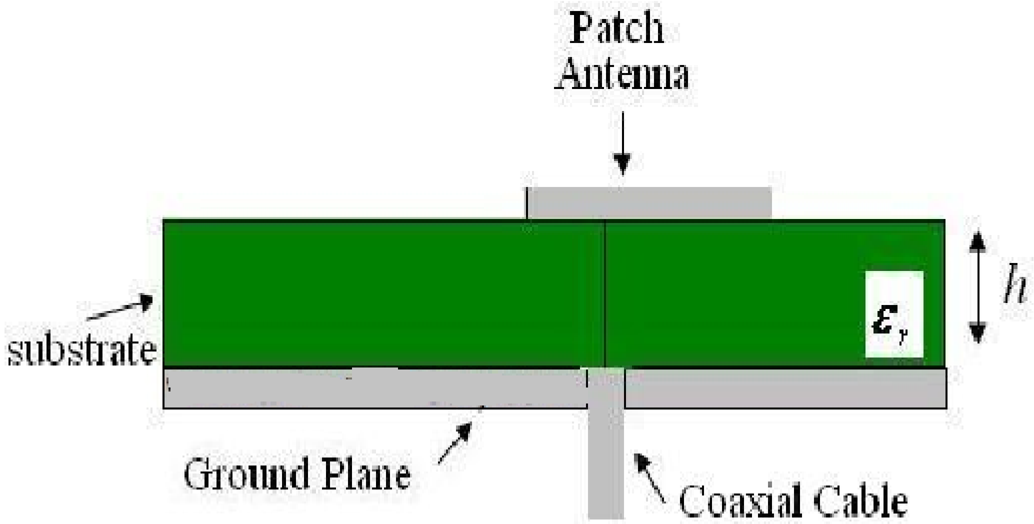


Fig. 2.4 Coaxial cable feed of patch antenna.

The position of the feed can be altered as before (in the same way as the inset feed, above) to control the input impedance.

The coaxial feed introduces an inductance into the feed that may need to be taken into account if the height *h* gets large (an appreciable fraction of a wavelength). In addition, the probe will also radiate, which can lead to radiation in undesirable directions.

2.2.4 Coupled (Indirect) Feeds

The feeds above can be altered such that they do not directly touch the antenna. For instance, the probe feed in Figure 3 can be trimmed such that it does not extend all the way up to the antenna. The inset feed can also be stopped just before the patch antenna, as shown in Figure 2.5.

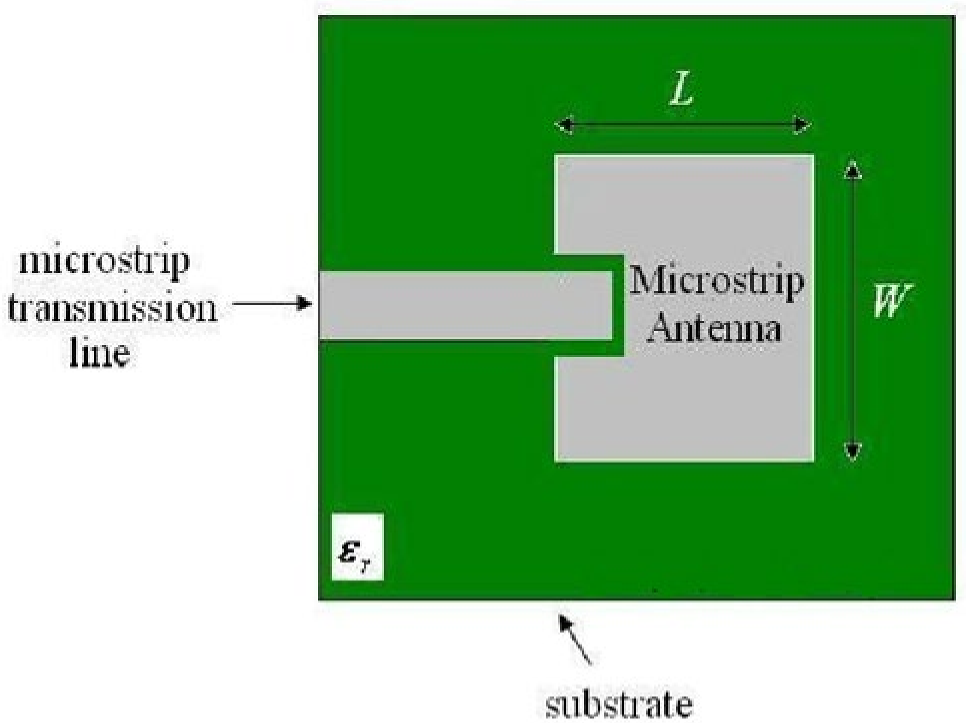


Fig. 2.5 Coupled (indirect) inset feed.

The advantage of the coupled feed is that it adds an extra degree of freedom to the design. The gap introduces a capacitance into the feed that can cancel out the inductance added by the probe feed.

2.2.5 Aperture Feeds

Another method of feeding microstrip antennas is the aperture feed. In this technique, the feed circuitry (transmission line) is shielded from the antenna by a conducting plane with a hole (aperture) to transmit energy to the antenna, as shown in Figure 2.6.

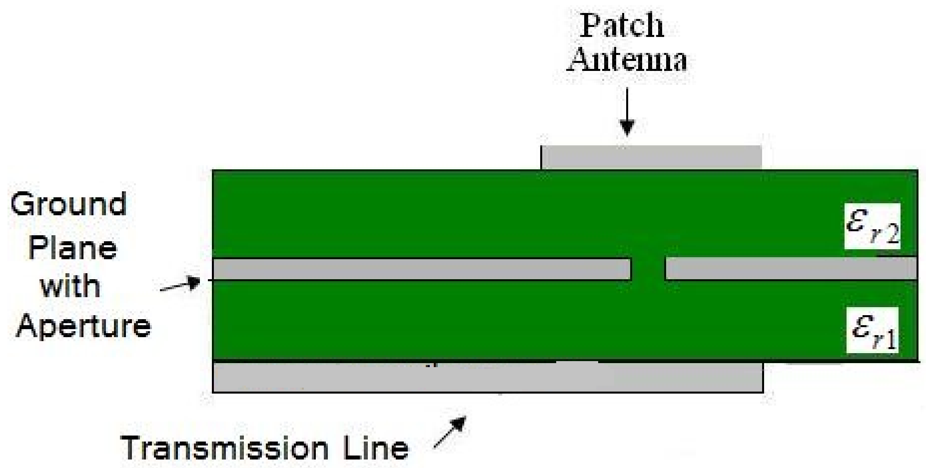


Fig. 2.6 Aperture coupled feed.

The upper substrate can be made with a lower permittivity to produce loosely bound fringing fields, yielding better radiation. The lower substrate can be independently made with a high value of permittivity for tightly coupled fields that don't produce spurious radiation. The disadvantage of this method is increased difficulty in fabrication.

2.3 ADVANTAGES OF MICROSTRIP ANTENNA:

Microstrip antenna have several advantages compared to conventional microwave antennas and therefore many applications over the broad frequency range from 100MHz to 50GHz.some of the principle advantages are:

- Light weight, low volume, low profile planar configurations which can be made conformal.
- These antennas have low scattering cross section.
- They operate at microwave frequencies where traditional antennas are not feasible to be designed.
- This antenna type has smaller size and hence will provide small size end devices.

- The microstrip based antennas are easily etched on any PCB and will also provide easy access for troubleshooting during design and development. This is due to the fact that microstrip pattern is visible and accessible from top. Hence they are easy to fabricate and comfortable on curved parts of the device. Hence it is easy to integrate them with MICs or MMICs.
- As the patch antennas are fed along centerline to symmetry, it minimizes excitation of other undesired modes.
- The microstrip patches of various shapes e.g. rectangular, square, triangular etc. are easily etched.
- They are capable of supporting multiple frequency bands (dual, triple).
- They support dual polarization types viz. linear and circular both.

2.4 APPLICATIONS IN WIRELESS COMMUNICATIONS

The Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this Microstrip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the Microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications. Microstrip patch antenna has several applications. Some of these applications are discussed as below:

Mobile and satellite communication application:

Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems. In case of satellite communication circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed points.

Global Positioning System applications:

Nowadays microstrip patch antennas with substrate having high permittivity sintered material are used for global positioning system. These antennas are circularly polarized, very compact and quite expensive due to its positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicles, aircraft and maritime vessels to find their position accurately.

Radio Frequency Identification (RFID):

RFID uses in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically RFID system is a tag or transponder and a transceiver or reader. Worldwide Interoperability for Microwave Access (WiMax): The IEEE 802.16 standard is known as WiMax. It can reach upto 30 mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMax compliant communication equipment.

Radar Application:

Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas. Rectenna Application: Rectenna is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC power. Rectenna is a combination of four subsystems i.e. Antenna, ore rectification filter, rectifier, post rectification filter. in rectenna application, it is necessary to design antennas with very high directive characteristics to meet the demands of long-distance links. Since the aim is to use the rectenna to transfer DC power through wireless links for a long distance, this can only be accomplished by increasing the electrical size of the antenna.

Telemedicine Application:

In telemedicine application antenna is operating at 2.45 GHz. Wearable microstrip antenna is suitable for Wireless Body Area Network (WBAN). The proposed antenna achieved a higher gain and front to back ratio compared to the other antennas, in addition to the semi directional radiation pattern which is preferred over the omni-directional pattern to overcome unnecessary radiation to the user's body and satisfies the requirement for on-body and off-body applications. A antenna having gain of 6.7 dB and a F/B ratio of 11.7 dB and resonates at 2.45GHz is suitable for telemedicine applications.

Medicinal applications of patch:

It is found that in the treatment of malignant tumors the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should possess light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the Microstrip radiator for inducing hyperthermia was based on the printed dipoles and annular rings which were designed on S-band. And later on the design was based on the circular microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled Microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body. A flexible patch applicator can be seen in the figure below which operates at 430 MHz.

CHAPTER 3

MIMO ANTENNAS

MIMO ANTENNA

Due to its advantages of high data rate and link reliability, the multiple-input multiple-output (MIMO) technology has attracted lots of attention in modern wireless communications. By placing multiple antenna elements at the transmitter and receiver ends of the wireless communication system, MIMO can not only improve the capacity of channel, but also reduce the effects of multi-path fading. It is well known that the channel capacity of a MIMO system increases with the uncorrelated channels. To achieve the maximum channel capacity of MIMO systems, it is necessary to minimize the channel correlation related to the mutual coupling between antenna elements and the spatial correlation. Usually, the mutual coupling between the elements is reduced by etching gaps or loading branches on the ground plane, placing the elements orthogonally, loading parasitic strips and using neutralization lines. On the other hand, the spatial correlation of a MIMO channel is governed by the radiation pattern of the antenna. Therefore, one potential solution to increase the channel capacity is to adopt the pattern reconfigurable antenna to the MIMO system.

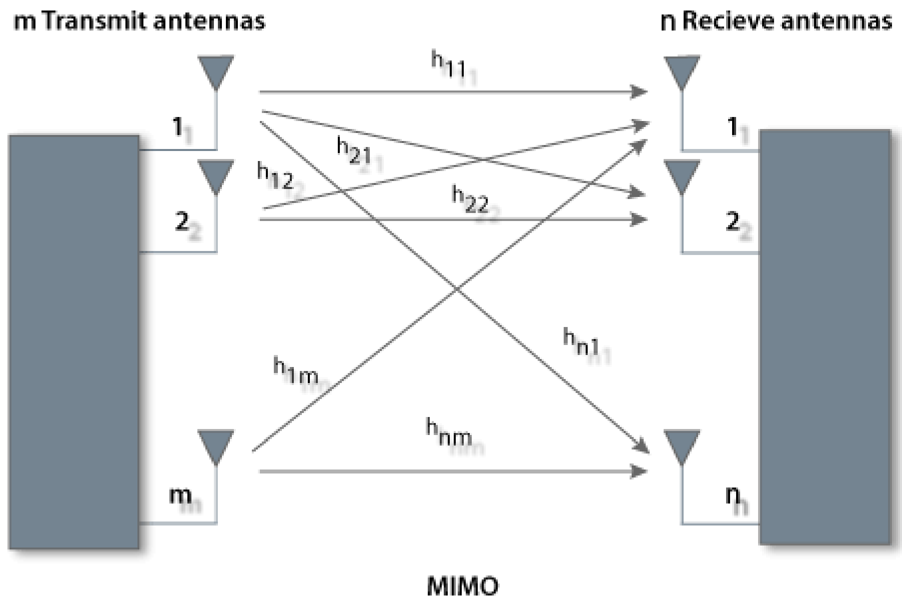


Fig. 3.1 MIMO Antenna

3.1 MIMO DEFINITION

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver)**.** In radio, **multiple-input and multiple-output**, or **MIMO** is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation**.** In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation.

3.2 ADVANTAGES

- The higher data rate can be achieved with the help of multiple antennas and SM(Spatial Multiplexing) Technique. This helps in achieving higher downlink and uplink throughput.
- The systems with MIMO offers high QoS(Quality of Service) with increased spectral efficiency and data rates.
- MIMO based system minimize fading effects seen by the information travelling from transmit to receive end. This is due to various diversity techniques such as time, frequency and space.
- **Beam steering** –This provides two major benefits: First, beam steering can directionally focus the RF energy on a single user, ignoring the remaining space. It is also possible to track the user, reducing interference and boosting signal to noise wherever the user is located. Secondly, beam steering can solve the problem of RF multipath by discovering the best path and targeting RF energy toward that direction. Even when transceivers are stationary, environmental changes affect the many paths that an RF signal can take, so dynamically adjusting and selecting the best path maintains best connectivity and increases range in high interference environments.
- **Increased data capacity**– MIMO can add data carrying capacity without requiring additional bandwidth through ***spatial multiplexing***.
- MIMO offers the advantage of channelizing the space: Each spatial channel can become independent, thus breaking. Although an arbitrary number of spatial channels

is not practical, the ability to increase data rate by 50%, or perhaps double, within the same bandwidth use is a major advantage.

- **Diversity**– Because MIMO offers the ability to distinguish transmission over multiple paths, it is possible to encode the signal more efficiently if the effect of those paths is considered.
- Reliability and low susceptibility for tapping by unauthorized users.
- Increment in SNR and SINR.
- Complete scattering matrix for imaging
- Requires less antenna elements comparing with SAR.
- Lower bit rate error.

3.3 APPLICATIONS

- Fourth Generation (4G) LTE And LTE Advanced define very advanced air interfaces extensively relying on MIMO techniques.
- LTE primarily focuses on single-link MIMO relying on Spatial Multiplexing and space-time coding while LTE-Advanced further extends the design to multi-user MIMO.
- In wireless local area networks (WLAN), the IEEE 802.11n (Wi-Fi), MIMO technology is implemented in the standard using three different techniques: antenna selection, space-time coding and possibly beam forming.
- MIMO is also used in Mobile radio telephone standards such as recent 3GPP and 3GPP2. In 3GPP, High-Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards take MIMO into account. Moreover, to fully support cellular environments .
- MIMO wireless communications architectures and processing techniques can be applied to sensing problems. This is studied in a sub-discipline called MIMO radar.
- MIMO technology can be used in non-wireless communications systems. One example is the home networking standard, which defines a power line communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).
- MIMO Systems and Applications can contribute to the concept of Green Radio Communications, while supporting a reduction in the energy consumption.

- MIMO is used in Ad-Hoc network (A collection of wireless mobile nodes that self-configure to form a network)
- MIMO is used in mobile Wi-Max to increase spectral efficiency.
- MIMO is used in RFID(Radio frequency identification) to increase read reliability using space diversity and to increase read range and read throughput.
- MIMO enables the digital home i.e, MIMO delivers whole home coverage with the speed and reliability to stream multimedia applications.
- MIMO can reliably connect cabled video devices, computer networking devices, broadband connections, phone lines, music, storage devices, etc.
- MIMO is used in Pager, text messaging applications such as blackberry.
- MIMO is used in Narrowband applications where limited bandwidth, lower data rate and higher performance is required
- MIMO is used in power line control and digital multi Tone systems(DMT).

3.4 PERFORMANCE PARAMETERS

These are some of the performance parameters for MIMO antenna.

3.4.1 Envelope correlation co-efficient (ECC)

Envelope Correlation Coefficient tells us how independent two antennas radiation patterns are. So if one antenna was completely horizontally polarized and the other was completely vertically polarized the two antenna would have a correlation of zero. Similarly, if one antenna only radiated energy towards the sky, and the other only radiated towards ground, these antennas would have an ECC of 0. Hence, Envelope Correlation Coefficient takes into account the antennas radiation pattern shape, polarization, and even the relative phase of the fields between the two antennas.

The good value of ECC is 0.5 and higher than 0.5 is considered bad and 0.3 or less is considered pretty good for MIMO applications.

In general, correlation can be decreased via:

- Having distinct polarization – If antenna 1 is vertically polarized and antenna 2 is horizontally polarized they will have low correlation
- Increasing separation between antennas – When antennas are space further apart, their far field patterns become uncorrelated. This is because the relative phase between them is not constant. Hence, even if you used identical

antennas oriented in the same direction, they can have low ECC if they are spaced far enough apart.

- Ensuring direction of peak radiation is distinct – If antennas are closely spaced and have the same orientation, it is possible to lower ECC if the direction of peak radiation can be offset.

It turns out that for highly efficient antennas, the ECC can be completely determined from the antenna isolation. If antennas produce the same radiation pattern, then they will also have tight coupling. This is because antennas have the same properties for transmit and receive, so if antenna 1 is transmitting a radiation pattern, antenna 2 will see this pattern and receive energy proportional to how correlated the antennas.

The formula for ECC in terms of isolation is as follows:

$$\rho_e = \frac{|S_{11}^{\star} S_{12} + S_{21}^{\star} S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}$$

This shows that the envelope Correlation Coefficient can be measured with just a vector network analyzer.

3.4.2 TOTAL ACTIVE REFLECTION COEFFICIENT (TARC):

The total active reflection coefficient (TARC) relates the total incident power to the total outgoing power in an N-port microwave component. The TARC is mainly used for multiple-input multiple-output (MIMO) antenna systems and array antennas, where the outgoing power is unwanted reflected power. The name shows the similarities with the active reflection coefficient, which is used for single elements. The TARC is the square root of the sum of all outgoing powers at the ports, divided by the sum of all incident powers at the ports of an N-port antenna. Similarly to the active reflection coefficient, the TARC is a function of frequency, and it also depends on scan angle and tapering. With this definition We can characterize multi-port antenna's frequency bandwidth and radiation performance. The TARC was successfully utilized for practical antenna design, covering wide range of MIMO applications. Total active reflection coefficient (TARC) contains effect of mutual coupling, which provides a more meaning measure of MIMO efficiency.

The TARC is a real number between zero and one, although it is typically presented in decibel scale. When the value of the TARC is equal to zero, all the delivered power is accepted by the antenna and when it is equal to one, all the delivered is coming back as outgoing power (thus the all power is reflected, but not necessarily in the same port).

As with all reflection coefficients, a small reflection coefficient does not guarantee a high radiation efficiency since the small reflected signal could also be due to losses.

3.4.3 DIVERSITY GAIN (DG):

Diversity gain is the increase in signal-to-interference ratio due to some diversity scheme, or how much the transmission power can be reduced when a diversity scheme is introduced, without a performance loss. Diversity gain is usually expressed in decibels, and sometimes as a power ratio. An example is soft handoff gain. For selection combining N signals are received, and the strongest signal is selected.

Diversity techniques are used to reduce the impact of fading by combining antenna elements that experience different fading. Diversity performance can be characterized by diversity order, which is the number of independently fading antenna elements.

In order to find the **diversity gain**, the power samples of the two branches are combined by selection combining (SC) and maximal ratio combining (MRC). With SC the branch with the highest power for each of the 3750 equal measurement situations is always selected

Diversity gain is proportional to the number of transmit antennas despite the multiplexing of multiple users.

3.4.4 MEAN EFFECTIVE GAIN (MEG):

The mean effective gain (MEG) is one of the most important parameters for the characterization of antennas in wireless channels. An analysis of some fundamental properties of the MEG is provided and corresponding physical interpretations are given. Three points are analyzed in detail: (i) closed-form expressions for MEG in a mixed environment with both stochastic and deterministic components are provided, showing that the MEG can be written as a sum of gains for the deterministic and stochastic components, (ii) it is shown that under some assumptions, the propagation channel and the antenna are equivalent in the sense that the impact of the channel cross-polarization ratio (XPR) and the antenna effective cross-polar discrimination on the MEG are symmetrical, (iii) based on the fact that MEG depends on random variables, such as the XPR and antenna rotations because of user's movements, the average, the minimum and maximum MEG of antennas are defined, respectively.

The mean effective gain (MEG), which is a single parameter describing the impact of the antenna on the link budget, has emerged as the way of characterizing the communication performance of handsets including the antennas in real propagation environments. Currently, mainly due to practical reasons, the total radiated power (TRP) isotropic ally radiated by the mobile terminal is used in the link budget calculations, together with an attenuation factor accounting for the losses in the user's body.

MEG is the average received power that in the Rayleigh fading environment completely defines the first-order statistics of the signal envelope of the small-scale fading. Moreover, MEG is a measure of how a deterministic device, the antenna, performs in the stochastic channel. Finally, MEG is the natural extension of the communication link quality concept introduced by Wheeler for single-path channels, to the more general case of multipath channels. Wheeler defined the communication link quality as the ratio of the received power to the transmitted power and made use of the Friis equation. A more general definition and practical definition of MEG is defined relative a realistic reference antenna such as a half wavelength dipole.

CHAPTER 4

RECONFIGURABLE ANTENNAS

RECONFIGURABLE ANTENNAS

A reconfigurable antenna is an antenna capable of modifying its frequency and radiation properties dynamically, in a controlled and reversible manner.[2] In order to provide a dynamic response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tunable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications of its properties. Reconfigurable antennas differ from smart antennas because the reconfiguration mechanism lies inside the antenna, rather than in an external beam forming network. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements.

4.1 Introduction

Due to the rapid growth of wireless communications, and the high demand for the integration of multiple wireless standards into a single platform, it is highly desirable that the operating frequency, radiation pattern, and polarizations of antennas can be reconfigurable. Reconfigurable antennas modify their operating frequency, impedance bandwidth, polarization, and radiation pattern as per the operating requirements of the host system. They can radiate multiple patterns at different frequencies and polarizations. Obtaining the desired functionality for a reconfigurable antenna and integrating it into a complete system to achieve an efficient and cost-effective solution is a challenging task for antenna designers. Converting an antenna into a reconfigurable device by applying different techniques to change the antenna's internal structure has been challenging. Multiple factors need to be considered such as achieving a good gain, good efficiency, stable radiation pattern, and a good impedance match throughout all the antenna's operation states. To achieve a good gain, stable radiation pattern, and a good impedance throughout the operation states, the reconfigurable antenna designers must focus on the following questions: (i) Which antenna property (e.g. Frequency, radiation pattern, or polarization) must be modified? (ii) How are the radiating elements of the antenna structure reconfigured to achieve the required property? (iii) Which reconfiguration technique can minimize the negative effects on the antenna performances? A reconfigurable antenna provides the same.

A reconfigurable antenna provides the same functionality as that given by multiple single-purpose antennas. This offers saving in costs, weight, volume, and maintenance/repair resources. The following subsections present the definition of the critical parameters for antenna development.

4.2 Classification of Reconfigurable Antennas

Based on the operational properties dynamically adjusted, e.g. frequency of operation, radiation pattern, polarization or a combination of any of these properties, reconfigurable antennas can be classified as follows:

1. **Frequency Reconfigurable Antennas**: These antennas can be developed by two mechanisms: electrical or mechanical. The electrical mechanism employs discrete tuning and continuous tuning methods. Discrete tuning can be achieved by radio frequency (RF) switches and continuous tuning can be achieved by varactor diodes. The mechanical mechanism employs the impedance loading tunable materials such as liquid crystals, meta surface to achieve the frequency reconfiguration.
2. **Pattern Reconfigurable Antennas**: These antennas use movable/rotatable structure like meta surface or including switchable in reactively loaded capacitive elements for the intentional modification of the spherical distribution of radiation pattern.
3. **Polarization Reconfigurable Antennas**: These antennas use switching between different polarizations, i.e. from linear polarization to left hand circular polarization (LHCP) and right hand circular polarization (RHCP), using multi modes structure or meta surface. To reduce the polarization mismatch, losses in portable devices, switching between horizontal, vertical and circular polarizations are needed.
4. **Compound Reconfigurable Antennas**: These antennas use simultaneous tuning of several antenna parameters, e.g. frequency and radiation pattern, for independent reconfiguration of operating frequency, radiation pattern and polarization, via a parasitic pixel layer.

4.3 Types of Reconfigurable Antennas

4.3.1 Electrically Reconfigurable Antennas

Electronic switching components such as RF-MEMS, PIN diodes, varactor diodes or FETs are used in electrically reconfigurable antennas for surface current distributions by altering the antenna radiating structures or radiating edges. The integration of switches into the antenna structure makes it easier for designers to reach the desired reconfigurable functionality. The electrical mechanism employs discrete tuning and continuous tuning methods. These can be achieved by using p-i-n (PIN) diodes, varactor diodes, and field-effect-transistors (FETs). For operating these electronic components in the antenna circuit, direct-current (DC) source and biasing circuits are needed. An electrical reconfigurable antenna thus relies on a DC electrical source and electronic switching components which have an adverse effect on the operation and performance of the antenna.

4.3.2 Optically Reconfigurable Antennas

Optically reconfigurable antenna comes under the class of radiating elements that has the capability of changing the radiation properties with the use of switches which may be optical activation of silicon switches of reactive elements. The metal wires that may interfere with the antenna's radiation characteristics can be eliminated in case of optically controlled devices. The use of additional metallic microstrip or wired biasing lines makes the antenna complex and interference among the required radiation pattern makes the major issues in case of DC controlled microstrip antennas, can be overcome using optically controlled reconfigurable antenna. Resonant Frequency of an antenna can also be achieved by optically controlled switches. It is more preferable than electrical switches as optical control has more advantage over electrical control. Even at high microwave frequencies, the optical signal isolates the controlling optical signal from the controlled microwave signal. Optically controlled devices have the switching speed of 0.1-1 MHz. The reconfiguration in the frequency response from single-band to dual- band can be achieved by the use of photoconductive switches. Frequency agility of the antenna can be implemented by using the optical properties of P3HT (3-hexylthiophene), which is an organic semiconductor polymer that shows semiconductor properties based on organic components. Due to some advantages such as easy fabrication, mechanical flexibility, and tunable optical properties having good spectral overlap with optical wavelength irradiation and high charge-carrier mobility in addition with low band gap, organic semiconductor polymer is more preferred in many applications. Stability and solubility are two important features of organic semiconductor polymer that signifies it is stable in ambient condition and soluble in common organic solvents. The bandgap of P3HT is very small, approximately 1.9 eV and the absorption peak in the visible spectrum ranges from 450 to 600 nm. P3HT can be used as a patch material in case of an antenna that can be optically controlled. When the light source illuminates the organic polymer, then an electron-hole plasma region is induced as in a semiconductor material the photon energy is greater than the bandgap energy. This results a change in the resonant properties of the antenna. When laser light is incident on a semiconductor material such as silicon, gallium arsenide, an optical switch is formed and results in excitation of electrons from valence to conduction band for creating a conduction channel. Optically reconfigurable antenna is a type of antenna where we can achieve antenna reconfiguration by integrating a switch into it. In the absence of biasing lines, optical switches compensate the lossy behaviour and uses laser light for their activation . The main job is related with the switches that can be activated on the antenna structure.

4.3.3 Mechanical/Physically Reconfigurable Antennas

Antennas can also be reconfigured by physically altering the antenna radiating structure. The tuning of the antenna is achieved by a structural modification of the antenna radiating parts . The importance of this technique is that it does not rely on any switch mechanisms, biasing lines or optical fiber /laser diode integration. On the other hand, this technique depends on the limitation of the device to be physically reconfigured.

4.3.4 Reconfigurable Antennas Based on Smart Materials

Antennas are also made reconfigurable through a change in the substrate characteristics by using materials such as liquid crystals, dielectric fluids, ferrites or meta surfaces. The change in the material is achieved by a change in the relative electric permittivity or magnetic permeability. In fact, a liquid crystal is a nonlinear material whose dielectric constant can be changed under different voltage levels, by altering the orientation of the liquid crystal molecules. As for a ferrite material, a static applied electric/magnetic field can change the relative material permittivity/permeability. In meta surfaced antenna, the meta surface is placed directly atop the patch antenna and is rotated. This change the equivalent relative permittivity of the structure by which the resonant frequency of the antenna can be tuned. Frequency tuning can also be achieved using controllable electrical properties materials like barium-strontium-titanate (BST), yttrium iron garnet (YIG), liquid crystals, artificial fluids and dielectric fluids.

4.4 Applications

The advancements in wireless communication applications require new generation of reconfigurable antennas which can adjust to the environments and adopt reconfigurable capabilities as per the surrounding conditions. The reconfigurable antennas are used in cognitive radio system, MIMO systems, satellite communication, biomedical application, military and industrial applications. Some of the applications are presented here.

Frequency Reconfigurable Antenna for a Cognitive Radio System

Due to the rapid growth in the communication system the demand of frequency band increase that leads to scarcity in the RF spectrum. Mainly, the scarcity of RF spectrum arises due to the inefficient spectrum allocation. As the frequency bands are used more, the cognitive radio (CR) comes into account. To overcome the future communication problems cognitive radios are used which improves the spectrum usage efficiently. CR has the capability to use the unoccupied space in a wide frequency range by sensing and detecting the available channels before initializing communication. The development of the CR puts a great challenge to antenna design. In general, the introduction of CR and allocation of spectrum offers new challenges to the frequency reconfigurable antenna as the antenna can tune the frequency without sacrificing the gain and radiation properties. There is one way to overcome this solution that integration of reconfigurable filter to the antenna structure which is known as filtenna which can be integrated at the feeding line or also on the ground plane of the antenna. Most of the reconfiguration mechanisms are integrated into the ultra-wide band (UWB) antenna in order to operate in multiband. It can be done by using some switches such as ideal switches, optical switches, p-i-n diodes, varactor diodes, linear actuators and also stepper motors are used for rotation of patches. The p-i-n diode switches acts as resistances to the flow of current and requires large amount of DC power for its operation to achieve low insertion loss and it uses complex biasing network. Photodetector switches like laser diodes do not require any biasing line to increase its performance, with ome limitations and is operated in fixed bands. The cognitive radio applications can be achieved by a compact filtennas with large tunable frequency bands. In, a planar ultra-wide band monopole antenna with a tunable T-shaped and H-shaped band pass filter helps to achieve tenability where the T-shaped filter is composed of a microstrip resonator with a stub and the H-shaped filter consists of two microstrip resonators connected with each other. The common tuning technique used for both the filters are stub and also a varactor to get miniaturization. As varactor signifies variable capacitance, this implies that with increase in variable capacitance, there is a decrease in the even resonant mode of the resonator without affecting the dominant odd mode. The operating band for T-shaped and H-shaped filtennas are 1.68 and 1.73 GHz. Cognitive Radio covers 32.9% of the frequency tuning range from 4.26 to 5.94 GHz and

36.7% frequency tuning that ranges from 3.85 to 5.58 GHz. A cognitive radio can monitor the channel and idle frequencies of the channel can be determined. Basically, idle frequency deals with the white space or unused space. The idle frequency is very useful in reconfigurable antenna. After identification of the unused space the reconfigurable antenna have the ability to tune its operation according to the requirement and thus increase the efficiency. Basically, the operation of cognitive radio can be represented in a cycle. The cognitive cycle is shown in Figure. The first step involves sensing the antenna and observing the antenna activity. Then the cognitive radio determines the suitable part for communication. After that the communicating antenna achieves the required mode of operation. The last and final step involves the process achieving cognition. This can be done by learning from the previous channel activity. The advantage of the cognitive radio is that it allows the device to self-decide and self-configure. The cognitive radio can self-realize the selected mode of communication.

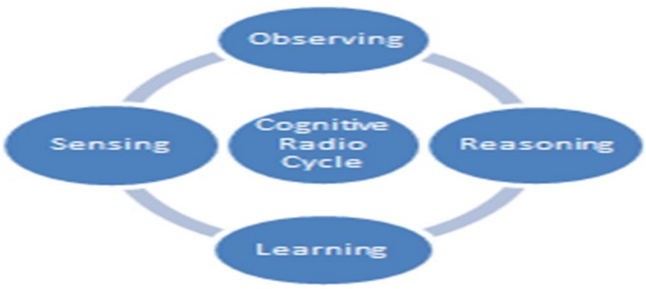


Fig.4.1 Frequency Reconfigurable Antenna for a Cognitive Radio System

Pattern Reconfigurable Antennas for MIMO Systems

Reconfigurable antennas are used to improve the performance of multi-input multi-output (MIMO) wireless communication system. A MIMO system employs multiple antennas at both the transmitter and the receiver front ends to send different information simultaneously, thereby increasing the communication spectral efficiency in a multipath environment. A MIMO system can adjust the modulation level, coding rate, and the transmission signalling schemes according to the varying channel conditions and user’s need. The use of radiation pattern/polarization reconfigurable antennas in a MIMO environment improves the channel reliability, capacity and figure of merit of system performance. Reconfigurable antenna arrays are also an attractive solution for MIMO systems to maintain good communication links, especially for handled devices where space is an important constraint As an example, we present a design and evaluation of pattern reconfigurable antennas for MIMO applications. Using two electrically steerable passive array radiator (ESPAR) antennas, the effect of uniform beam steering on MIMO system performance is evaluated. The MIMO-ESPAR system reduces the bit error rate (BER) in certain pattern combinations and improves the channel capacity. This ESPAR antenna design consists of one driven monopole in the centre, surrounded by a ring of six uniformly spaced parasitic monopoles. A pair of ESPAR antennas is fabricated on one substrate. The ESPAR patterns and beam angles with respect to test environment is shown in Figure. MIMO based antenna has several advantages such as it ensures a reliable communication between end users and increases the efficiency of spectrum.

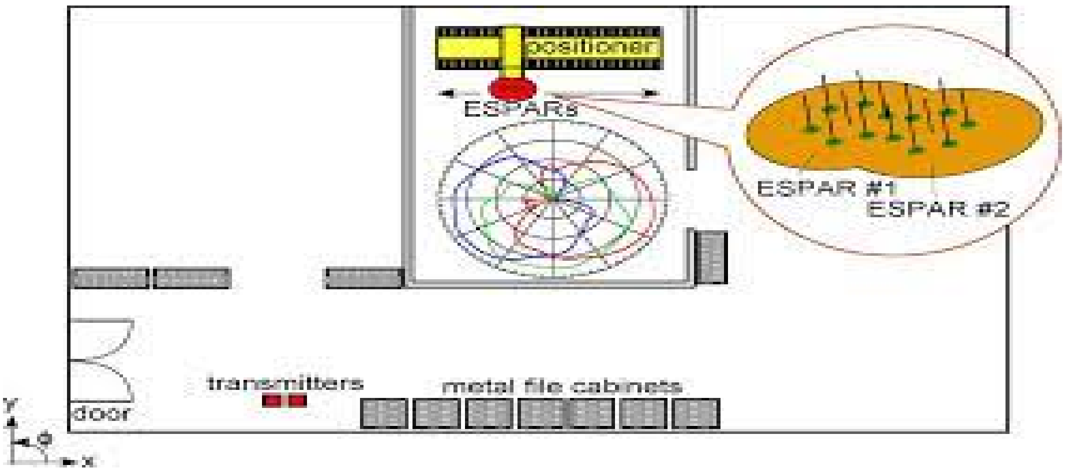


Fig.4.2 Pattern Reconfigurable Antennas for MIMO Systems

Reconfigurable Antennas for Satellite Application

The data back bone of the future in metropolitan areas is not much developed, can be overcome by satellite communication system. Recently, Google announced the Loon project that involves the flying balloons used to provide the internet connection everywhere and to every person throughout the world. The flying balloon costs less but its life time is very short whereas the satellite costs more with life time of many years. Satellite antenna requires a steerable antenna pattern. It is used for the alignment of the antenna of low-earth-orbit satellite towards a geo-stationary satellite. The different applications for beam-steering and forming antennas on a satellite platform is shown in Figure . In case of satellites and balloons both the nodes should be pointed to each other to form a backbone network and provides a networking platform for the users. Figure shows the communication between low-earth orbit with the station i.e. geo-stationary orbit or on ground. Beam steering is required at the nodes of the antenna. It helps in adapting the position of the antenna beam relative to them. It shows low weight and less complexity. Loon project shows highly meshed network that gives high complexity. Mechanical alignment of a conventional antenna is one of the implementation of antenna system with adjustable beam. It is bulk and heavy with drawbacks in terms of cost and reliability. The microwave components such as phase shifters tunable filters can overcome the above problems. These components can be realized as: (1) electronically tuned systems (2) mechanically tuned systems (3) functional materials. Basically, the used technologies are based on semiconductors as it has a high-volume market and shows acceptable performance. Liquid crystals are well known for its display technology shows a mesophase between the solid crystalline and liquid phase. The LC is in a viscous liquid phase showing anisotropic material properties. Liquid crystal can be used for inter-satellite links from LEO to GEO. The LC layer thickness reduces with increase in the frequency, results in a much faster tuning of phase shifter.

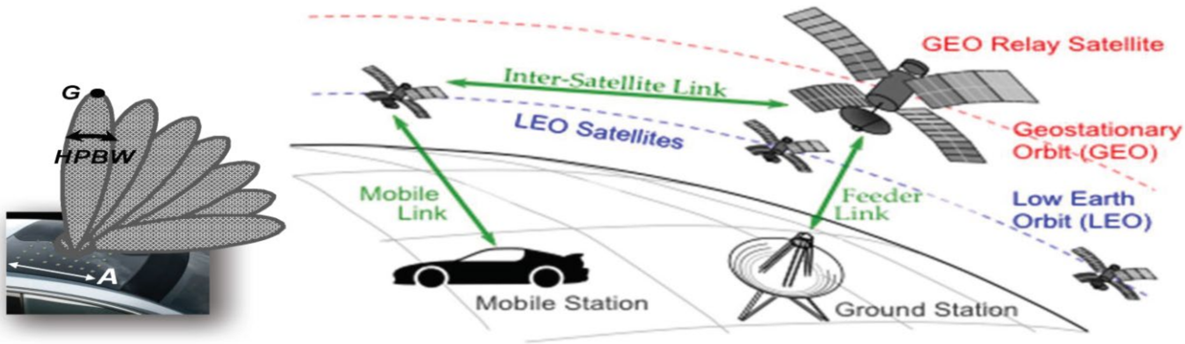


Fig.4.3 Reconfigurable Antennas for Satellite Application

Reconfigurable Antennas for Biomedical

Linear or circular polarization reconfigurable antennas have many advantages which are enhancement of communication channel, reduction of the multipath interference and polarization coding. In most of the cases, the operating bandwidths are narrow like in case of microstrip patch radiators. Basically, the polarization mismatch occurs in transmitter which can be compensated by polarization diversity in receiver antenna, the deterioration in the signal transmission would be affected by the multi-path distortion and polarization mismatching. Polarization diversity is mostly used in the antennas to improve the quality of the wireless links. One of the most important examples is body-centric wireless communication system (BWCS) as shown in Figure. Inductive link (short range) and far-field Radio-frequency link (long range) is two important approaches of BWCS. The inductive link uses coils and it has advantages of long distance communication and high data rate for information transformation. On-body and Off- body are two wireless devices which are operated in linear mode and can be realized by PIFAs. Due to free movement of human body the orientation of these devices are arbitrary, which may cause multi-path fading. To overcome multi-path fading and polarization mismatch, the external receiver antenna requires features like polarization diversity. The polarization reconfigurability can be achieved using PIN diodes in multi slot antenna. In the multi-slot antenna, pin diodes are used to switch between four polarization modes which are 0^0, ± 45^0 and 90^0 at frequencies between 2.2 GHz and 2.6 GHz. The design results in broadside radiation with wide bandwidth and characterized with stable gain for all the modes. In , the antenna with polarization diversity minimizes polarization mismatching and induces capability of compensating the effect of multipath distortion, which will able to scan different polarizations. One possible scenario of body-centric wireless communication system (BWCS) with polarization reconfigurable antenna is shown in Figure. A patient has several on body and implantable devices to communicate with an external antenna or receiver which is connected with a data processing equipment. Medical doctors can receive various real time information of the patient through body centric wireless communication system (BWCS) network.

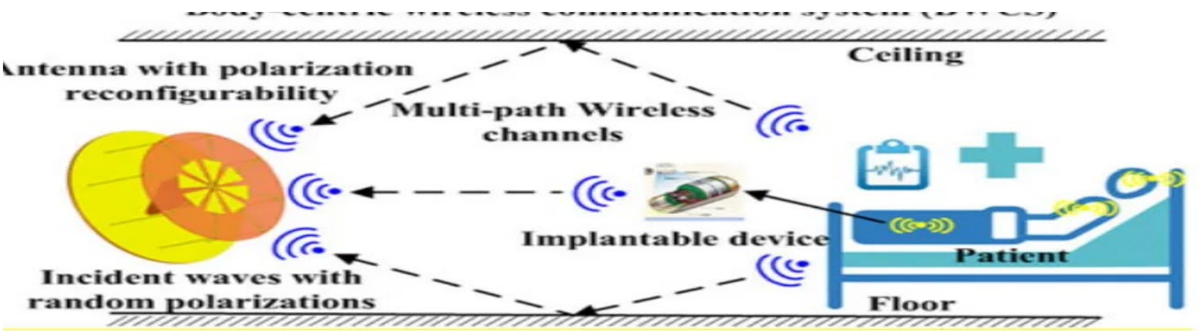


Fig.4.4 Reconfigurable Antennas for Biomedical

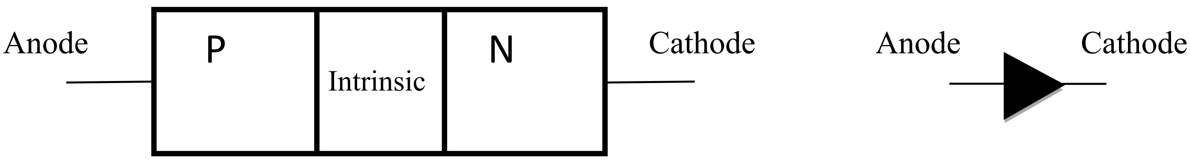
4.5 Advantages of Reconfigurable Antennas

Reconfigurable antennas can support more than one wireless standard, and deliver the same performance as that of multiple antennas. Hence, reconfigurable antennas have the following advantages: (i) low cost, low volume, simple integration, and good isolation between different wireless standards, (ii) low front-end processing that means no need for front-end filtering and good out-of-band rejection, (iii) best candidate for software-defined radios which can adapt to new surroundings, and (iv) change functionality as per the mission changes, act as a single element or as an array, providing narrow band or wideband as per the requirements. The cost of the reconfigurable antennas can be linked to different parameters as summarized below: (i) design of the biasing network for activation/deactivation of the elements in the antenna structure, (ii) required power consumption of active components, (iii) generation of harmonics and intermodulation products, and (iv) fast tuning of the antenna radiation characteristics to assure a correct functioning of the system.

4.6 PIN diode switching technique

Reconfigurability in the antenna can be obtained by incorporating a variety of switching techniques as discussed. In this project, the PIN diode switching technique is employed to get the reconfigurability among the bands. PIN diode offers fast switching speed i.e., 120nsec compared to other techniques.

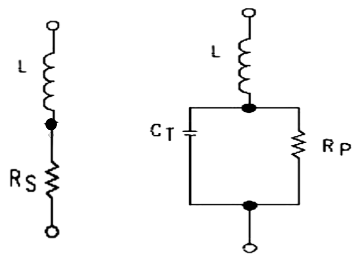
A PIN diode is formed by doping a silicon wafer with P and N semiconductor materials in the opposite side. The region between P type and N type i.e., the un-doped region is called the intrinsic region. The pictorial and symbolic representation of the PIN diode is shown in Figure 4.5.1.



(a) (b)

Fig.4.5 PIN diode (a) pictorial representation (b) symbolic representation

The symbolic representation of the PIN diode shown in Figure.4.5.1 (b) looks like the normal PN diode representation. At low frequencies, PIN diode works as normal PN diode and at high frequencies (microwave frequencies), it works as a variable resistor.



(a) (b)

Fig.4.6 PIN diode equivalent circuit model (a) ON state (b) OFF state

The equivalent model of forward (ON) and reverse bias (OFF) conditions of a PIN diode at high frequencies.

The diode forward condition is modeled with the series connection of the resistor (R_S) and the inductor (L). In reverse bias condition, it is the combination of the inductor (L) in series with the parallel connection of the resistor (R_P) and capacitor (C_T).

In this project, BAR64-02 pin diode is used. It is operated in the range of 1MHz to 6GHz. In forward bias, the diode allows current flow by offering a low resistance of R_S=2.1Ω. In reverse bias, it offers high resistance value i.e., R_P=3.1kΩ and does not allow the current flow. In this case, it behaves as a parallel plate capacitor with capacitance value C_T=0.23pF. The value of packaging inductance is the same for both cases and its value is L=0.6nH.

The incorporation of diodes in the antenna design affects the antenna's performance. The downshift in resonant frequency is due to the capacitance of the diode and the reduction in gain is due to the OFF state resistance of the diode.

To obtain the proper functioning of the antenna, the C value must be reduced. In this project, the capacitance value of the diode is reduced from 0.23pF to 0.02pF and it may be obtained by varying the biasing voltage.

4.6.1. HFSS modelling of PIN diode

In High Frequency Structure Simulator (HFSS) software, the diode functioning is represented with the help of 2-D rectangular boxes. The symbolic representation of diode in HFSS and the corresponding ON & OFF states.

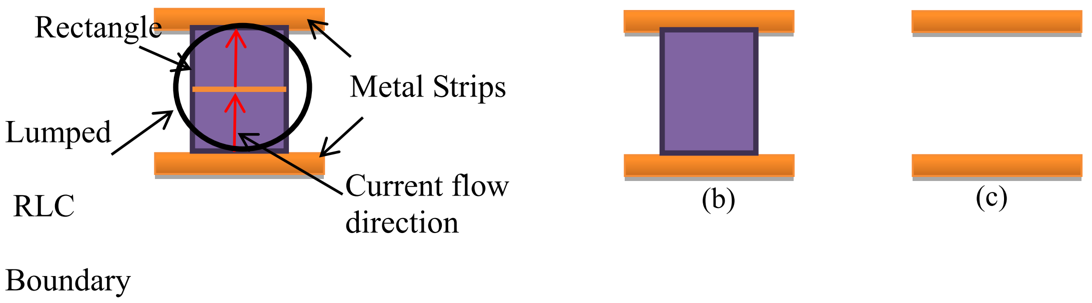
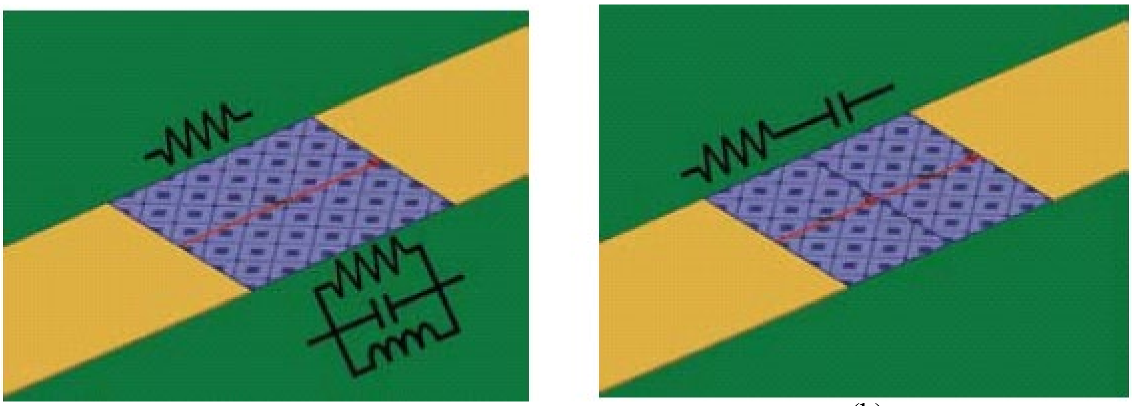


Fig 4.7 HFSS modelling of PIN diode (a) symbolic representation (b) ON state (c) OFF state

Usually, diodes are placed in the slot structures or in the gaps between the metal contacts. Here the diode is represented by using two rectangles and the current flow direction is represented by an arrow mark from one metal contact to another metal contact. The R, L, and C values to the rectangles are assigned using lumped RLC boundary and the detailed description of the lumped RLC boundary is discussed in next section. When the diode is in ON condition, it allows the current flow from one metal contact to another metal contact. In OFF condition, the diode does not allow the current flow and works as a parallel plate capacitor.

4.6.2. Lumped RLC boundary

Lumped RLC boundary represents the parallel connection of R, L, and C values and it is used to assign the R, L, and C values to the rectangles to make them as diode equivalents.

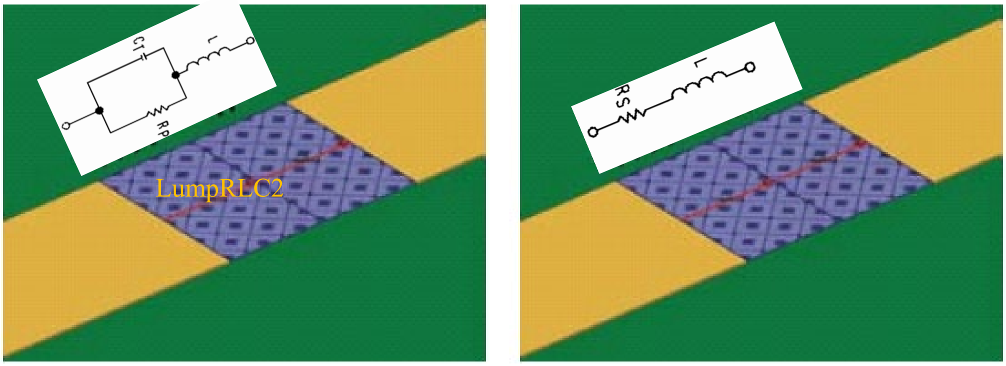


(a) (b)

Fig.4.8 (a) Representation of single resistor or parallel combination of lumped components (b) Representation of a series combination of lumped components

A single value or parallel combination of lumped elements is obtained by using a single rectangle as shown in Figure 4.6.2 (a) where as to obtain a series combination of any lumped elements; two rectangles must be required as shown in Figure 4.6.2 (b).

In this project work, two rectangles are used to form the diode equivalent as shown in Figure 4.6.3. The value assignment to the one rectangle is common for both ON and OFF cases where as the value assignment to the other rectangle is varied in ON and OFF cases.



(a)(a) (b)

Fig.4.9 Representation of diode (a) OFF state (b)ON state

To one rectangle, inductance value (L=0.6nH) is assigned and it is common for both cases i.e., ON and OFF.

Fig.4.10 Display of lumped RLC boundary for assigning L value

To the other rectangle, parallel combination of C_T and R_P (C_T=0.15pF and R_P=5kΩ) are assigned in OFF case and R_S value (R_S=3Ω) is assigned in ON case

CHAPTER 5
ANTENNA DESIGN AND RESULTS

ANTENNA DESIGN AND RESULTS

This chapter describes the analysis of different modes of the single element rectangular micro strip patch antenna (RMSA). This chapter also describes about multiple-input-multiple-output MIMO RMSA. The performance of the antenna is analyzed by measuring various parameters viz., reflection coefficient, voltage standing wave ratio (VSWR), and current distribution, etc.

5.1 SINGLE ELEMENT RECTANGULAR MICROSTRIP PATCH ANTENNA AT 2.45GHz

5.1.1 DESIGN EQUATIONS OF RECTANGULAR MICRO STRIP ANTENNA

This section explains the design evolution of the proposed single element Rectangular micro strip patch antenna. The following Equations are used to design the proposed antenna.

The width of the patch (W)

$$W = \frac{C}{2f_0\sqrt{\frac{\epsilon_r + 1}{2}}} \text{……………………. (1)}$$

Where,

C is velocity of light

f_0 is Resonant Frequency

ε_r is Relative Dielectric Constant

Effective dielectric constant (ε_{eff})

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{1 + 12\frac{h}{W}} \text{…………………….. (2)}$$

h is height of the substrate

Effective length (L_{eff})

$$L_{eff} = \frac{C}{2f_0\sqrt{\epsilon_{eff}}} \text{………………………… (3)}$$

Length Extension (ΔL)

$$\Delta L = 0.412h\,\frac{(\epsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \text{………………… (4)}$$

Actual length of patch (L):

$$L = L_{eff} - 2\Delta L \text{……………………… (5)}$$

5.1.2 SINGLE ELEMENT RMSA

The Single Element Rectangular Micro strip Patch Antenna using FR-4 Epoxy as a substrate with dielectric constant ϵ_r=4.4 and thickness h=1.6mm is designed. The operating frequency of the antenna is considered as 2.45GHz. The desired specifications considered for the design are S_{11}< -10dB & VSWR< 2. The design is shown in the below fig.5.1.

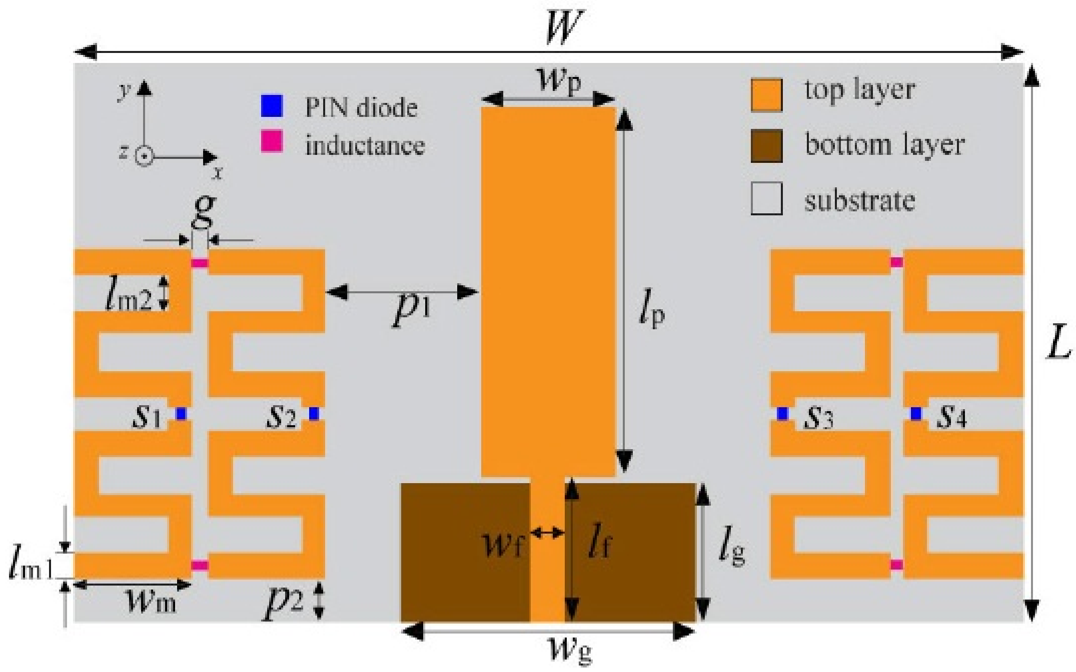


Fig.5.1 Configuration of single antenna element

The dimensions of the Single element rectangular micro strip patch antenna are mentioned in below table 5.1.

Table 5.1 Parameters of a single element patch antenna

PARAMETER	VALUE (in mm)
Length of the Substrate (L)	80
Width of the Substrate (W)	45
Length of the Ground (l_g)	11
Width of the Ground (w_p)	25
Length of the Patch (l_p)	30
Width of the Patch (w_g)	11.5
Length of the Feed (l_f)	12
Width of the Feed (w_f)	2.98

w_m	10
l_{m1}	2
l_{m2}	3
p_1	13.26
p_2	3
g	1

5.1.3 DESIGN LAYOUT

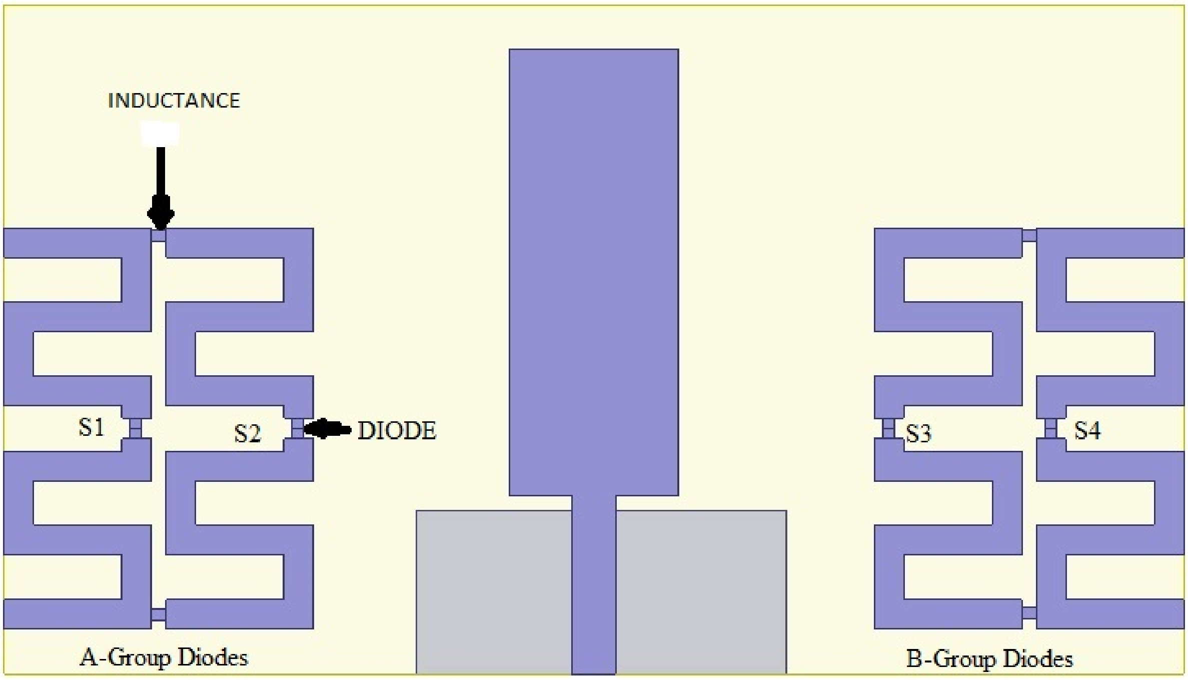


Fig 5.2 Design Layout of Rectangular Micro Strip Antenna

Fig.5.2 shows the geometry of the antenna element. It is composed of a rectangular monopole and two sets of parasitic meandering strips symmetrically placed on both sides of the monopole.

Four PIN diodes S1, S2, S3 and S4 are inserted in the parasitic strips, and the complexity of the bias circuit is reduced through mounting two 12nH inductors between the adjacent strips. By changing the bias voltages of the diodes, the set of parasitic strips operates as a director or a reflector, and thus the radiation pattern of the element can be reconfigured.

S1 and S2 Diodes are considered as A-group Diodes and S3 and S4 Diodes are considered as B-group Diodes.

The antenna element is designed to operate at 2.45 GHz and simulated with HFSS.

5.2 MODES OF RMSA ANTENNA

By varying the conditions of the diodes based on their switching conditions we have 3 modes.

The nature of the 3 modes are described in the below table 5.2

Table 5.2 Operation of modes of antenna element

MODE	A-group Diodes(s1,s2)	B-group Diodes(s3,s4)
Mode 1	Off	Off
Mode 2	On	Off
Mode 3	Off	On

5.2.1 Mode 1

As described in the table 5.2, in mode 1 both A-group Diodes and B-group Diodes are in off conditions.

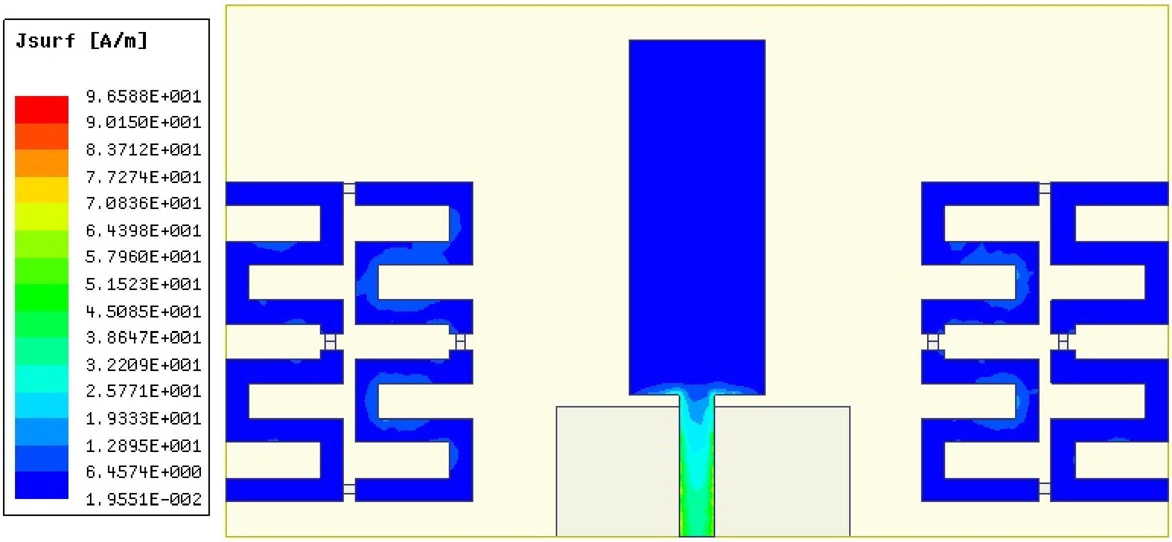


Fig.5.3 Current Distribution in Mode 1 Operation

As the both group diodes are off, antenna radiates in both direction and no radiated energy is absorbed by the parasitic strips, So the radiation pattern will be bi-directional.

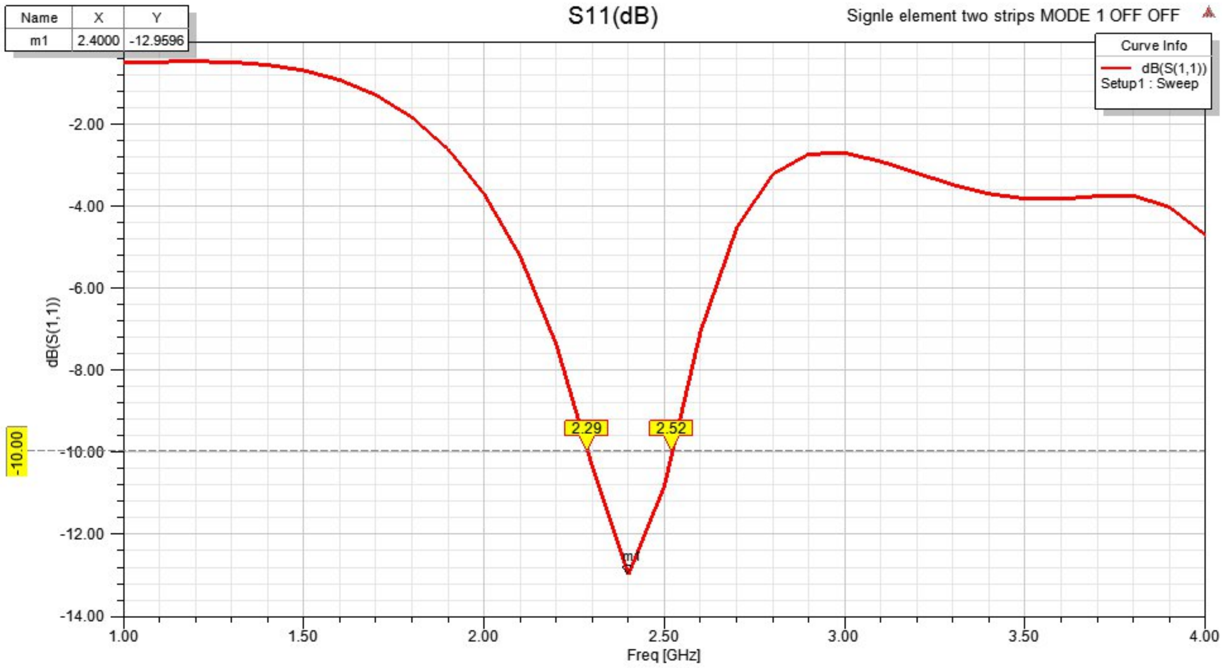


Fig.5.4 Reflection Coefficient of Mode 1

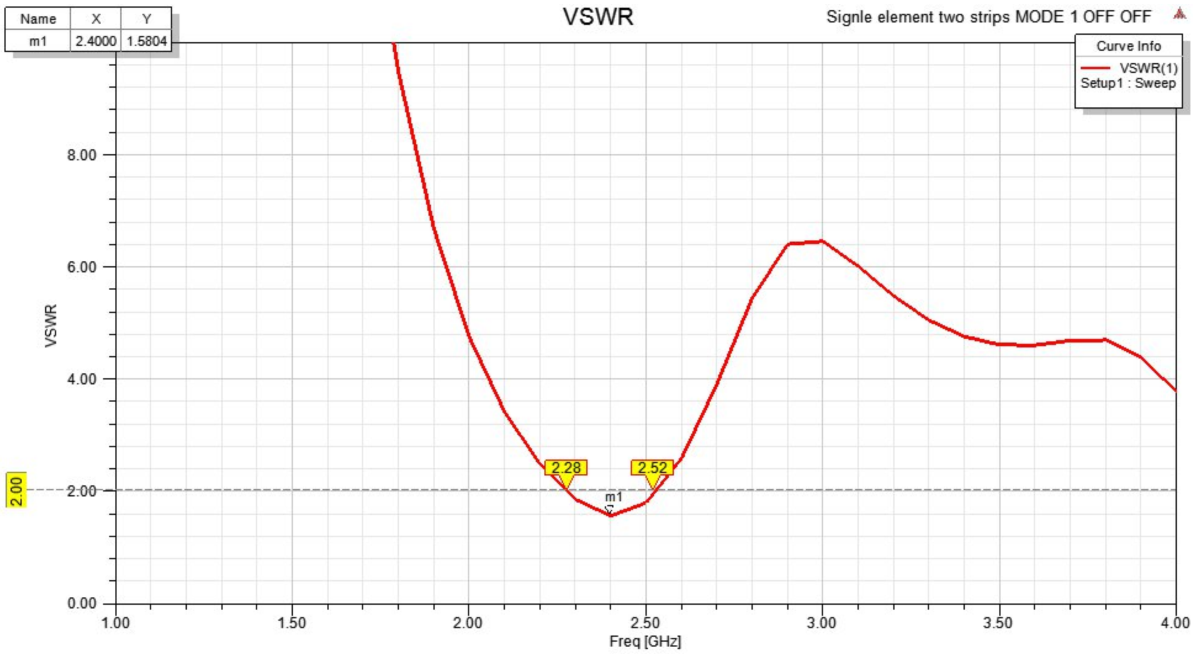


Fig.5.5 VSWR of Mode 1

As shown in the above fig.5.4 and fig.5.5 the reflection coefficient value of Mode 1 is S_{11}= -12.9596 dB which is less than -10 dB and the VSWR value is equal to 1.5804 which is less than 2 at 2.45GHz . So both VSWR and reflection coefficient are obtained in the desired range.

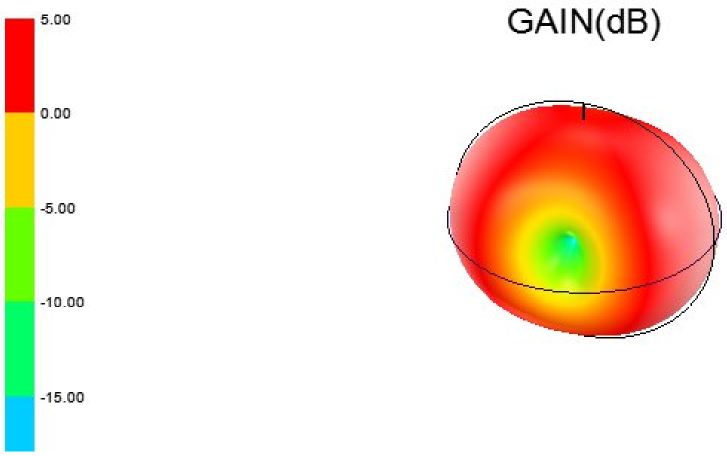


Fig.5.6 Gain of Antenna in Mode 1

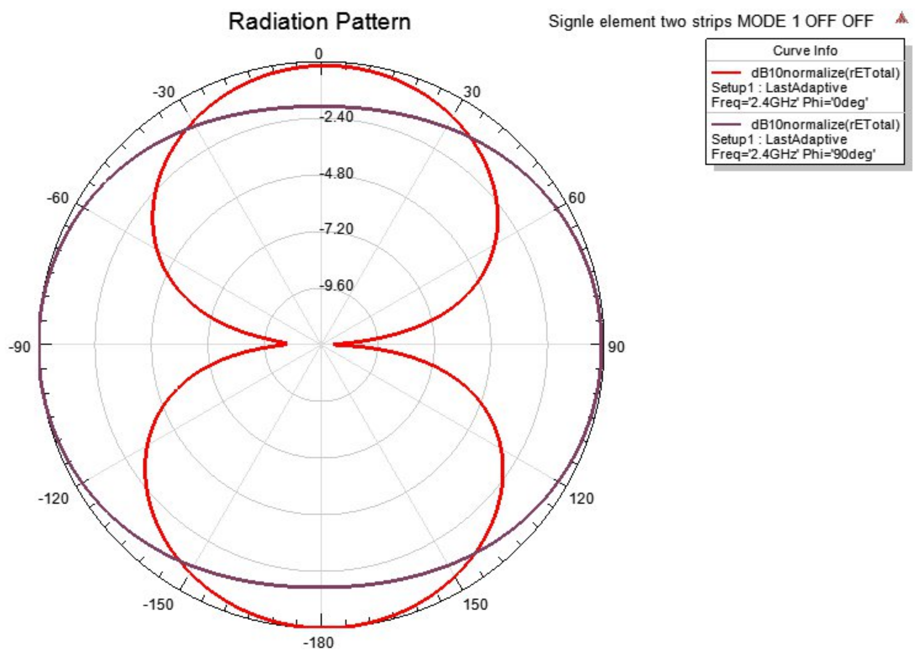


Fig.5.7 Radiation pattern in Mode 1

As Shown in the gain plot, the radiation obtained is bi-directional and in radiation pattern plot, In E-field where phi=0° the maximum radiation is in the direction of 0° and -180° and In H-field where phi=90° the maximum radiation is in the direction of 90° and -90°.

5.2.2 MODE 2

As described in the table 5.2, in mode 2 A-group Diodes are on and B-group Diodes are in off condition.

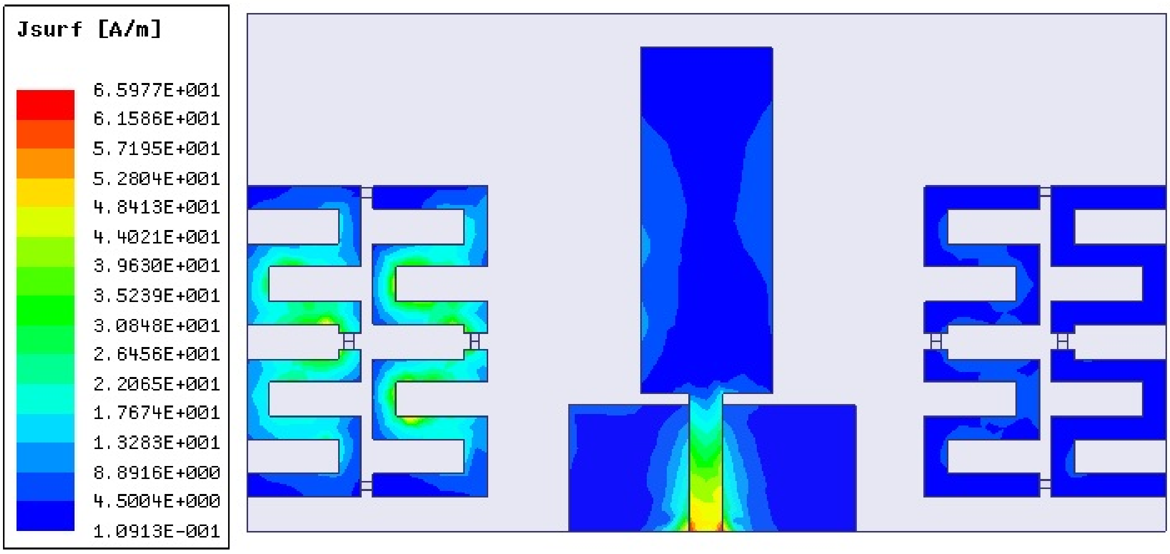


Fig.5.8 Current Distribution in Mode 2 Operation

In mode 2, the current is mainly concentrated on the left strips as the diodes on the left are on. So the radiation released is absorbed by the strips on the left side leaving the direction of radiation pattern one side only i.e. to the right side.

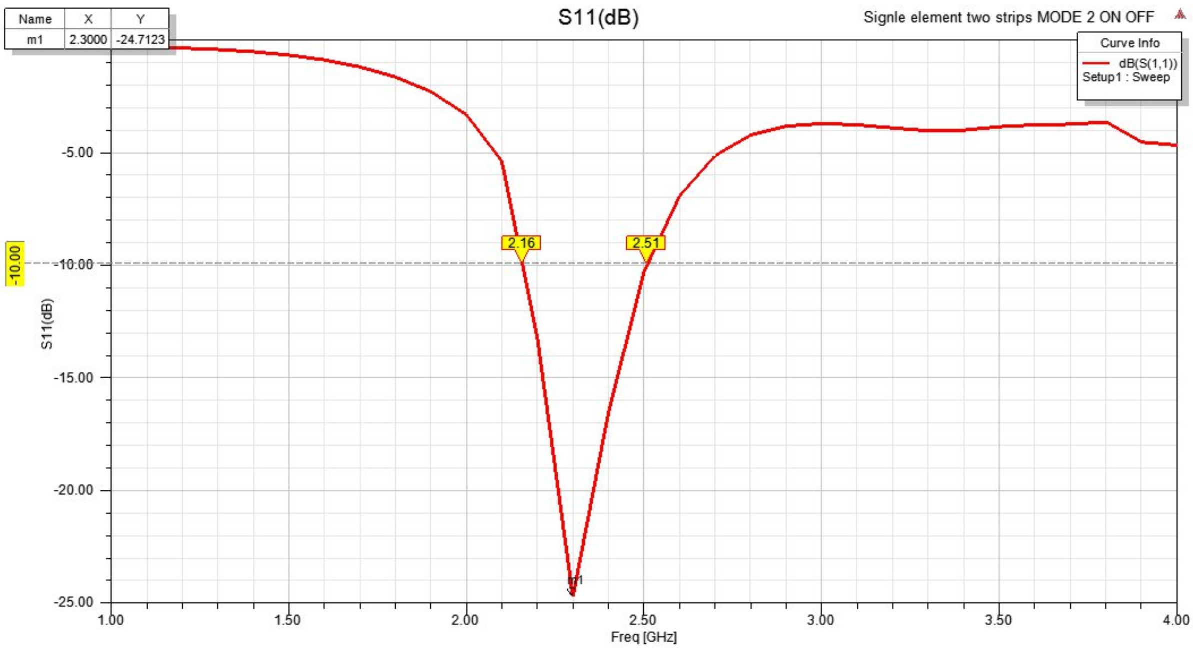


Fig.5.9 Reflection Coefficient of Mode 2

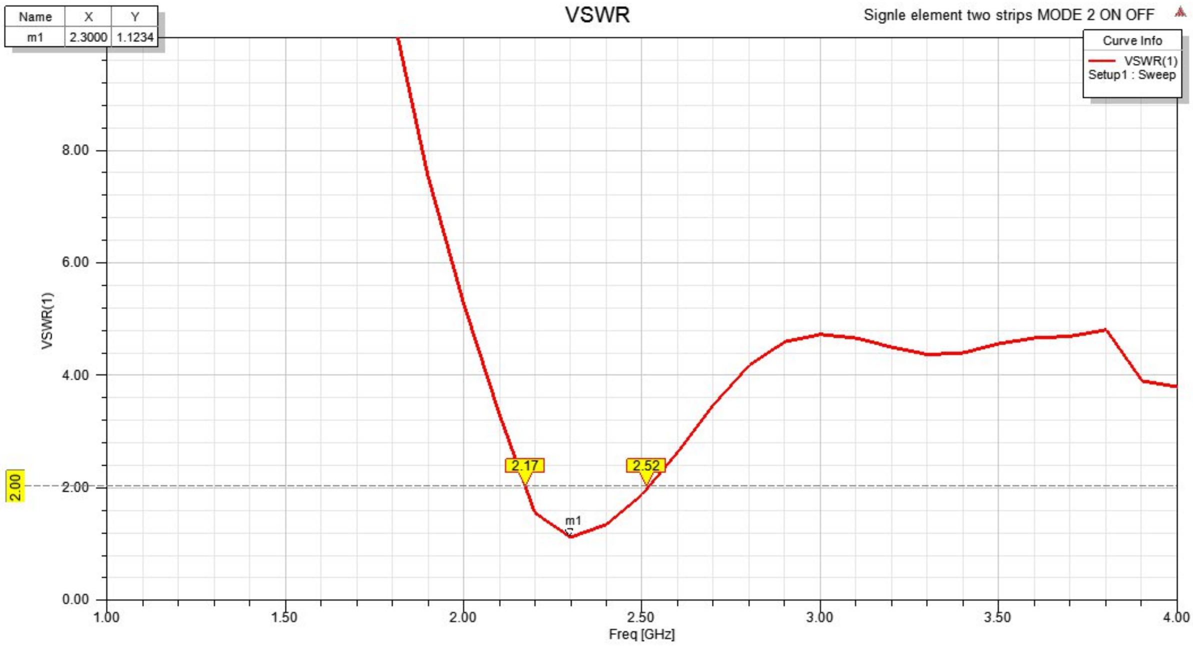


Fig.5.10 VSWR of Mode 2

As shown in the above fig.5.9 and fig 5.10, the reflection coefficient value of Mode 2 is S_{11}= -24.7123 dB which is less than -10 dB and the VSWR value is equal to 1.1234 which is less than 2 at 2.45GHz . So both VSWR and reflection coefficient are obtained in the desired range.

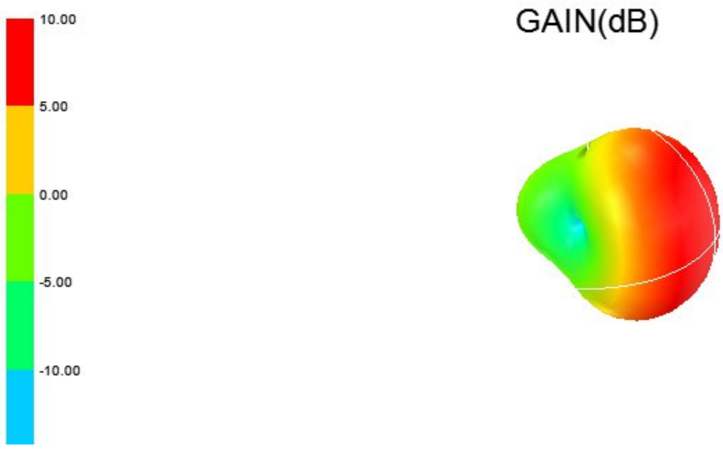


Fig.5.11 Gain of Antenna in Mode 2

As shown in the above fig.5.11, the radiation pattern is on single direction and is maximum in the positive x- direction

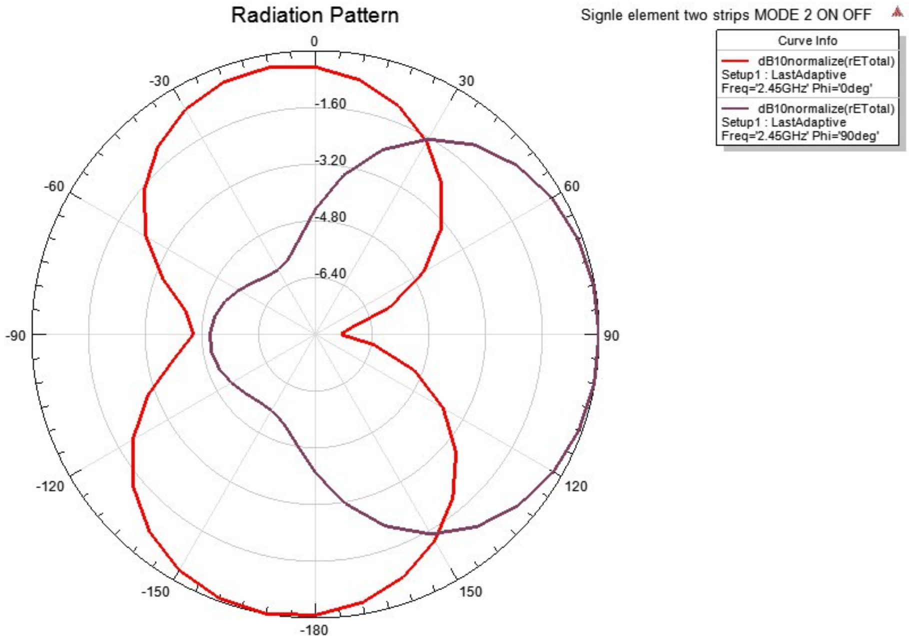


Fig.5.12 Radiation pattern in Mode 2

In radiation pattern plot, In E-field where phi=0° the maximum radiation is in the direction of -170° and In H-field where phi=90° the maximum radiation is in the direction of 90°.

5.2.3 MODE 3

As described in the table 5.2, in mode 3 A-group Diodes are off and B-group Diodes are in on.

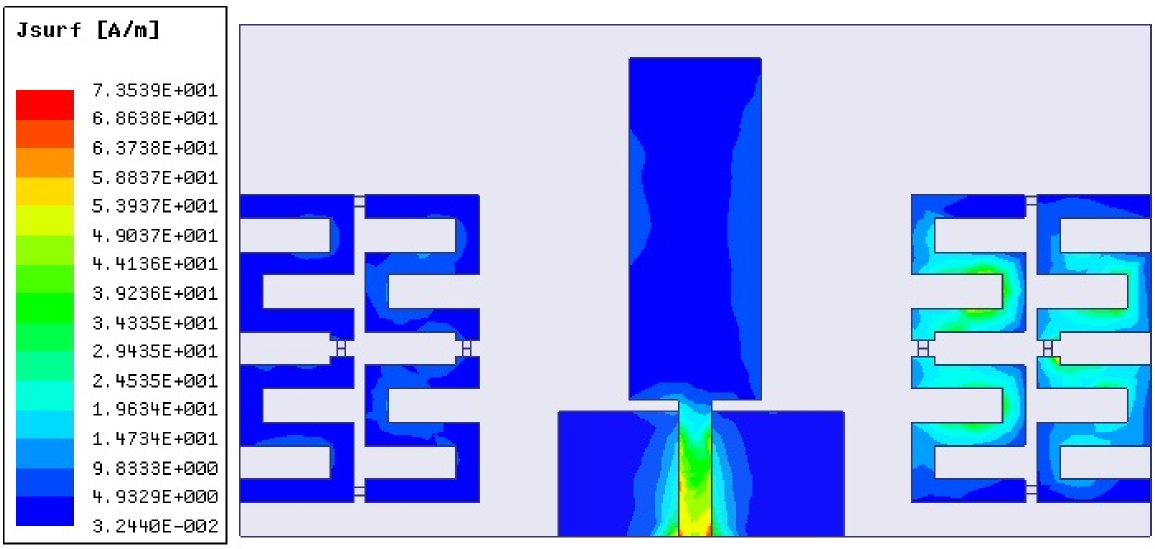


Fig.5.13 Current Distribution in Mode 3 Operation

Mode 3 works opposite to Mode 2. The radiation released is absorbed by the strips placed on the right side of the patch as the strips are in on condition and there is no absorption of radiation in the left side, So current flows only on the right side strips.

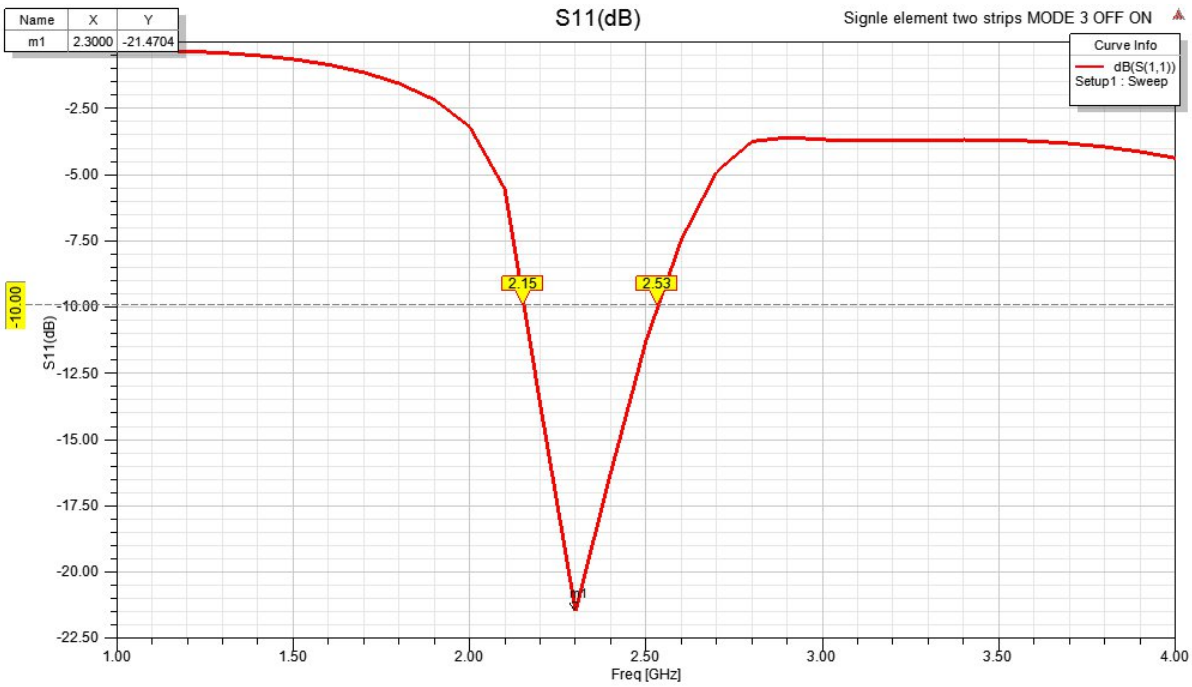


Fig.5.14 Reflection Coefficient of Mode 3

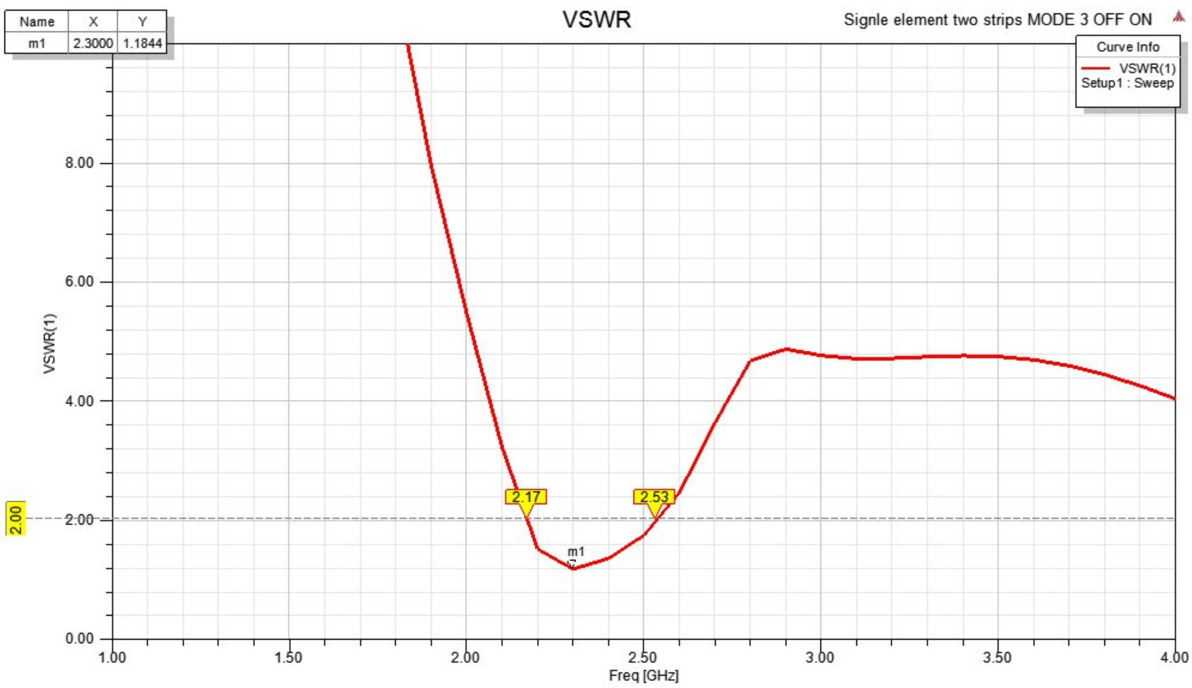


Fig.5.15 VSWR of Mode 3

As shown in the above fig.5.14 and fig 5.15, the reflection coefficient value of Mode 3 is S_{11}= -21.4704 dB which is less than -10 dB and the VSWR value is equal to 1.1844 which is less than 2 at 2.45GHz . So both VSWR and reflection coefficient are obtained in the desired range.

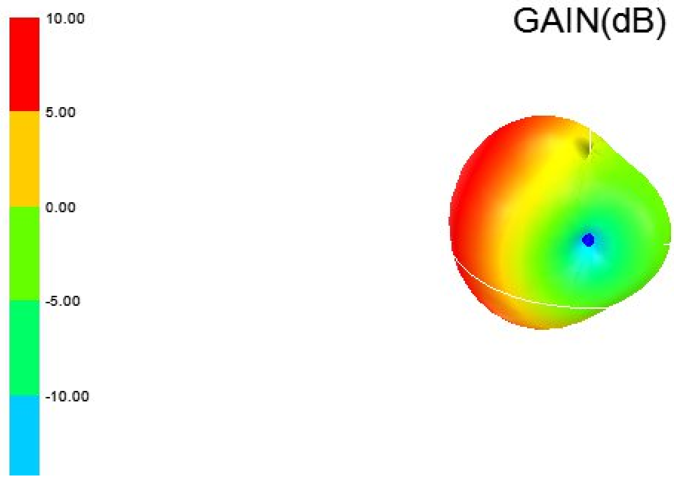


Fig.5.16 Gain of Antenna in Mode 3

As shown in the above figure 5.16 the radiation pattern is on single direction and is maximum in the negative x- direction

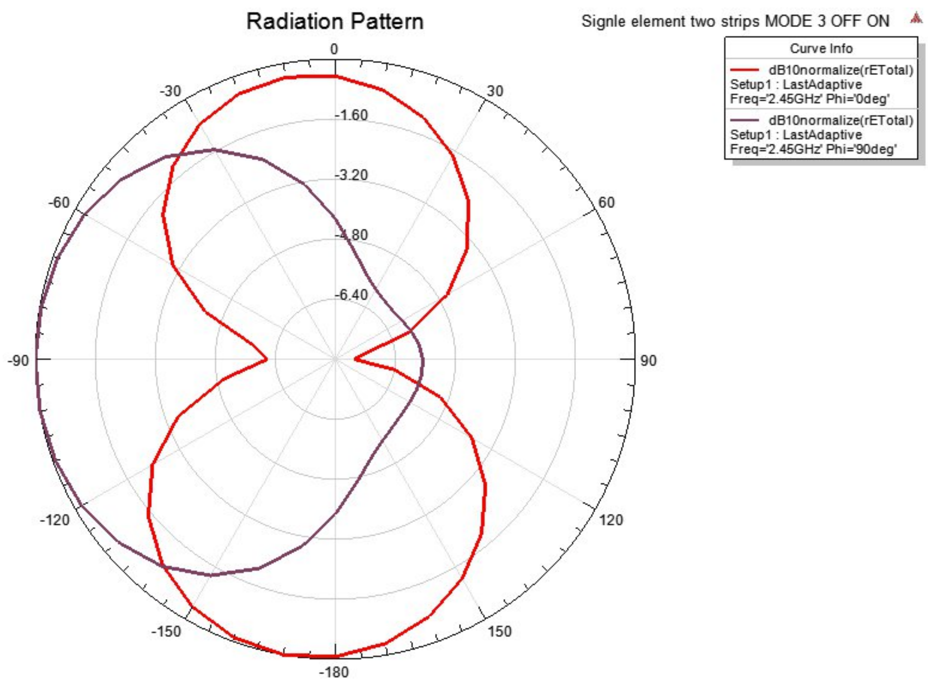


Fig.5.17 Radiation pattern in Mode 3

In radiation pattern plot, In E-field where phi=0° the maximum radiation is in the direction of -170° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

5.2.4 PARAMETRIC STUDY

5.2.4.1 Effect of length of parasitic strips on Reflection Coefficient

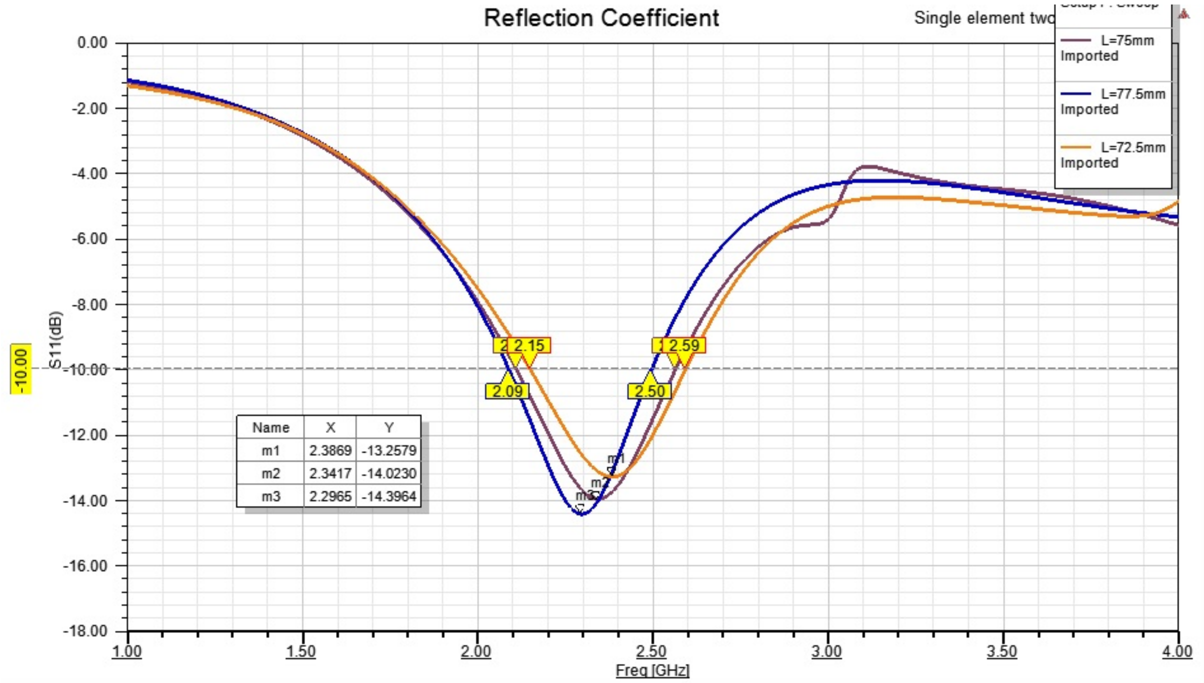


Fig.5.18 Effect of length of parasitic strips on Reflection coefficient

The above figure shows the comparison between strips of different lengths. Lengths of the parasitic strips have a significant effect on the performance of the antenna element. Three parasitic strips of lengths 72.5 mm, 75 mm and 77.5 mm are taken into consideration and their respective reflection coefficients are -13.2759 dB, --14.0230 dB and -14.3964dB. It is clear that the impedance matching becomes better as the length of strips increases. The front-to-back ratio is more when the parasitic strip length is 75 mm.

5.2.4.2 Comparison of Reflection Coefficient of 3 Modes

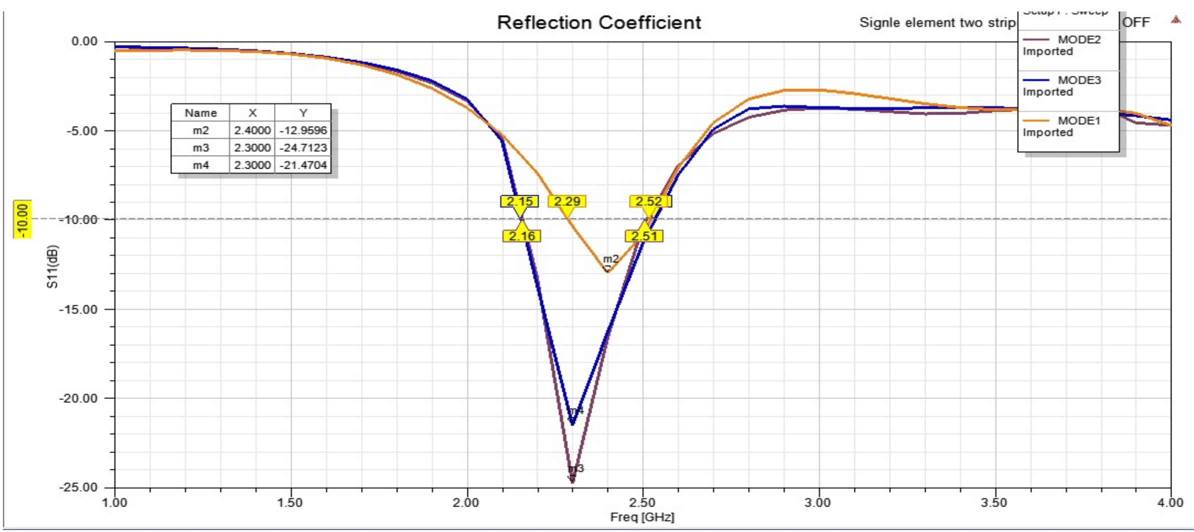


Fig.5.19 Comparison of Reflection Coefficient of 3 Modes

As shown in the above figure 5.19, the 3 modes of an antenna are radiating nearly at same frequency i.e. at 2.45GHz which is same as the desired frequency selected.

5.3 TWO ELEMENT MIMO ANTENNA

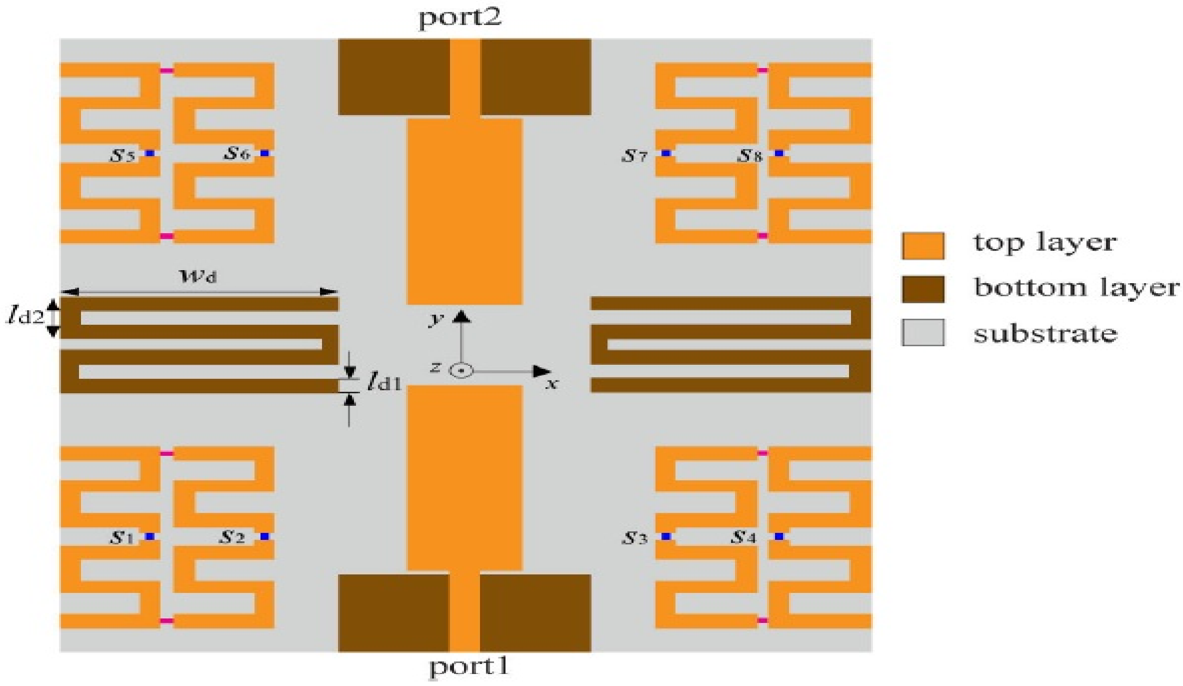


Fig.5.20 Configuration of two element MIMO antenna

Fig.5.20 shows the configuration of the pattern reconfigurable MIMO antenna. It consists of two antenna elements, which are arranged opposite to each other along the y-axis. Two decoupling strips are introduced between the ground planes to improve the isolation.

The parameters of the elements are the same as those of the element in Fig.5.1. The distance between the patches of the elements is 12 mm. The optimal size of the decoupling strips is as follows: l_{d1}=2 mm, l_{d2}=6 mm and w_d=28 mm, respectively.

5.3.1 DESIGN LAYOUT WITH AND WITHOUT DECOUPLING STRIPS

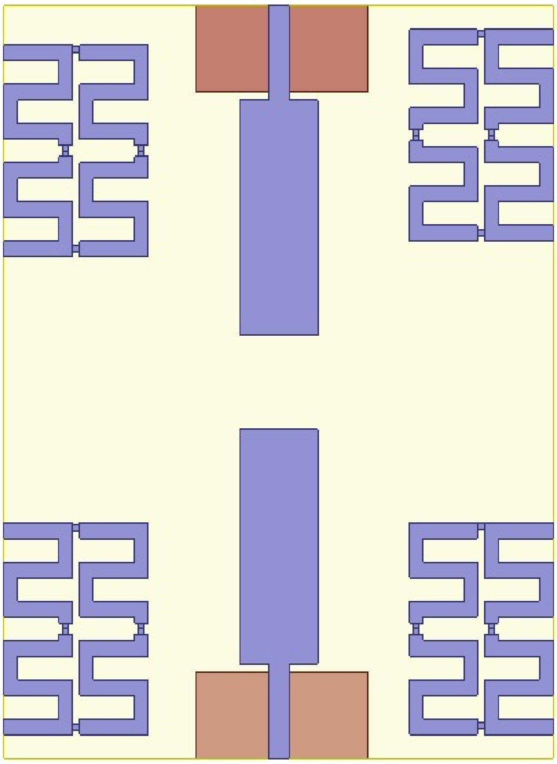


Fig.5.21 2 Element MIMO antenna without Decoupling strips

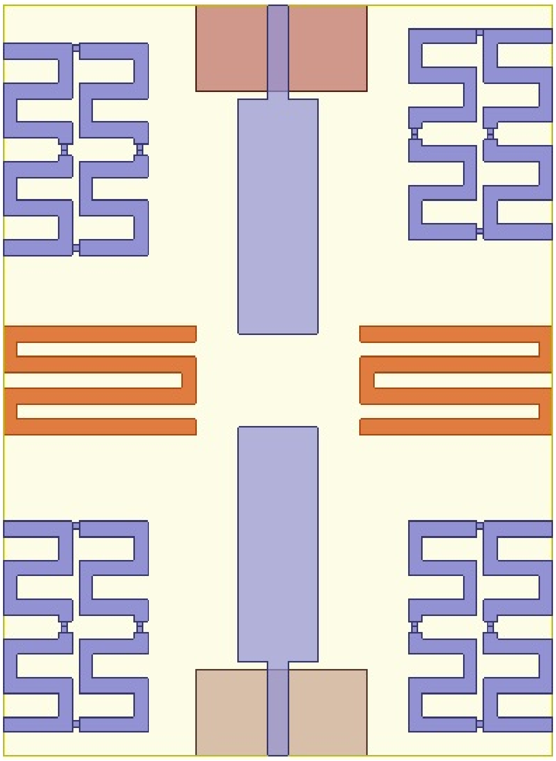


Fig.5.22 2 Element MIMO antenna with Decoupling strips

As shown in the above fig.5.21 and fig.5.22, Decoupling strips were introduced to absorb the radiation and current released by one such that it has no effect on the other antenna parameters. It also improves the parameters like ECC, TARC and S-Parameter with Decoupling when compared to antenna without Decoupling.

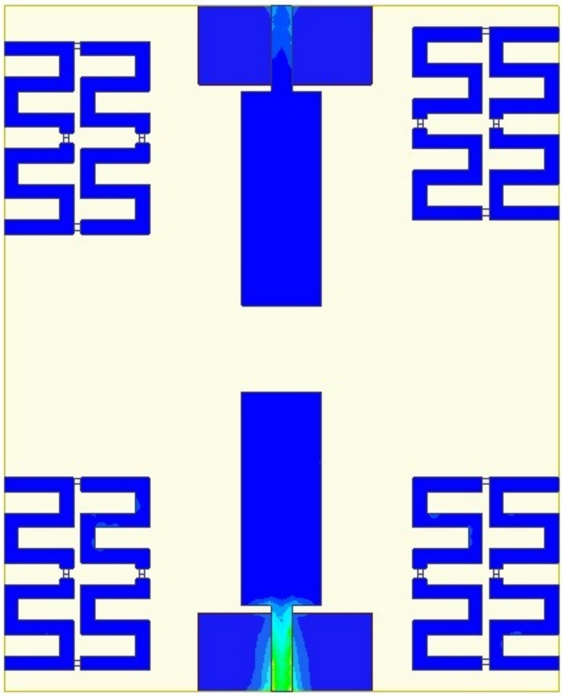


Fig.5.23 Current Distribution without Decoupling Strips

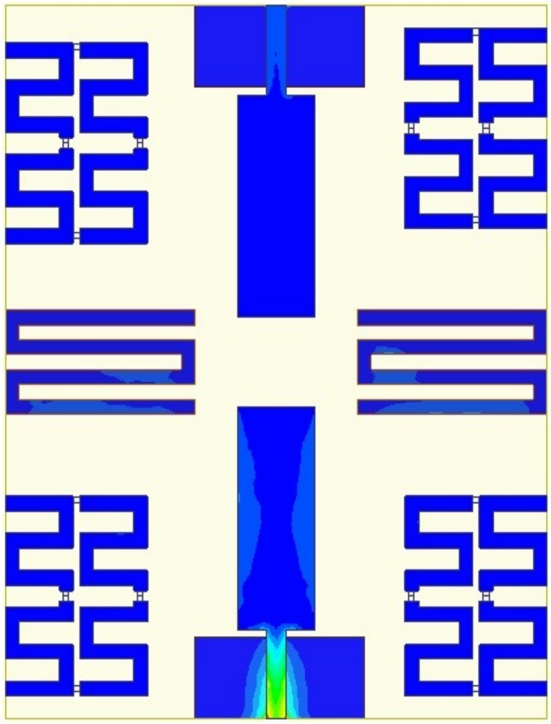


Fig.5.24 Current Distribution with Decoupling Strips

The above fig.5.23 and fig.5.24 shows the current Distribution of the antenna elements without Decoupling strips and with decoupling strips.

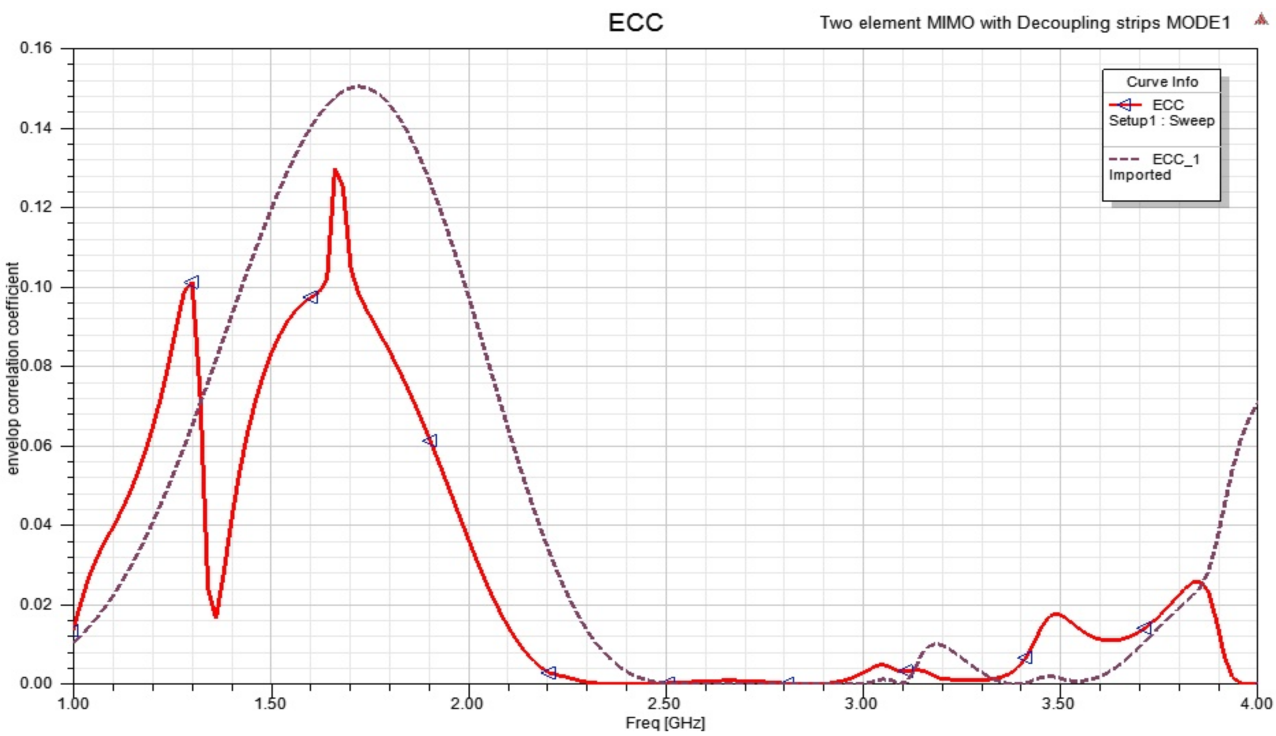


Fig.5.25 ECC Comparison For the Effect of Decoupling strips

Envelope Correlation Coefficient tells us how independent two antennas' radiation patterns are. Envelope Correlation Coefficient takes into account the antennas' radiation pattern shape, polarization, and even the relative phase of the fields between the two antennas.

ECC= (mag(conjg(S(1,1))*S(1,2)+conjg(S(2,1))*S(2,2)))^2/((1-mag(S(1,1))^2-mag(S(2,1))^2)*(1-mag(S(2,2))^2-mag(S(1,2))^2))

Generally, ECC value of 0.5 is ok, higher than 0.5 is considered bad, and 0.3 or less is considered pretty well for MIMO applications.

So as shown in fig.5.25, Solid line represents MIMO antenna with Decoupling Strips which has an ECC value ideally equal to 0 at 2.45GHz frequency which is good and less when compared to the MIMO antenna without Decoupling Strips.

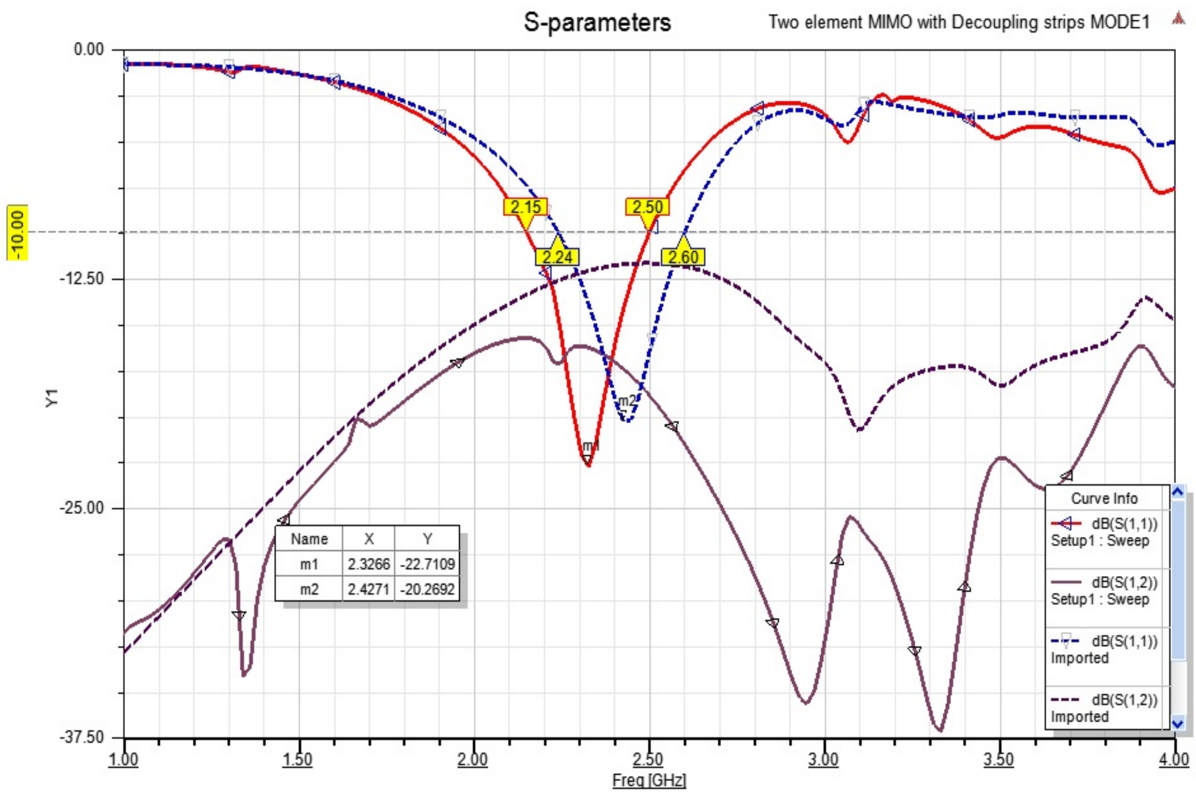


Fig.5.26 S-Parameters Comparison for the Effect of Decoupling strips

S-parameters describe the input-output relationship between in an electrical system. S-Parameters are used to describe the relationship between different ports**.** As shown in above fig.5.26, S_{11}, S_{12} value with decoupling is less than S_{11}, S_{12} value without Decoupling.

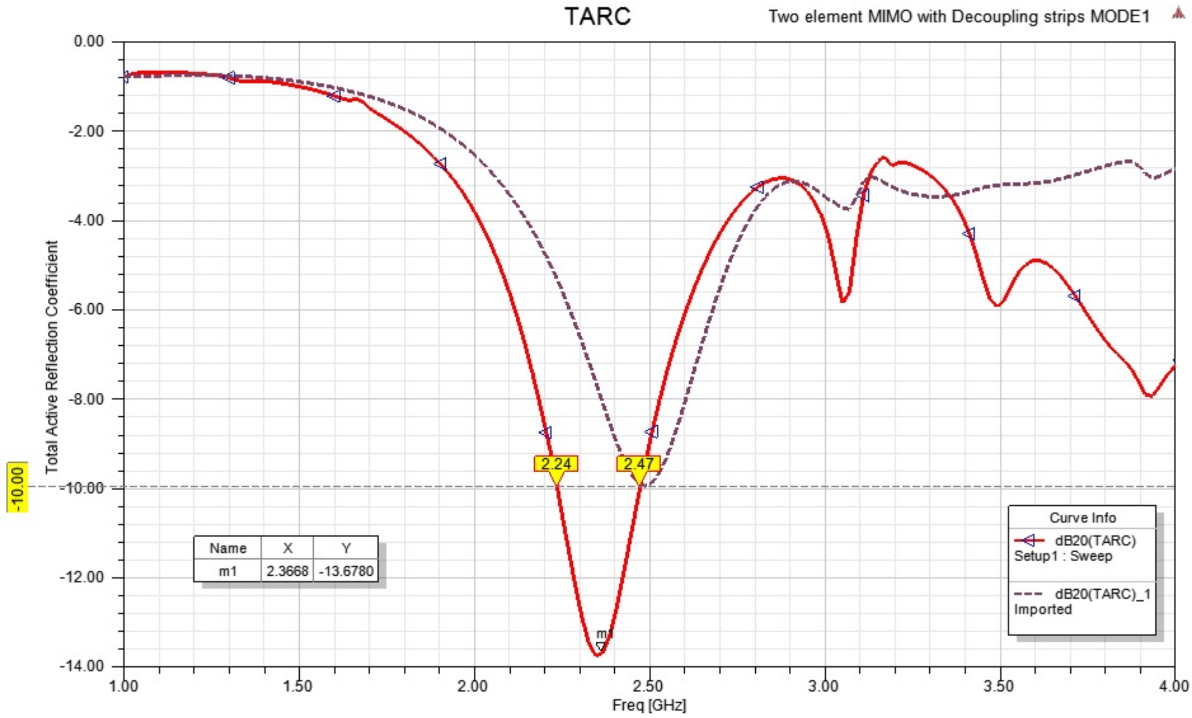


Fig.5.27 TARC Comparison for the effect of Decoupling Strips

TARC Stand for total active reflection coefficient. It relates the total incident power to the total outgoing power in an N-port Microwave Component. The TARC is mainly used for multiple-input multiple-output (MIMO) antenna systems and array antennas, where the outgoing power is unwanted reflected power. The TARC is the square root of the sum of all outgoing powers at the ports, divided by the sum of all incident powers at the ports of an N-port antenna. The value of the TARC should be less than -10dB.

TARC= (mag(S(1,1)+S(1,2))^2+ mag(S(2,1)+S(2,2))^2)^0.5/2^0.5

As shown in figure 5.27, the TARC value with Decoupling Strips is -13.6870, which is less than that of the value without Decoupling Strips.

5.4 MODES OF TWO ELEMENT MIMO ANTENNA

By varying the conditions of the diodes based on their switching conditions we have 9 modes.

The nature of the 9 modes are described in the below table 5.3

Table 5.3 Operation of modes of antenna element

MODE	S1,S2	S3,S4	S5,S6	S7,S8
Mode 1	Off	Off	Off	Off
Mode 2	On	Off	On	Off
Mode 3	Off	On	Off	On

Mode 4	Off	Off	On	Off
Mode 5	Off	Off	Off	On
Mode 6	On	Off	Off	Off
Mode 7	Off	On	Off	Off
Mode 8	On	Off	Off	On
Mode 9	Off	On	On	Off

S-PARAMETER COMPARISON FOR MODES 1, 4 AND 5

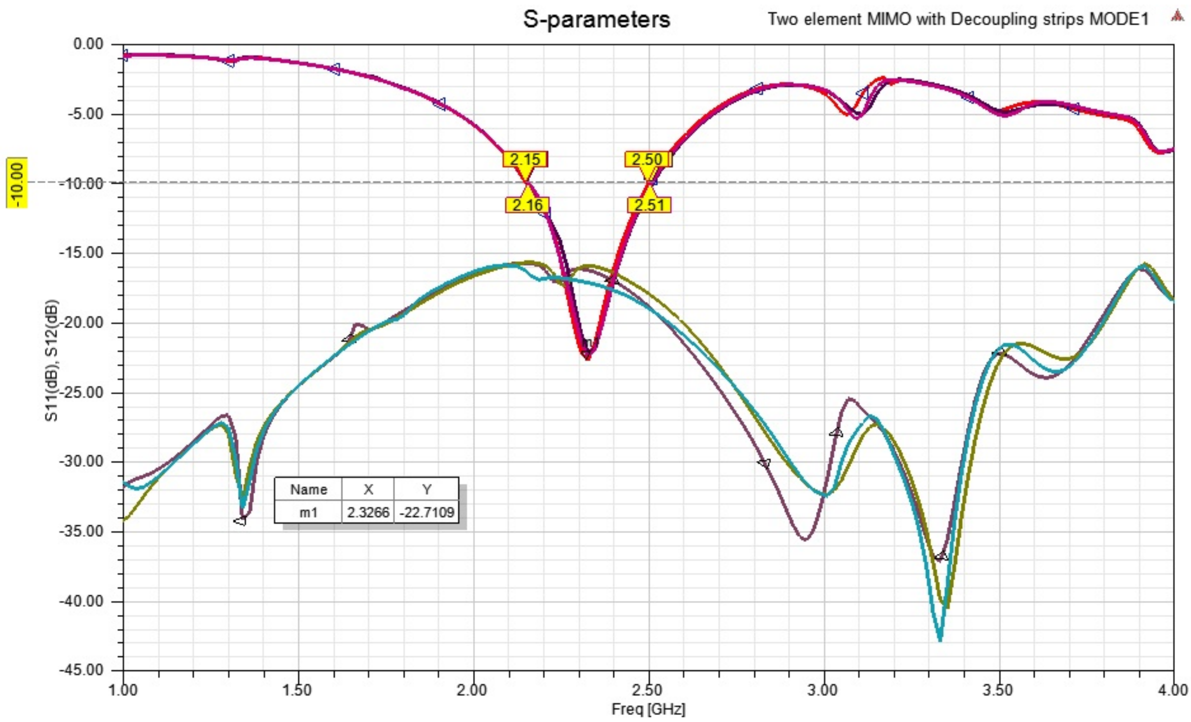


Fig.5.28 S-Parameter Comparison for Modes 1, 4 and 5

As shown in fig.5.37, It shows the comparison of S-Parameters of Mode1, 4 and 5. We can observe that these 3 modes are radiating at a same frequency i.e. at 2.45 GHz with a value a -22.7109dB.

5.4.1 RADIATION PATTERNS

Even though the return loss and isolation components of Modes 1, 4 and 5 are similar, the 9 modes give different radiation patterns at different maxima.

MODE 1

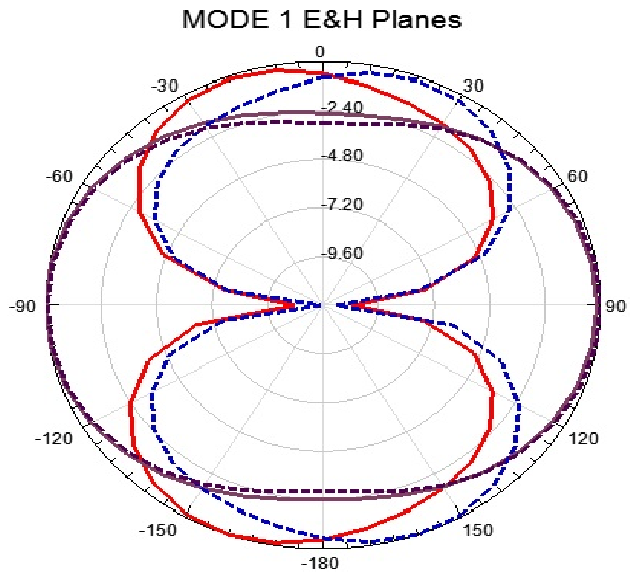


Fig.5.29 Radiation Pattern of Mode 1

As Shown in the fig.5.29, the solid lines represent the Data at port 1 and the dotted lines represent data at Port 2

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -160° and In H-field where phi=90° the maximum radiation is in the direction of -90° and +90.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +160° and In H-field where phi=90° the maximum radiation is in the direction of +90° and -90°

Therefore, the elements operate in a bidirectional pattern, and thus the antenna exhibits a bi-directional behaviour.

MODE 2

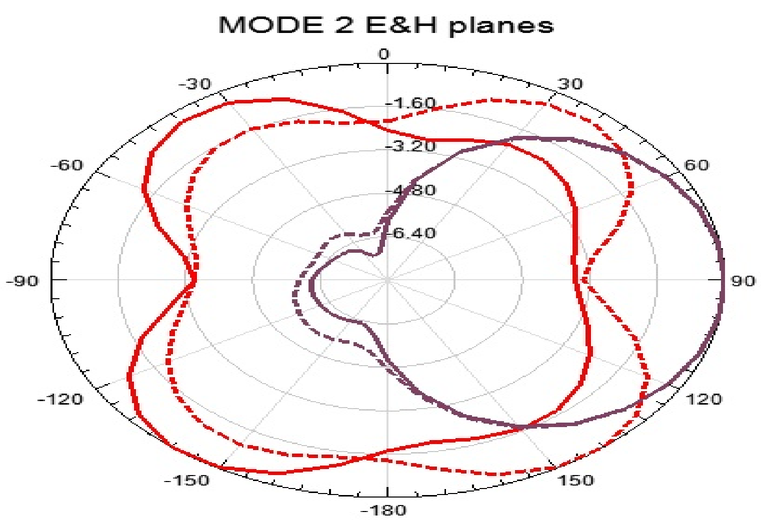


Fig.5.30 Radiation Pattern of Mode 2

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -140° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +145° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

Therefore, the elements operate in a directional pattern in the direction of negative and positive x-axis at both ports.

MODE 3

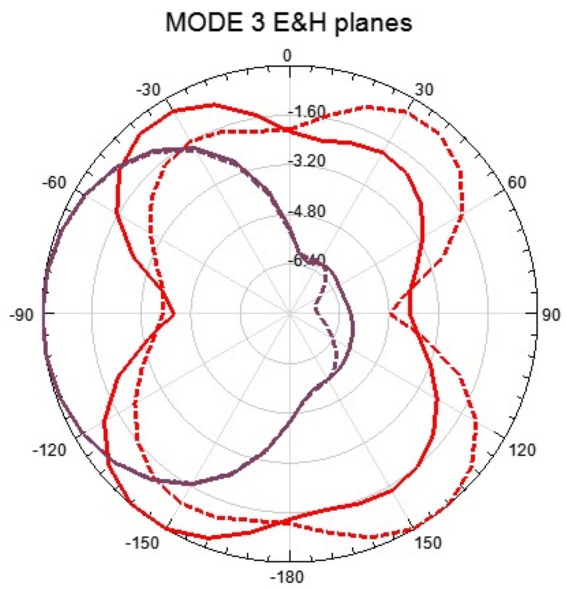


Fig.5.31 Radiation Pattern of Mode 3

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -145° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +145° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

As similar to Mode 2, the elements operate in a directional pattern in the direction of negative and positive x-axis at both ports.

MODE 4

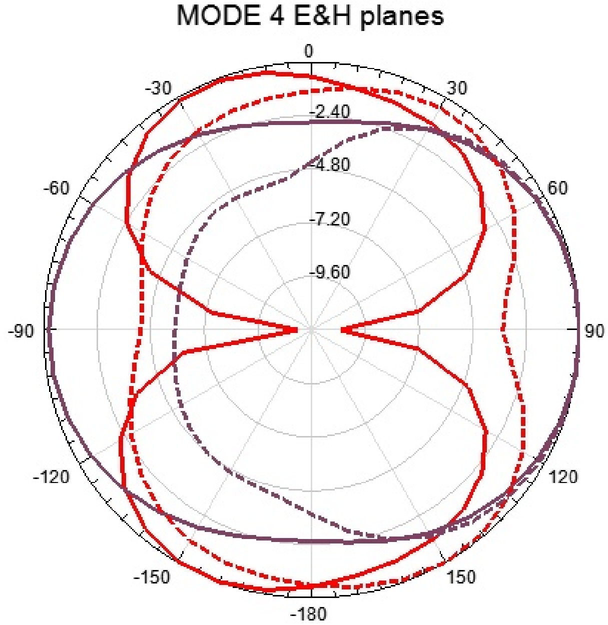


Fig.5.32 Radiation Pattern of Mode 4

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -155° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +150° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

Therefore, the antenna provides a bidirectional pattern at port 1 and a directional pattern along the positive and negative *x*-axis at port 2.

MODE 5

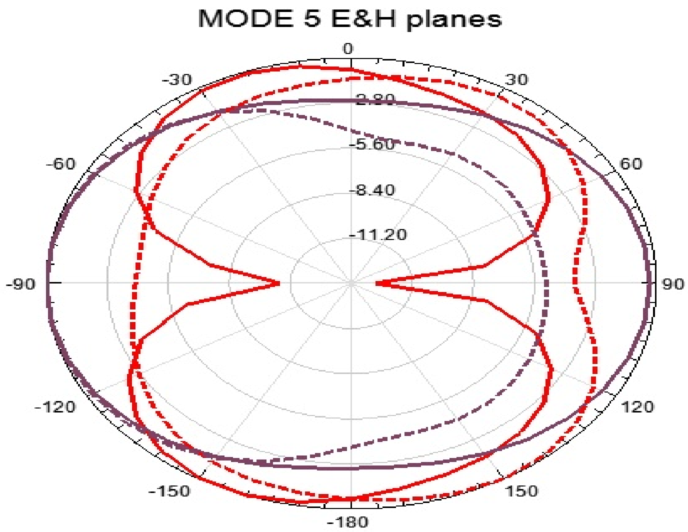


Fig.5.33 Radiation Pattern of Mode 5

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -155° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +150° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

It is similar to Mode 4 and the antenna provides a bidirectional pattern at port 1 and a directional pattern along the positive and negative *x*-axis at port 2.

MODE 6

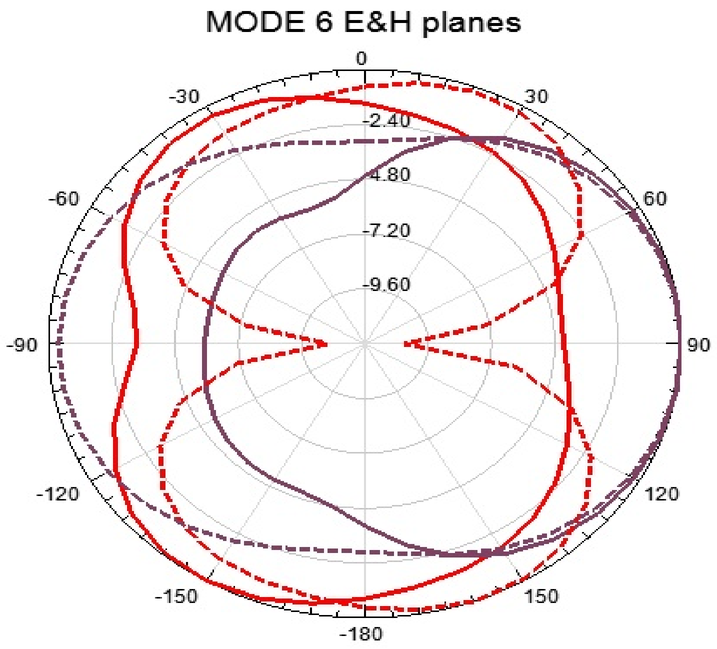


Fig.5.34 Radiation Pattern of Mode 6

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -150° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +160° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

Therefore, the pattern is directional at port 1 and bidirectional at port 2.

MODE 7

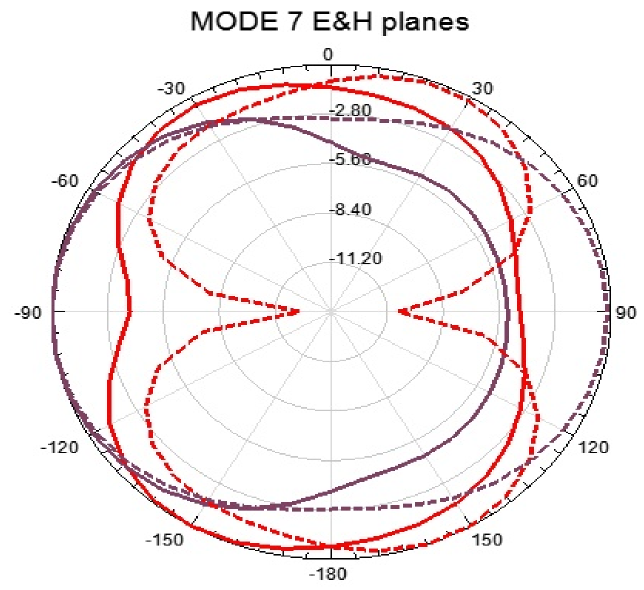


Fig.5.35 Radiation Pattern of Mode 7

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -150° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +155° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

It is similar to Mode 6 and the pattern is directional at port 1 and bidirectional at port 2.

MODE 8

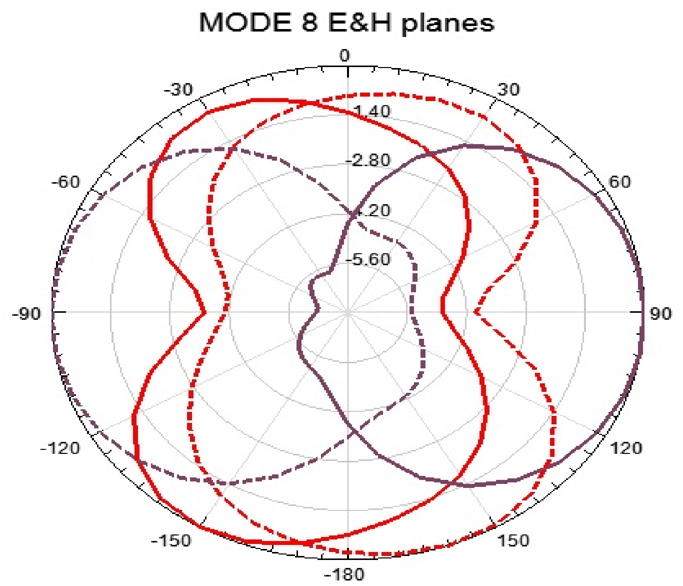


Fig.5.36 Radiation Pattern of Mode 8

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -150° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +160° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

Therefore, a directional pattern along the positive and negative *x*-axis at ports 1 and 2 is generated.

MODE 9

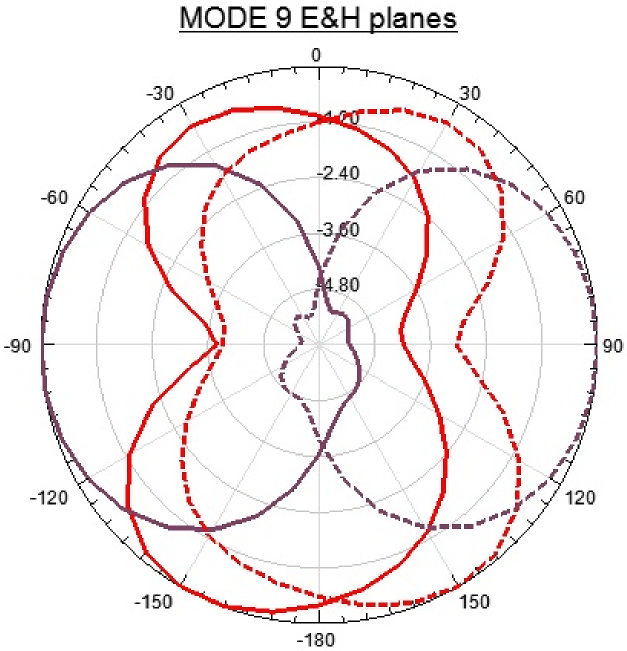


Fig.5.37 Radiation Pattern of Mode 9

At port 1, In E-field where phi=0° the maximum radiation is in the direction of -150° and In H-field where phi=90° the maximum radiation is in the direction of -90°.

At port 2, In E-field where phi=0° the maximum radiation is in the direction of +150° and In H-field where phi=90° the maximum radiation is in the direction of +90°.

This mode is opposite to Mode 8. So, a directional pattern along the positive and negative *x*-axis at ports 2 and 1 is generated.

From the radiation patterns of 9 Modes, Here Mode 1 is Bi-directional, Mode 2 and 3 are uni-directional giving same patterns but in opposite Direction, Similarly Mode 4 and 5, Mode 6 and 7, Mode 8 and 9 Works in same way. We observe that the radiation Patterns were changing and hence we conclude that the MIMO antenna shows Pattern Re-configurability.

CONCLUSION

A low-profile planar MIMO antenna with the pattern reconfigurable characteristic is demonstrated. The antenna consists of two monopole elements arranged opposite to each other, and the isolation between the elements is improved through introducing two decoupling strips. The pattern reconfigurable property is achieved by controlling the states of the PIN diodes embedded in the parasitic strips of the elements.

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