A Tri Band Reconfigurable Microstrip Patch Antenna Using Shorted Strip Technique

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by

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under the guidance of

Dr.M.M.Sharma
and
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Malaviya National Institute of Technology, Jaipur

[2017]

Dedicated to
My Family

CERTIFICATE

This is to certify that the thesis entitled **A Tri Band Reconfigurable Microstrip Patch Antenna Using Shorted Strip Technique**, submitted by **Abhinav Vinod Deshpande** to Malaviya National Institute of Technology, Jaipur, is a record of bonafide research work carried out under my supervision and is worthy of consideration for the award of the degree of Master of Technology of the Institute.

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DECLARATION

I certify that

1. the work contained in this thesis is original and has been done by me under the guidance of my supervisor.
2. the work has not been submitted to any other Institute for any degree or diploma.
3. I have followed the guidelines provided by the Institute in preparing the thesis.
4. whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

Abhinav Vinod Deshpande

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List of Important Abbreviations

AF	array factor
AR	axial ratio
BFSK	binary phase shift keying
BWFN	beam width between the first nulls
CCW	counter clockwise
CPW	co planar waveguide
CST	computer simulation technology
CW	clockwise
E-field	electric field
EHF	extremely high frequency
ELF	extremely low frequency
FBW	fractional bandwidth
FCC	Federal Communications Commission
FPGA	field-programmable gate array
FR-4	Fire Retardant UV-94
FSS	frequency selective surface
GPS	global positioning system
GSM	global system for mobile communication
HF	high frequency
H-field	magnetic field
HPBW	half power bemwidth
LF	low frequency
MF	medium frequency
MIMO	multiple input, multiple output
MPA	microstrip patch antenna
MTA	microstrip traveling wave antenna
PLF	polarization loss factor
RADAR	radio detection and ranging

RF-MEMS	radio frequency microelectromechanical system
RFID	radio frequency identification
SHF	super high frequency
SMA	SubMiniature version A
TE	transverse electric
TEM	transverse electromagnetic
TM	transverse magnetic
UHF	ultra high frequency
UWB	ultawideband
VHF	very high frequency
VLF	very low frequency
VSWR	voltage standing wave ratio
WiMax	worldwide interoperability for microwave access
WLAN	wireless local area network

List of Important Symbols

Ae	effective area of an antenna
B	beamwidth of an antenna
β	phase constant
c	velocity of the electromagnetic wave in free space
D	directivity of the antenna or dimension of the antenna
ϵ_{ap}	aperture efficiency
ϵ_r	relative permittivity or relative dielectric constant
ϵ_{reff}	effective dielectric constant
η	efficiency of an antenna
f	frequency of the wave
f_r	resonant frequency
G	gain of an antenna
Γ	reflection coefficient
k	wavenumber
λ	wavelength of the wave
Ω	angle in steradians
ω	angular frequency
$\mathscr{P}$	instantaneous total power
P_{rad}	average radiated power
Q	qualty factor of an antenna
R	distance from the antenna
θ	steering angle
U	radiation intensity
U_0	radiation intensity of an isotropic source
v	velocity of the electromagnetic wave in medium other than free space
$\mathscr{W}$	instantaneous poynting vector
Y_0	characteristic admittance

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Abstract

Reconfigurable microstrip patch antennas has been evolved in the past decade due to its numerous merits. The need of a particular communicating equipment to be more multifunctional so that it can survive in today's competiting environment, has led to the development of reconfigurable antennas. Also they are used to overcome the degradation of the quality of the received signal due to the harsh environmental conditions. Cognitive radios makes use of frequency reconfigurable antennas so as to switch to other unused radio frequency when there is no proper reception achieved at some operating frequency. So these antennas are very much useful to improve communication links also.

In this text a novel design of compact low cost tri band reconfigurable antenna with shorted stubs resulting in frequency switching capabilities, is presented. The operating frequencies of the antenna are f1= 4.85 GHz (4.05-7.10 GHz), f2= 10.04 GHz (9.05-12 GHz) and f3=15.09 GHz . The three resonant frequencies of the antenna lies in standard IEEE microwave bands of C band (4-8 GHz), X band (8-12 GHz) and Ku band (12-18 GHz). This antenna is a modified version of its ultrawideband counterpart which provided the operation in the range of 3.1 GHz to 10.6 GHz. The multiband property is obtained by the inclusion of the triangular and rectangular slots in the ground plane. The antenna is made reconfigurable by parasitic elements with shorted pins. This antenna is switched between the resonant frequencies by the different combinations of microwave switches. The input impedance of the antenna is matched perfectly to that of the transmission line of 50 ohm for each band. This matching property is achieved by the introduction of three corner cuts in the patch. The simulated result is carried out in CST microwave studio. This type of switchable antenna can be used in different types of RADARs and Satellite applications.

In this text initially all the basics related to the antenna have been discussed, so that the reader should feel familier to all the concepts related to antenna. Next the theory related to Microstrip Patch antennas followed by Reconfigurable antennas are discussed. Then the stepwise design procedure covering all the design related issues of the project has been discussed in detail with related simulated results. At the end, the text has some concluding remarks with some discussion on scope of future work.

Key Words - Tri Band, Reconfigurable, microstrip patch antenna, C, X and Ku band, parasitic elements, partial ground, corner cuts.

Contents

CHAPTER 1

Introduction and Review

1.1 Electromagnetic Spectrum

Energy radiated in the form of continuous wave by antennas, oscillates at radio frequencies. The free space waves associated with it range in length from thousands of meters at the long wave extreme to fractions of a millimetre at the short wave extreme. The posiotion of the radio waves in the entire electromagnetic spectrum can be seen from Figure1.1. Short radio waves and long infrared waves overlap into a zone called a *twilight zone* that may belongs to both. The wavelength *lambda* of a wave is related to the frequency f and velocity v of the wave by

$$\lambda = \frac{v}{f} \tag{1.1}$$

Thus the wavelength depends on the velocity v which inturn depends on the medium. In this sense, frequency is a more fundamental quantity since it is inde-

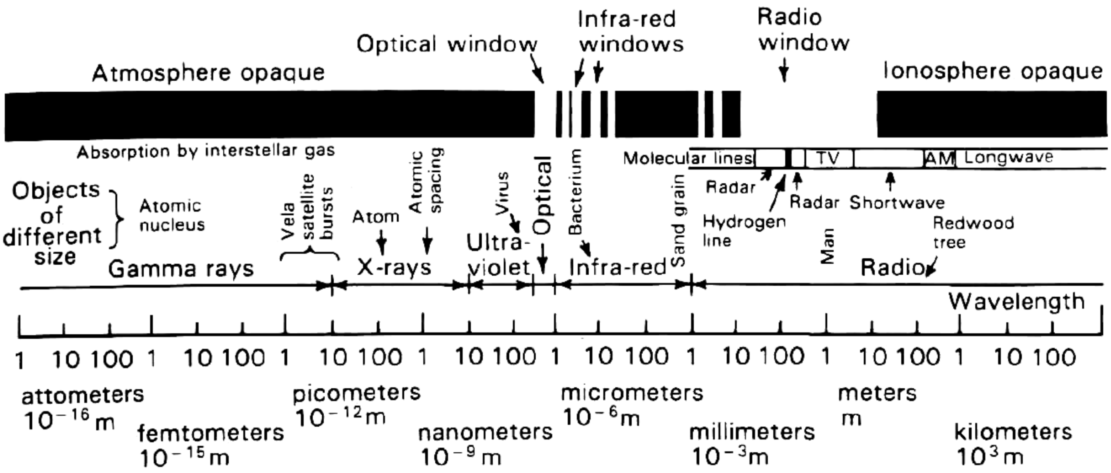


Figure 1.1: The Electromagnetic Spectrum.

pendent of the medium. When the medium is free space (vacuum)

$$v = c = 3 \times 10^8 ms^{-1} \tag{1.2}$$

Example of wavelength for a given frequency. For a frequency of 300 MHz the corresponding wavelength is given by

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 ms^{-1}}{300 \times 10^6 Hz} = 1m \tag{1.3}$$

In a lossles nonmagnetic dielectric medium with relative permittivity $\epsilon_r = 2$, the same wave has a velocity

$$v = \frac{c}{\sqrt{\epsilon_r}} = \frac{3 \times 10^8}{\sqrt{2}} = 2.12 \times 10^8 ms^{-1} \tag{1.4}$$

$$\lambda = \frac{v}{f} = \frac{2.12 \times 10^8}{300 \times 10^6} = 0.707m = 707mm \tag{1.5}$$

Table 1.1: Radio frequency band designations [41]

Frequency	**Wavelength**	**Band designations**
30-300 Hz	10-1 Mm	ELF(extremely low frequency
300-3000 Hz	1 Mm-100 km	
3-30 kHz	100-1 km	VLF(very low frequency)
30-300 kHz	10-1 km	LF(low frequency)
300-3000 kHz	1 km-100 m	MF(medium frequency)
3-30 MHz	100-10 m	HF(high frequency)
30-300 MHz	10-1 m	VHF(very high frequency)
300-3000 MHz	1 m-10 cm	UHF(ultra high frequency)
3-30 GHz	10-1 cm	SHF(super high frequency)
30-300 GHz	1 cm-1 mm	EHF(extremely high frequency)
300-3000 GHz	1 mm-100 μm	
Frequency	**Wavelength**	**IEEE Radar Band designations**
1-2 GHz	30-15 cm	L
2-4 GHz	15-7.5 cm	S
4-8 GHz	7.5-3.75 cm	C
8-12 GHz	3.75-2.50 cm	X
12-18 GHz	2.50-1.67 cm	Ku
18-27 GHz	1.67-1.11 cm	K
27-40 GHz	1.11 cm-7.5 mm	Ka

The L,S,C,X,Ku,K and Ka bands are the standard microwave frequency bands. These bands finds variety of application in defence system, satellite communications and in several other government applications.

1.2 Introduction to Microwave Engineering

Frequency in the range of 100 MHz to 1000 GHz generally referred to as RF and microwave frequencies [42]. The branch associated with this is called *RF and Microwave engineering.* The frequencies from VHF (30-300 MHz) to UHF (300-3000 MHz) are referred to as RF frequencies, whereas frequencies from 3 to 300 GHz are Microwave frequencies. Signals having wavelength in the range of millimetres are known as *millimetre waves.* The Figure 1.1 shows the electromagnetic spectrum. The position of RF and Microwave frequency bands can also be observed.

The standard Network Theory algorithms won't work in the microwave field, due to the high frequency and also by the effect of transit time. It thus restricted as a special case of Maxwell's equations which forms the basics of electromagnetic theory. Due to the transit time effect, the lumped circuit approximations is not valid at high frequencies [42]. Due to the dimensions of the device at microwave frequencies is comparable to the operating wavelength, the phase of the current and voltage varies significantly along the physical dimensions of the device. Thus the microwave component are referred as *distributed elements.* At lower frequency, the wavelength is quite large such that there is hardly any phase variation between voltage and current.

Next, if we move to the higher side of the frequency spectrum, we come in the field of fibre optic engineering, where the wavelength is very small as compared to the dimension of the component. In this field the well known Maxwell's equation is reduced to geometrical optics and the optical system is designed by using the theory of geometrical optics. These techniques are applicable to millimetre wave system, where they are known as *Quasi optical.*

1.3 Applications of Microwave Engineering

Despite the high frequencies and short wavelengths of microwave energy make for difficulties in the analysis and design of microwave devices and systems, these same aspects provide unique opportunities in the field of microwave systems and engineering. The following considerations can be useful in practice:

1) Gain of the antenna is proportional to the antenna's electrical size. For a given antenna size more gain is achieved by increasing the frequency to the higher side. This makes microwave system more popular.

2) At higher frequency, bandwidth, which is directly related to data rate, is higher. For example, 1% bandwidth of 600 MHz is 6 MHz which after BFSK modulation outputs a data rate of about 6 Mbps. Whereas if we come at higher frequency, at 60 GHz a 1% bandwidth is of about 600 MHz, thus allowing 600 Mbps.

3) Unlike the lower frequency signals which are bent by the ionosphere, the microwave frequency signals are less affected by it. Thus microwave finds its wide applications in satellite and terrestrial communication link having higher capacities. It is also widely used in frequency reuse at minimal distance location.

4) The radar cross section or the effective area of reflection of RADAR target is usually directly proportional to the electrical size of the target. If we consider point 1 and linking with this, microwave finds wide applications in RADAR engineering.

The RADAR system finds wide application in defence area, in missile guidance control. In commercial sector RADAR is useful in air traffic control, vehicle collision avoidance and distance measurements. In the scientific area, it finds applications in weather predictions, remote sensing [42].

Used in microwave radiometry where the microwave energy emitted by an object is sensed. It is useful in the area of remote sensing.

Microwaves are widely used in wireless telephony with the help of cellular frequency reuse concept. The Satellite communication also depends on microwave technology. The satellites are solely responsible for cellular voice, video and data connection worldwide.

1.4 Definition of an antenna

"A *radio antenna* may be defined as the structure associated with the region of transition between a guided wave and a free space wave or vice versa." [41].

In connection with this definition it is also useful to consider what is meant by the *transmission line* and *resonator*.

"A *transmission line* is a device which is used for transmitting or guideing radio frequency energy from one point to another." While the transmisssion of the signal takes place it is necessary that it should suffer from minimum attenuation and heat losses. This means that while coveying the energy, transmission line acts as a guiding medium where the enrgy is bounded closely to it.

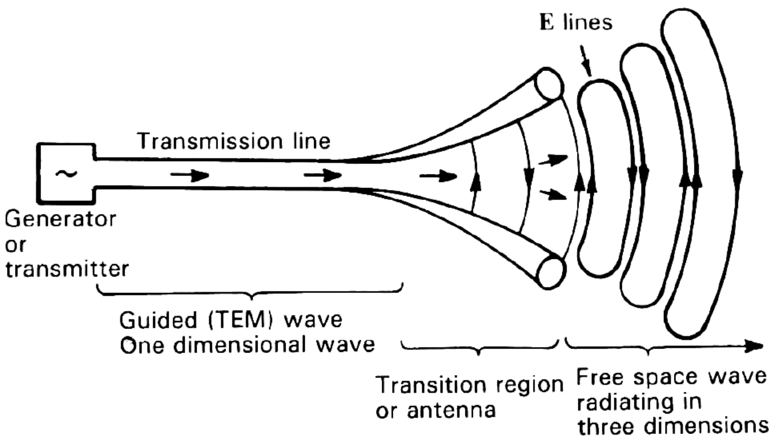


Figure 1.2: The antenna is a transition region between guided wave and free space wave.

An infinite, lossless transmission line when connected with a generator consist of a uniform travelling wave along the length of the line. If the line is short circuited, the outgoing travelling wave is reflected, standing wave gets produced on the line due to the outgoing and the reflected waves interference. A standing wave consist of a local concentrations of energy. A pure standing wave gets created if the reflected wave is equal to the outgoing wave. The energy concentrations in such a wave oscillates from entirely electric to entirely magnetic and back twice per cycle. Such energy behaviour is a characteristics of a resonant circuit, or we can term it as *resonator*. Although the term resonator, may be applied to any device with standing waves, the term is usually reserved for device with stored energy concentrations that are large compared with the net flow of energy per cycle. Where there is only an outer conductor, as in a short circuited section of waveguide, the device is called a *cavity resonator*.

"Thus the antenna *radiates energy or receives energy*, transmission lines *guide energy*, while resonators *stores energy*".

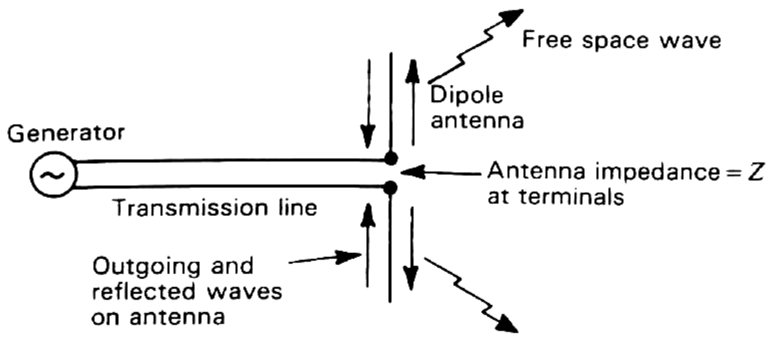


Figure 1.3: The Antenna launches a free-space wave but appears as a circuit impedance to the transmission line.

A guided wave travelling along a transmission line which opens out, as in Figure 1.2, will radiate as a free space wave. The guided wave is in the form of plane wave while the free space wave is a spherically expanded kind of wave.

Along the uniform part of the line, the energy is guided as a plane wave with little attenuation, provided the spacing between the conducting wires is a small fraction of a wavelength.

At the right, as the separation of the transmission line approaches a wavelength or more, the wave tends to be radiated so that the opened out line acts as a antenna which launches a free space wave. The current on the transmission line flow out on the transmission line and end there, but the associated fields keep on going.

To be more explicit,"the region of transmission between the guided wave and the free space wave may be defined as an *antenna*."

As a receiving device the definition is completely reciprocal. Thus an antenna is the region of transition between a free space wave and a guided wave. Thus, "*an antenna is a transition device, or transducer, between guided wave and a free space wave, or vice versa*."

While transmission lines are usually designed so as to minimize radiation, antennas are designed to radiate energy as efficiently as possible. Consider a transmission line connected to a dipole antenna which is shown in Figure1.3. The dipole is reffered as an antenna because it launches a free space wave. However, it may also be considered as a section of an open ended transmission line. In addition, it exhibits many similar characteristics as of a resonator, since energy reflected from the ends of the dipole gives rise to a standing wave and energy storage near the antenna. Thus a single device in this case the dipole, exhibits simultaneously properties characteristics of an *antenna, transmission line* and *a resonator.*

The antenna can be alternatively defined as "*a transformer (or matching section) between a two input terminals and space (in transmitting case) or is a transformer between space and the input terminals of receiver (in the receiving case)*."

1.5 Monopole and Dipole

The dipole and monopole antennas are the most popular antennas discussed in modern wideband wireless communication systems. A monopole antenna comprises of vertical wire, tube or helical whip which is mounted perpendicularly on a conducting surface known as *ground plane*.

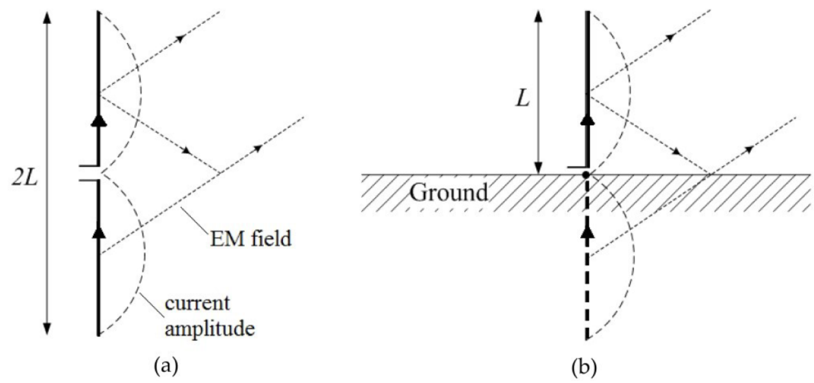


Figure 1.4: A dipole and a monopole antenna and its image

A monopole antenna has a radiation pattern same as that of a dipole antenna as the reflected wave from the ground plane seems to be generated from its image under the ground plane surface which can be identified as the missing half part of the equivalent dipole [31]. Figure 1.4 shows the monopole antenna mounted on a ground plane along with its image compared with an equivalent dipole. Similar to the dipole antennas, the length of a monopole antenna is a function of the wavelength with is typically around $\lambda/4$.

A $\lambda/4$ monopole mounted on a infinite ground plane has the similar field expressions and behaviour as that of a $\lambda/2$ dipole. The radiation pattern of the monopole is same as that of a dipole but is only present on the hemisphere above the ground plane, which is half the space used to radiate by a dipole. Thus, the gain of a monopole antenna will be double the gain of a similar dipole antenna.

Also, the radiation resistance of the monopole antenna will be half as that of a dipole antenna. However, practically, monopoles employ finite ground plane sizes and the radiation pattern is depended upon their size and shape. Ideally a ground plane should be greater than a quarter wavelength around the monopole base. An electrically small ground plane will cause the maximum radiation pattern to shift to higher elevation angles. In general as the ground plane size increases towards ∞, the angle of maximum radiation will be closer to the horizontal plane.

Monopole antennas can exhibit broader impedance bandwidths which can be enhanced by increasing the radius of the cylindrical element. This is true up to a point where the stepped radius from the feed probe to the cylindrical element becomes abrupt. Because of the omni-directional radiation patterns, vertical monopoles are widely used for non-directional radio communications, where the direction of the transmitter (or receiver) is unknown or constantly changing, such as radio broadcast and base-station antennas in mobile communications.

1.5.1 Planar monopole antennas

In planar monopole antennas, the cylindrical-shaped monopole conductor discussed before is replaced by a thin planar conductor e.g. a rectangular, square or circular-shaped monopole Figure1.5.

The monopole is usually mounted perpendicularly on a finite conducting ground plane. Planar antenna performance depends heavily on the ground plane size and the planar element and the ground plane gap [32]. The location of the monopole on the ground plane also has an influences in its pattern and impedance bandwidth. This type of monopole antenna can achieve much wider bandwidth than a whip antenna with the same height and ground plane size. In addition their efficiency can approach 100%.

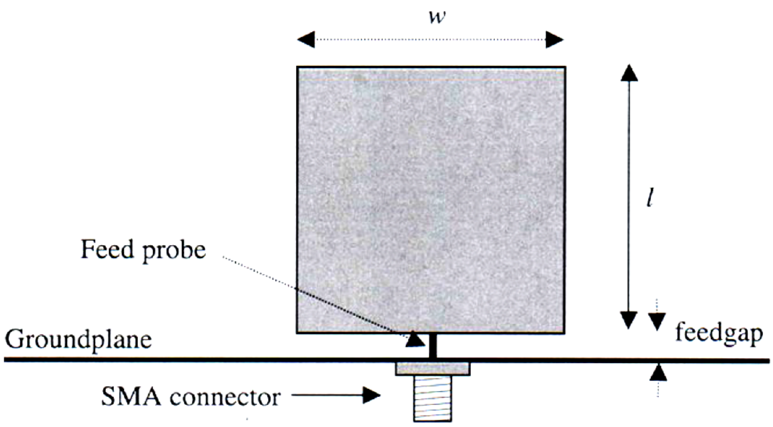


Figure 1.5: An example of planar monopole antennas

1.6 General Classification of Antenna Types

The typical antenna classification can be observed from the Figure 1.6. The Standard Antennas comprises of fixed frequency and radiation properties. Examples of this type of antennas are standard dipole or monopole antennas, whose radiation characteristic is defined by specific and fixed type of current distribution.

Adaptive antennas can be divided into two basic types: *phased arrays* and *reconfigurable antennas*. Phased arrays requires a cascade of multiple elements and five types of controls can be used to change the radiation pattern:

1. Geometrical configuration of the overall array (linear, circular, rectangular, spherical,etc.)
2. Distance between the elements
3. Amplitude excitation of each element
4. Phase excitation of each element
5. Relative pattern of each element

The method of controlling the phase between the elements is usually carried out to tilt the radiation pattern for beam-steering antenna design purpose.

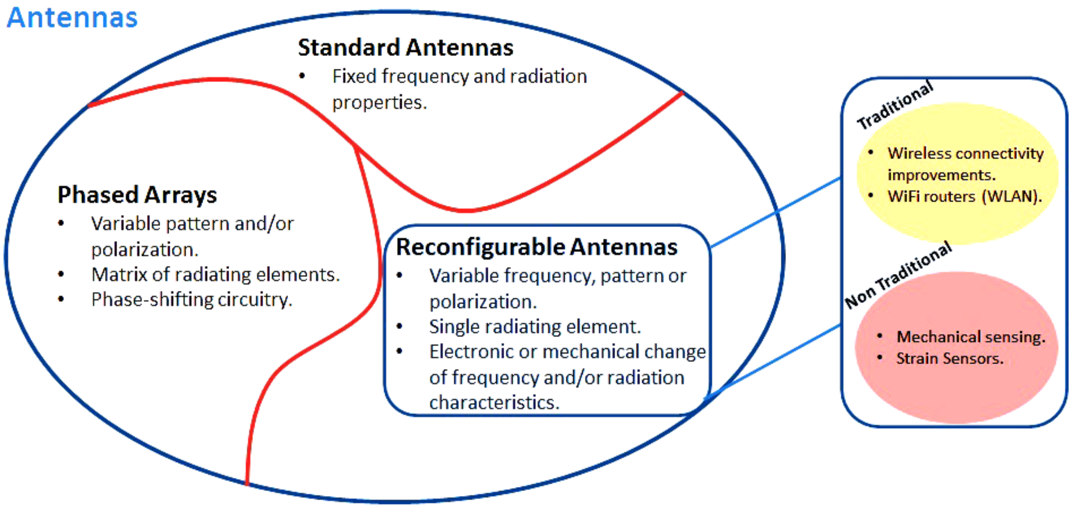


Figure 1.6: Classification of antenna.

The total field of an antenna array can be seen as the field of a single element, multiplied by a factor which is called the *array factor*. The array factor is a function of the geometry of the array and the excitation phase. The normalized array factor is given by:

$$AF = cos\left[\frac{1}{2}(kdcos\theta + \beta\right] \tag{1.6}$$

where k is the wavenumber, d is the distance between each antenna element, θ is the steering angle, and β is the phase shift between the antenna elements. The total field of an array of identical elements is equal to the product of the field of a single element and the array factor of that array:

$$\boxed{E(total) = [E(single\ element)] \times [arrayfactor]} \tag{1.7}$$

This is known as *pattern multiplication of arrays of identical elements*. Phased arrays are characterized by large form factors. They require phase shifting circuitry to steer the directional beam so as to provide the necessary phase. On the other hand, reconfigurable antennas comprises of a single radiating element, capable of generating different patterns or polarizations. The reconfigurable antenna solution is generally preferable with respect to a phased array antenna because:

i) it employs a single active element, thus occupying a smaller space and

ii) it allows for high radiation efficiency as it avoids the use of phase shifters and power dividers.

Generally the reconfigurable antennas are divided into two main classes depending upon their reconfigurable outputs.

1)***Frequency reconfigurable antennas***: These are the antennas which are able to adapt their resonant frequency based on the desired operational frequency, so as to reduce the use of multiple antennas for different applications.

2)***Pattern-reconfigurable antennas***: These are the antennas which can change their radiation pattern or state of polarization in order to enhance the capacity of the wireless communication channel.

By changing the current distribution on the metallic surface elements with the help of switches or reactive components such as PIN diodes or varactor diodes or by stretching a flexible design, the reconfigurability is achieved.

Different types of reconfigurable antennas have been proposed which are capable of changing pattern and polarization state. These antennas may employ switches or variable capacitors to change the distribution of current on the metalic surface of the active element; or may employ an active antenna element surrounded by passive elements (i.e., parasitic elements) loaded with variable capacitors or connected to switches. Furthermore, these classes of reconfigurable antennas have been used for different purposes.

The traditional electrically reconfigurable antennas find variety of applications for throughput maximization within WiFi routers and other WLAN devices, whereas stretchable antennas are used as frequency-reconfigurable antennas in the field of mechanical sensing, such as crack detection and other strain sensing.

1.7 Classification based on the structure of the radiating element

1.7.1 Wire Antennas

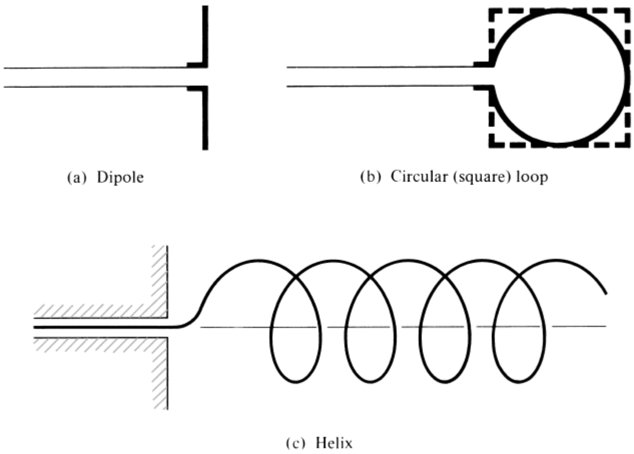


Figure 1.7: Wire antenna configuration.

Wire antennas are the most basic antennas which are familiar to everyone. It also has simple radiation patterns and is the most basic antennas. It consists of a radiating element in the form of simple conducting wire. The wire can take many shapes in the form of helix, circular or square loop, etc. The various configurations of wire antennas is shown in the Figure 1.7. There are also subdivisions under loop antenna i.e. rectangle, ellipse, square, etc. Out of these, circular loop is widely used due to its simplicity [39].

1.7.2 Aperture Antennas

As the system is operated in the higher range of frequencies the wire antennas are not enough. The antennas used in these cases are more sophisticated in construction. These are shown in the Figure1.8. These antennas can be directly connected to the mouth of the waveguide. The meaning of aperture is an opening or hole. Thus it acts as an opening for the electromagnetic wave to radiate in free space. These are mostly used in aircraft and spacecraft applications.

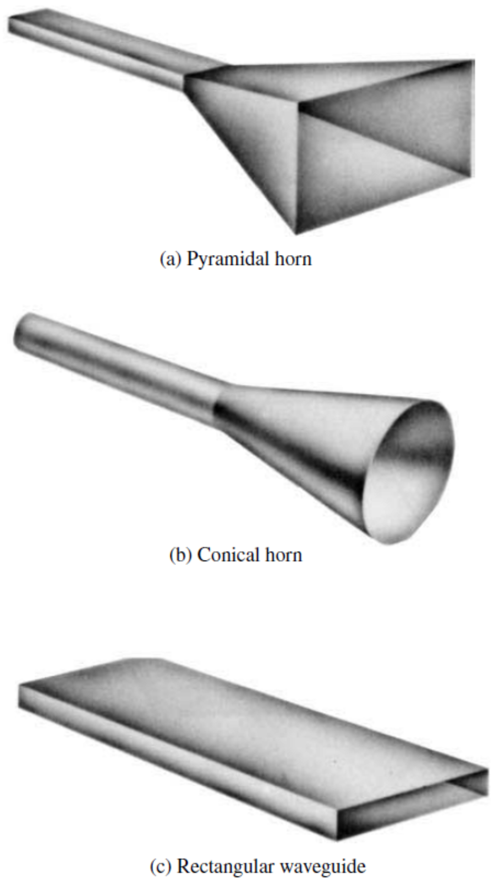


Figure 1.8: Aperture antenna configurations.

1.7.3 Microstrip Antennas

The microstrip patch antennas or simply MPA's are the planar antennas which is gaining much popularity in the past decade. It finds variety of applications in many areas due to its numerous advantages. It is especially the main research topics of many researchers across the world. These antennas are assumed to replace the other conventional antennas in the coming years. It consists of a substrate material of some dielectric constant.

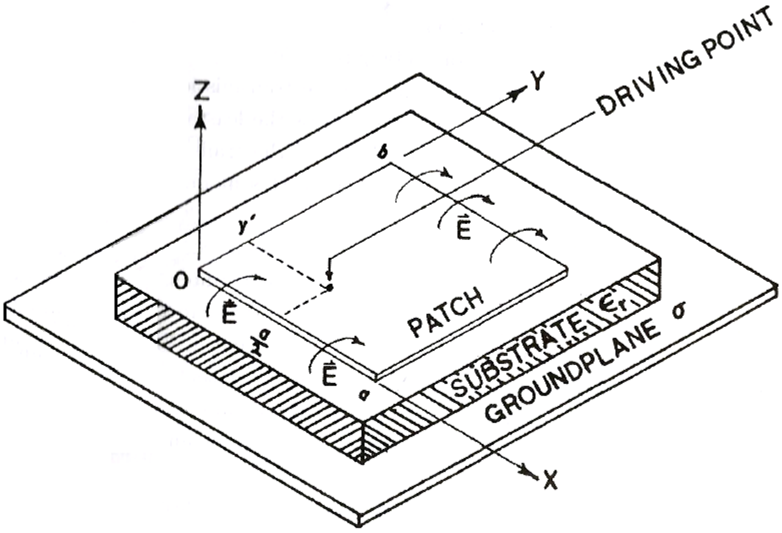


Figure 1.9: Microstrip patch antennas

The upper layer of this substrate consists of the radiating element known as the patch [40]. And finally at the backside it consists of a ground plane. The name *microstrip antenna* comes due to the use of microstrip line which is used to give or supply microwave power to the radiating element. The arrangement is shown in Figure1.9. Initially the microwave engineers usually employed a striplines to fabricate the circuits in microwave devices. It consists of two conductors acting as a ground plane and a strip in the middle of it, for guiding the signal. As the advancement of technology has taken place in the past years, it is replaced by the similar structure known as a *microstrip line*. The main advantage of microstrip line as compared to strip line is that the former can be made by monolithic integrated circuits.

1.7.4 Array Antennas

In several applications the gain consideration is the most important aspect. For example the gain of the microstrip patch antenna is quite low. So the single microstrip antenna cannot be used in these applications. Several arrangements are to be used to achieve the desired gain. These arrangements are known as an *array*. However array may also consist of group of other antennas. The arrangements must be such that the radiation properties of the individual element must add *in phase* to give enhancement in gain. The different array configurations are shown in the Figure1.10 [39].

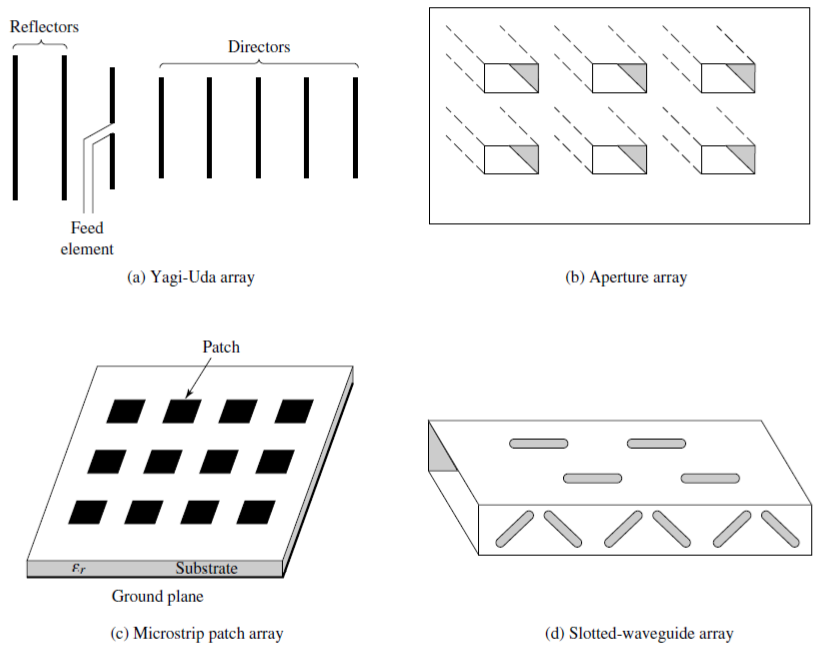


Figure 1.10: Wire, aperture, microstrip array configurations.

1.7.5 Reflector Antennas

These antennas are very much famous for long distance communication. It is used especially in the satellite communication. Its unique construction enables it to be used in areas where higher directivity is desired. It consist of a active element along with the reflector. The reflector forms the essential part of the antenna since it converts the spherical wavefront radiation to the planar wavefront radiation, thus making the antenna highly directional. For this the active or driven element is to be placed at the focal point. Several enhancements has been done in this type of technology. Figure1.11 shows the different configurations of the reflector antennas.

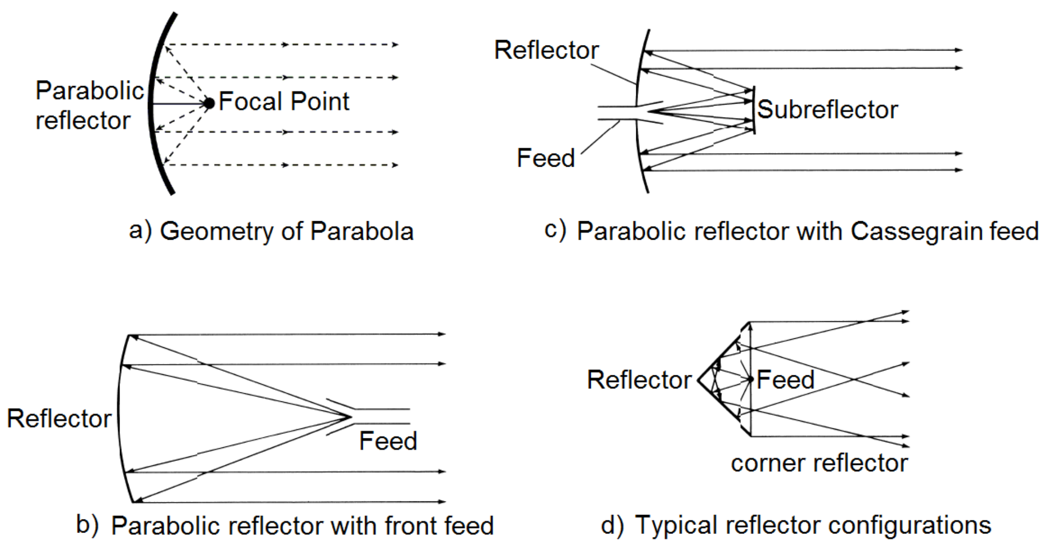


Figure 1.11: Reflector antenna configurations.

1.7.6 Lens Antennas

These are the antennas which are basically used for converging the beam so that it should not diverge in the undesired direction. It serves the same purpose as that of the reflector antennas. These antennas convert many diverging beams to the desired form of the plane waves. The ability to converge and the amount by which the beam is focussed is depended upon the type of material used for making the lens. They are use at the higher range of frequencies. They becomes bulkier at lower frequencies. Figure1.12 shows different lens antennas [39].

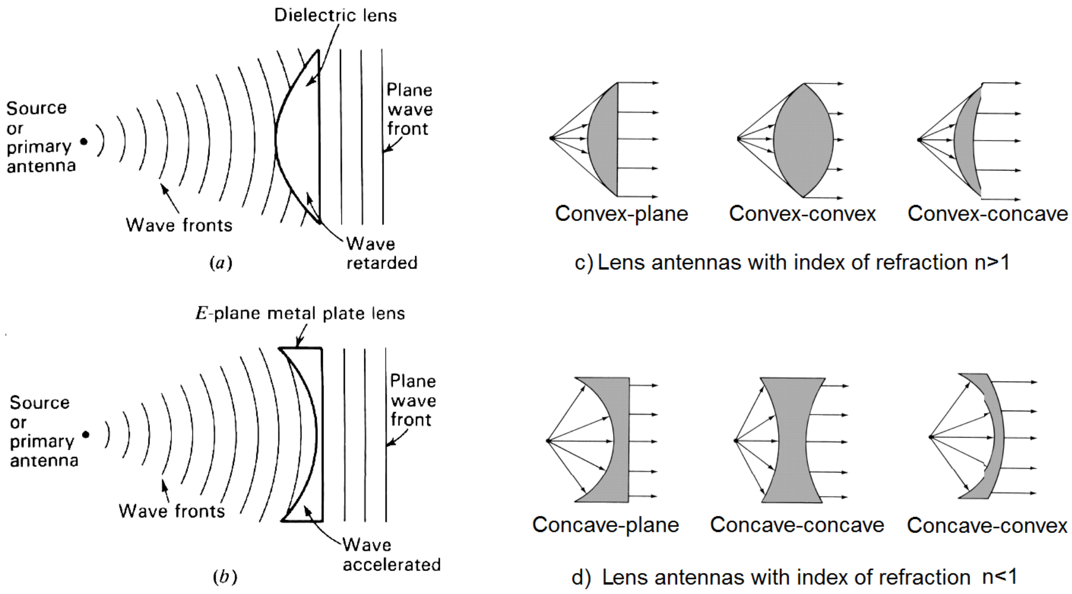


Figure 1.12: Lens antennas

1.8 Basic antenna parameters

Discussion on certain parameters are necessary to describe the performance of an antenna. Some of the parameters are interrelated and sometimes confusing. The other parameters also exist, but are not discussed here as they are beyond the scope of this text.

1.8.1 Radiation Pattern

The radiated energy from the radiator is not at all same in all the directions. It is different in some directions. The radiator radiates more in some direction and and lesser in other directions. The energy emiited by the radiator is measured in the form of Field strength of the antenna.

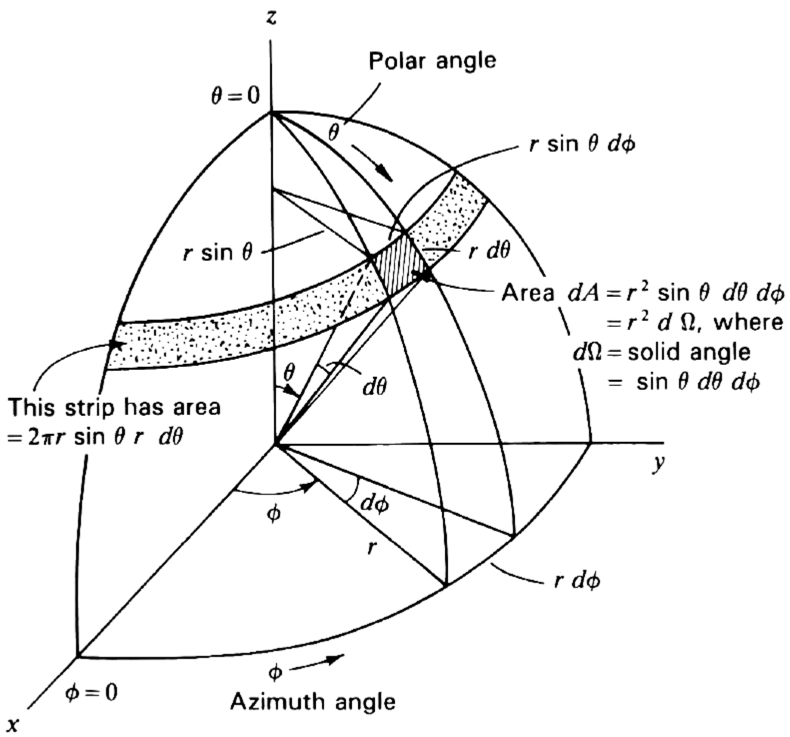


Figure 1.13: Coordinate system for antenna analysis.

The radition patern of the test antenna can then be stated as the polar graph showing the field strength in all the direction at a same distance from the antenna. The points or magnitude of the field strength is calculated in all the direction and is ploted in polar plot. Thus the graph plotted will be a three dimentional figure. But this is shown in two dimensional in many textbooks hoping the reader can visualise in 3D.

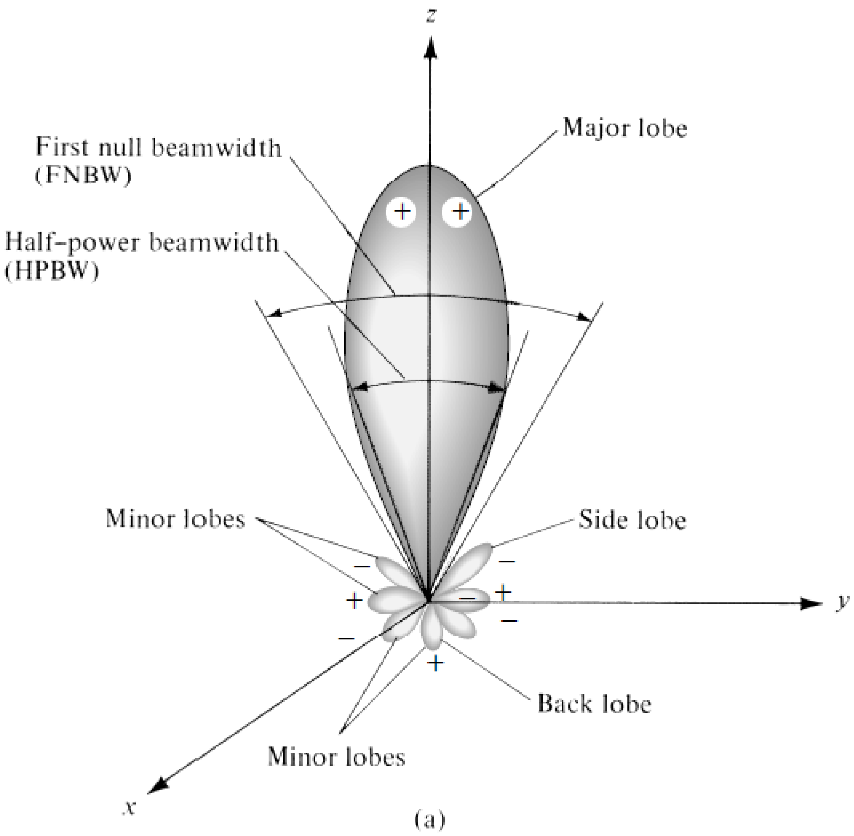
Or in other wirds the three dimensional figure obtained is sliced from the centre of the figure especially a centre of sphere to indicate the radiation pattern. So if the three dimensional figure is sliced in horizonatal planes or in vertical plane, these patterns are called as *Horizontal pattern or Vertical pattern.*

The radiation patterns differs from antenna to antenna. Thus finally the radiation pattrern is again defined as “the graphical representation of the radiation characteristics of the antenna in three dimensional co-ordinates shown in Figure 1.13”. In nearly all the cases the pattern is calculated in the far field region of the antenna.

A locus or polar plot of the received power is at a constant spherical distance is known as *power pattern.* Whereas the plot of the electric and magnetic field is called the *field pattern.* The point at which the field achieves the half of the maximum power is called the *Half power points* and the associated beamwidth is known as *Half power beam width(HPBW).*

1.8.2 Radiation Pattern Lobes

The radiation pattern of a particular antenna is divided into several small patterns. These different patterns are referred as a *Lobes* of an antenna. These are usually separated by the weak radiation intensity of the antenna. Any antenna may consist of more than one lobes in any case.



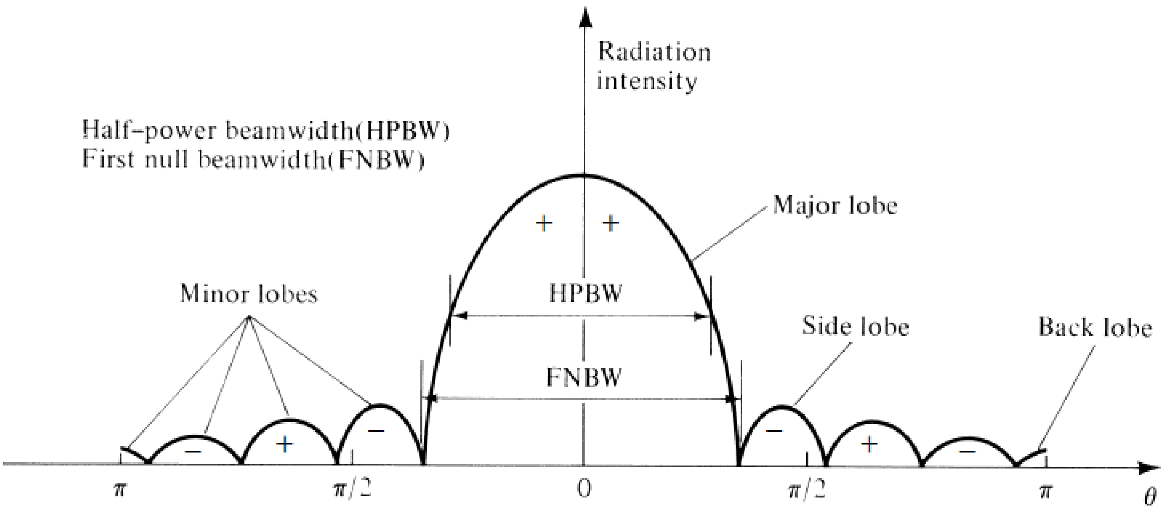


Figure 1.14: (a) Radiation lobes and beamwidths of an antenna pattern.
(b) Linear plot of power pattern and its associated lobes and beamwidths.

There are different nomenclature given to such types of lobes.

Major lobe: It is the lobe directed in the direction of maximum radiation. It is aligned in the direction in which maximum power is to be transferred or received.

Minor Lobe: These are the lobes excluding the major lobes having relatively smaller field intensities. It may be single or may be more than one.

Side lobe: It is associated with the direction. It should not be confused with the minor lobes. These are the lobes which are directed anywhere except the main beam direction.

Back Lobe: It is a single lobe which positioned exactly in opposite direction as that of the manor lobe. It should be as small as possible for directive antennas. These all can be observed from Figure1.14.

1.8.3 Review of the definition of Isotropic, Omnidirectional and Directional patterns.

1)***Isotropic pattern***: These are the pattern which are practically no where available. It is usually a hypothetical case and is only exist in theory. These are the pattern radiated by the antenna in all the directions. The radiation pattern of these types of antennas will be in a shape of a sphere. These patterns are generally used as a standard patterns. It is used to calculate the associated gain, directivity of a particular antenna.

2)***Omnidirectional pattern***: It may exist in real case with some exceptions. These are the patters radiated by the antennas in all the direction in a particular plane. Here it is a mention of a plane which makes it different from the Isotropic ones. The radiation pattern comprise of circular disc type of shape but not a sphere.

2)***Directional pattern***: These are practically available. Antennas which shows directive property or the antennas which radiates maximum in particular direction has these types of pattern. The pattern looks like a long balloon oriented in the direction of radiation. The antennas of these types are parabolic reflectors, horn antennas, etc. The horn antennas and the associated emitted beam is shown in Figure 1.15.

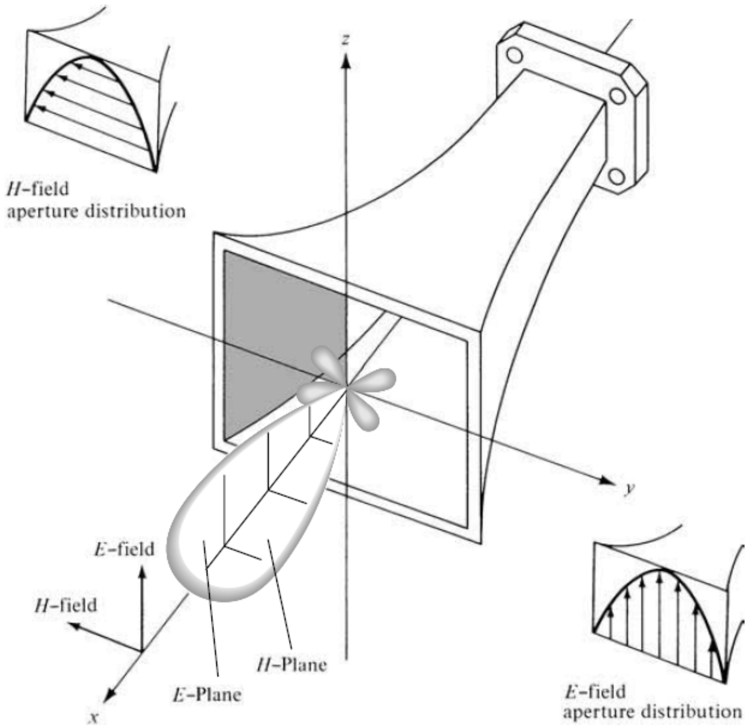


Figure 1.15: Principal E- and H-plane patterns for a pyramidal horn antenna.

1.8.4 Principal Patterns

In general the antenna radiation properties is usually expressed in termas of E-plane and H-palne patterns. In case of antenna having the linear polarisation properties, the E-field pattern is the electric field plane pattern of maximum radiation and the H-field pattern is the magnetic field plane pattern of maximum radiation. In most cases the orientation of the antenna is so adjusted to obtain at least one plane pattern which will be able to coincide with the "geometric principal planes". Figure1.16

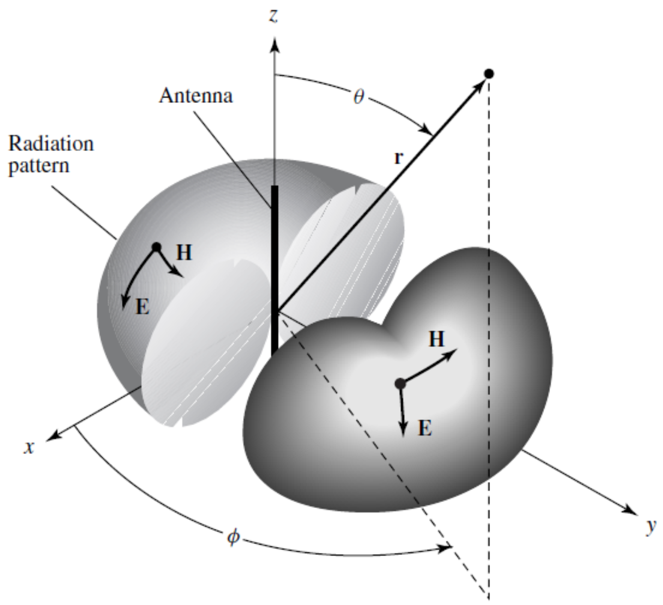


Figure 1.16: Omnidirectional antenna pattern.

1.8.5 Antenna Field Types

The three dimensional space around the antenna can be bifurcated in three different categories.

1)***Reactive near-field***: It is defined as the area or space around the antenna in which the amount of reactive field is comparably larger than the other fields. It exist at a distance very close to the physical antenna.It is at a distance of approximately R<$0.62\sqrt{D^3/\lambda}$ from the antenna.

2)***Radiating near field or the well known Fresnel region***: It is the field away from the antenna in which the radiation field percentage is more. Here the distribution of the field is totally depended on the distance from the antenna where this field is measured. It exist in between $R \geq 0.62\sqrt{D^3/\lambda}$ and $R < 2D^2/\lambda$.

3)***Far field region or well known Fraunhofer region***: As the name suggest, it is the field far away from the antenna. In these field the distribution of the field is totally independent of the distance from the antenna where this field is measured. The region beyond $2D^2/\lambda$ is actually a Far field region.

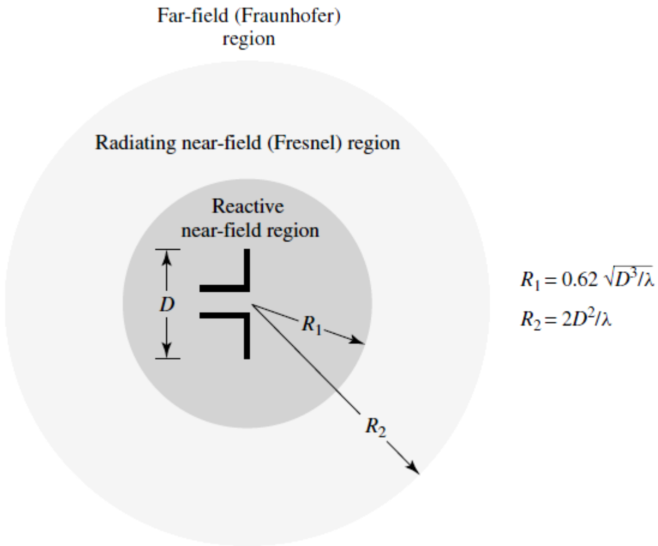


Figure 1.17: Field regions of an antenna.

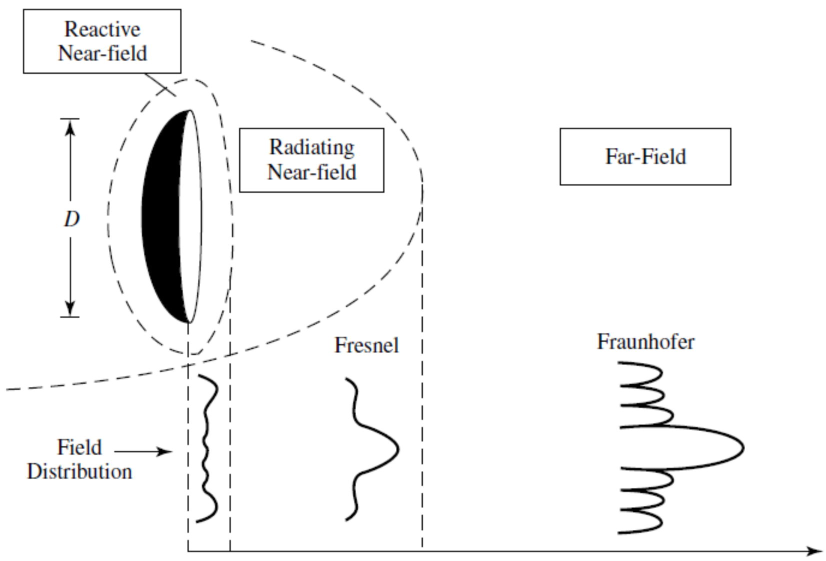


Figure 1.18: Changes of antenna amplitude pattern shape from reactive near field toward the far field.

The Figure1.17 clearly indicates the three different types of field regions. The variation of the amplitude pattern of the antenna at three different field regions is shown in the Figure1.18. We can observe, as the field starts to radiate from the antenna, it is nearly uniform and the major, minor lobes are undistinguishable. But as the filed progresses from near to far, slowly the lobes starts forming and the major lobe can be easily determined.

1.8.6 Radiation Power Density or The Pointing vector

The analysis of the electromagnetic wave emitted by the radiating element, can be easily carried out by first knowing the associated power within it. With the help of Poynting Vector we can calculate the associated power of the electromagnetic wave. It is given by,

$$\mathscr{W} = \mathscr{E} \times \mathscr{H} \tag{1.8}$$

$\mathscr{W}$ = instantaneous Poynting vector (W/m^2)

$\mathscr{E}$ = instantaneous electric-field intensity (V/m)

$\mathscr{H}$= instantaneous magnetic-field intensity (A/m)

If the power crossing a particular closed surface is to be calculated, then we make use of contour integration in which the normal component of the vector is integrated over closed surface. It is given by,

$$\mathscr{P} = \oiint \mathscr{W}.\mathrm{ds} = \oiint \mathscr{W}.\hat{n}\mathrm{da} \tag{1.9}$$

$\mathscr{P}$= instantaneous total power (W)

$\hat{n}$= unit vector normal to the surface

da= infinitesimal area of the closed surface (m2)

Average power density is need to be calculated for the pupose of time varying field analysis. Since it is an average, it is calculated by integrating the pointing vector and dividing by the period. Thus the complex $\mathscr{E}$ and $\mathscr{H}$ field are related to E and H by

$$\mathscr{E}(x, y, z; t) = Re[E(x, y, z)e^{j\omega t}] \tag{1.10}$$

$$\mathscr{H}(x, y, z; t) = Re[H(x, y, z)e^{j\omega t}] \tag{1.11}$$

Using the definitions of Eq.1.10 and Eq.1.11 and the identity $Re[Ee^{j\omega t}] = \frac{1}{2}[Ee^{j\omega t} + E^{*}e^{j\omega t}]$, Eq.1.8can be written as

$$\mathscr{W} = \mathscr{E} \times \mathscr{H} = \frac{1}{2}Re[E \times H^{*}] + \frac{1}{2}Re[E \times He^{j2\omega t}] \tag{1.12}$$

We can observe from equation 1.13 that the first term is independent of time, whereas the second term depends on twice the frequency. Thus the average pointing vector is given by

$$W_{av}(x, y, z) = [\mathscr{W}(x, y, z; t)]_{av} = \frac{1}{2}Re[E \times H^{*}](W/m^{2}) \tag{1.13}$$

The E and H filed is representing the peak values that's why the term $\frac{1}{2}$ is coming in the eq. is should be noted that this $\frac{1}{2}$ can be omitted in case of RMS value calculatons. We should emphasize on $(E \times H^{*})/2$ component. The real part of it represents the average power density and the imaginary part is representing the stored power density of electromagnetic fields. However in the far field region the power density of the EM wave is referred as radiation intensity [39]. Thus by Eq 1.14 the average power radiated is given by

$$\boxed{P_{rad} = P_{av} = \oiint W_{rad}.\mathrm{ds} = \oiint W_{av}.\hat{n}\mathrm{da} = \frac{1}{2}\oiint Re(E \times H^{*}).\mathrm{da}} \tag{1.14}$$

1.8.7 Radiation Intensity

The famous definition of the radiaton intensity is given by the many authors as "Power radiated by the antenna per unit solid angle." It is the parameter which is independent of the distance from the antenna. It is denoted by U . Here the solid angle is given by

$$d\Omega = \frac{ds}{r^2} \tag{1.15}$$

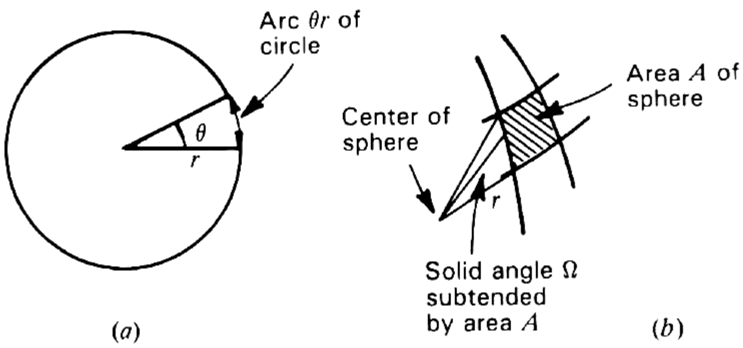


Figure 1.19: Relation between beamsolid angle and normal angle.

Its unit is steradian. And also the unit of power is watts. Then the unit of radiation intensity is watts/steradian. It is obtained by just multiplying the square of the distance to the radiation density.

$$\boxed{U = r^2 W_{rad}} \tag{1.16}$$

where

U=radiation intensity (W/unit solid angle)

W_{rad}= radiation density (W/m^2) The total power is obtained by integrating the radiation intensity, as given by Eq.1.16, over the entire solid angle of 4π. Thus

$$P_{rad} = \oiint_{\Omega} U.\mathrm{d}\Omega = \int_0^{2\pi} \int_0^{\pi} U sin(\theta)\mathrm{d}\theta\mathrm{d}\phi \tag{1.17}$$

where $d\Omega$ = element of solid angle = $sin(\theta)d(\theta)d(\phi)$.
For anisotropic source U is independent of the angles θ and ϕ, as was the case for W_{rad}. Thus Eq.1.17 can be written as

$$P_{rad} = \oiint_{\Omega} U_0 \mathrm{d}\Omega = U_0 \oiint_{\Omega} \mathrm{d}\Omega = 4\pi U_0 \tag{1.18}$$

or the radiation intensity of an isotropic source as

$$\boxed{U_0 = \frac{P_{rad}}{4\pi}} \tag{1.19}$$

1.8.8 Antenna Beamwidth

It is basically used to determine the directive properties of the antenna. The beam width of the antenna is defined as "*the angular distance between the points where the radiated power is half as compared to its maximum value*" or in another way "*it is the angular separation of the points on either side of the maximum value where the power is half of its maximum value.*" It is also called *beamwidth between half power points* or directly *Half power beam width(HPBW).*

In some applications the beamwidth is defined by considering the nulls in the radiation pattern. It is generally reffered as Beamwidth between the first null or BWFN which is the angular separation between the first nulls from the main lobe. The beamwidth of a particular antenna depends on the following factors:

1) Radiation pattern shape
2) Wavelength
3) Dimension of a particular test antenna.

Usefulness of antenna beamwidth in practical applications: If the antenna having the narrower beamwidth is used at the receiving side, it will give perfect results of, from where the signal is coming from the transmitter. As the beam

is very narrow it can find the direction where the transmitter is located. If the angle is slightly deviated the considerable changes is obtained at the output of the receiver.
Thus we can state the relation between the directivity and the beamwidth as

$$D = \frac{4\pi}{\Omega} = \frac{4\pi}{B} \tag{1.20}$$

$$D \propto \frac{1}{Beamwidth} \tag{1.21}$$

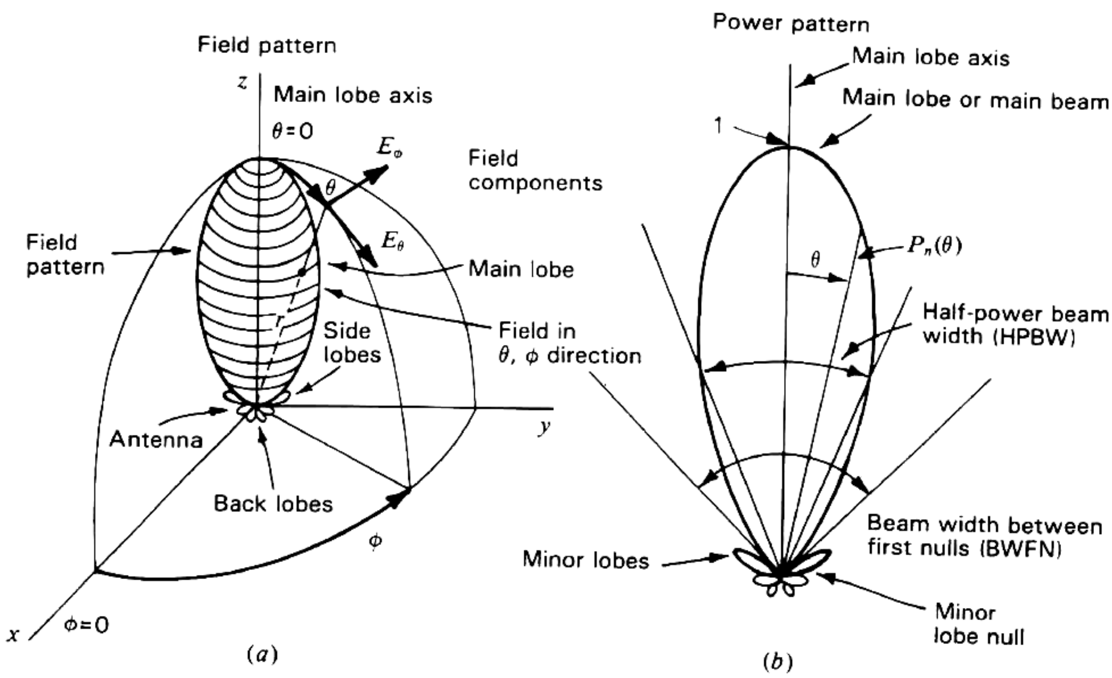


Figure 1.20: Three- and two-dimensional power patterns

Thus *the sharper the pattern the higher the gain or directivity.* This property is very much usefull in RADAR applications for detecting an echo from a particular target. Conical scanning makes use of such narrow beams.

1.8.9 Antenna Efficiency

The efficiency of the antenna can be well defined as "*the ratio of total power radiated by the antenna to the power supplied to a particular antenna.*"

$$\boxed{\text{Antenna Efficiency } (\eta) = \frac{RadiatedPower}{InputPower}} \tag{1.22}$$

Let I be the current flowing in the antenna, then

$$\eta = \frac{I^2 R_r}{I^2(R_r + R_l)} \tag{1.23}$$

$$\%\eta = \frac{R_r}{R_r + R_l} \times 100 \tag{1.24}$$

where,

R_r is the radiation resistance,

R_l is the resistance associated with the losses.

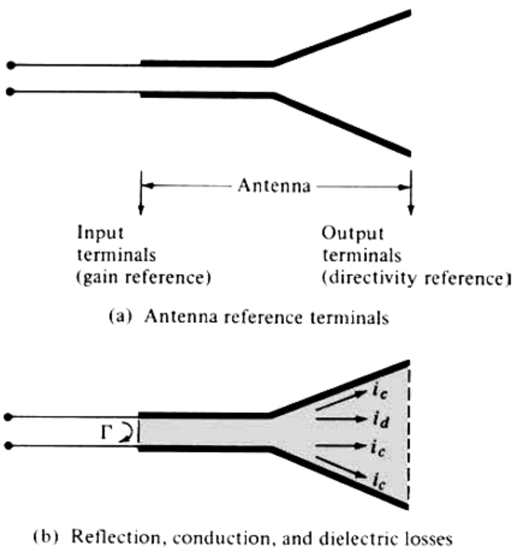


Figure 1.21: Reference terminals and losses of an antenna.

It is usually an indirect estimation of how well the antenna is working. It is associated with the losses at the input side and also the losses in the physical antenna structure. The total antenna efficiency η_0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due to

1. reflections because of the mismatch between the transmission line and the antenna
2. I^2R losses (conduction and dielectric).

In general, the overall efficiency can be written as

$$\boxed{\eta_0 = \eta_r \eta_c \eta_d} \tag{1.25}$$

where

η_0 = total efficiency (dimensionless)

η_r = reflection(mismatch) efficiency = $(1 - |\Gamma|^2)$ (dimensionless)

η_c = conduction efficiency (dimensionless)

η_d = dielectric efficiency (dimensionless)

Γ= voltage reflection coefficient at the input terminals of the antenna

$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$ where Z_{in} = antenna input impedance Z_0=characteristic impedance of the transmission line

VSWR = voltage standing wave ratio $= \frac{1+|\Gamma|}{1-|\Gamma|}$

Usually η_c and η_d are very difficult to compute, but they can be determined experimentally. Even by measurements they cannot be separated, and it is usually more convenient to write Eq.1.25 as

$$\boxed{\eta_0 = \eta_r \eta_{cd} = \eta_{cd}(1 - |\Gamma|^2)} \tag{1.26}$$

where $\eta_{cd} = \eta_c \eta_d$ = antenna radiation efficiency, which is used to relate the gain and directivity.

1.8.10 Directivity of an antenna

The directivity of an antenna is nothing but the ratio of radiation intensity of the antenna under test and the radiation intensity of a standard isotropic antenna used as a reference.

$$\boxed{D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}}} \tag{1.27}$$

If the direction is not known or not stated, then it is convenient to take it as a direction of maximum radiation. In other words the maximum directivity is given by

$$\boxed{D_{max} = D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}}} \tag{1.28}$$

where

D= directivity (dimensionless)

D_0= maximum directivity (dimensionless)

U= radiation intensity (W/unit solid angle)

U_{max}= maximum radiation intensity (W/unit solid angle)

U_0= radiation intensity of isotropic source (W/unit solid angle)

P_{rad}= total radiated power (W)

Directivity of the subject or test antenna can be referred as a how effectively that antenna is able to concentrate power into a limited solid angle.

1.8.11 Gain

Gain of an antenna is sometimes referred as a *figure of merit* of a antenna. The property of the antenna to concentrate the entire power radiated in a given or desired direction or in the receiving case the ability to absorb power efficiently from a desired direction is known as the *gain* of the antenna. Mathematically it is "*the ratio of maximum radiation intensity of the antenna under test to the maxi-*

mum radiation intensity from reference antenna applying the same input power". The radiation intensity of the isotropic antenna which here in this case acts as a reference antenna is nothing but the power accepted divided by 4π. Although the definition is similar to that of the directivity, it takes into consideration the efficiency of the antenna along with it directional properties.

The relative gain is another concept which generally used in many areas and is given as the ratio of power gain in a specified direction to the power gain of the reference antenna in the direction which is referred. If the antenna is 100% perfect i.e it does not have any losses such as I^2R, ohmic mismatch in dielectric, then the directivity and the gain can be used interchangeably.

$$\boxed{Gain = 4\pi \frac{radiation\ intensity}{total\ input\ power} = 4\pi \frac{U(\theta, \phi)}{P_{in}}} \tag{1.29}$$

In most cases we deal with *relative gain*, which is defined as "the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction." Thus

$$\boxed{G = \frac{4\pi U(\theta, \phi)}{P_{in}\ lossless\ isotropic\ source}} \tag{1.30}$$

When the direction is not stated, the power gain is usually taken in the direction of maximum radiation. We can write that the total radiated power (P_{rad}) is related to the total input power (P_{in}) by

$$P_{rad} = \eta_{cd} P_{in} \tag{1.31}$$

Using Eq.1.31 reduces Eq.1.30) to

$$G(\theta, \phi) = \eta_{cd} \left[4\pi \frac{U(\theta, \phi)}{P_{rad}} \right] \tag{1.32}$$

which is related to the directivity of (2-16) and (2-21) by

$$\boxed{G(\theta, \phi) = \eta_{cd} D(\theta, \phi)} \tag{1.33}$$

In a similar manner, the maximum value of the gain is related to the maximum directivity of Eq.1.27 by

$$\boxed{G_0 = G(\theta, \phi)|_{max} = \eta_{cd} D(\theta, \phi)|_{max} = \eta_{cd} D_0} \tag{1.34}$$

1.8.12 Bandwidth

The bandwidth Δf of an antenna is the range of frequencies at which

1) The gain of the antenna is higher than some desired value,

2) The satisfactory front to back ration is achieved,

3) The standing wave ratio on the transmission line or the feed line can be obtained below the standard value,

4) The return loss or typically the S11 parameter is below -10 dB line in case of patch antennas.

Alternatively, the bandwidth is the range of frequency on both side of the centre frequency at which the antenna fullfills all the desired performance characteristics.

As the wavelength decreases exponentially with frequency, two adjacent frequencies on the lower side of the frequency axis (e.g. 1 to 2 GHz) will have a much larger wavelength difference than two adjacent frequencies on the higher frequency axis (e.g. 5 to 6 GHz). Designing an antenna with larger bandwidth (S11 and AR) is more challenging at lower frequencies than higher frequencies. Therefore, fractional bandwidth is a just way of representing an antenna impedance or AR bandwidth (BW for AR dB). Bandwidths $>$ 10% are considered as wideband and they are called ultra-wideband if they have a FBW $>$ 20%.

The bandwidth of antenna is also related to the *quality factor(Q)* of the antenna as:-

$$\Delta f = f_2 - f_1 = \frac{f_r}{Q} = Bandwidth \tag{1.35}$$

$$\Delta f = \frac{f_r}{Q} \tag{1.36}$$

$$\Delta f \propto \frac{1}{Q} \tag{1.37}$$

where,

f_r is the resonant frequency,

Q=quality factor of an antenna which is given by,

$$\boxed{Q = 2\pi \frac{Total\ energy\ stored\ by\ the\ antenna}{Energy\ dissipated\ or\ radiated\ per\ cycle}} \tag{1.38}$$

This means "*the lower the value of Q the higher will be the Bandwidth of an antenna.*"

The normalized or the *fractional bandwidth (FBW)* of an antenna can be expressed as:

$$\boxed{FBW = \frac{BW}{f_c} = \frac{f_1 - f_2}{\frac{f_1+f_2}{2}}} \tag{1.39}$$

1.8.13 Polarization

The *polarization* of the antenna is stated in many text as "the orientation of the electric field vector of an electromagnetic wave in the given direction" or it may also be defined as "the shape or the locus made by the tip of the vector electric field while propagating in space from one point to another point". It is the most important phenomenon in the field of wireless communication.

The polarization radiation sphere can be subdivided into two categories i.e. *Co-*

polarisation and *Cross-polarisation.* Suppose the antenna is designed to operate in the vertical polarisation. So for this antenna the vertical polarisation is called the *Co-polarisation.* However due to some spurious radiation, some orthogonal polarisation componets also gets radiated which in the present case is the horizontal polarisation which usually undesired. This type of polarisation is called as *Cross polarisation.* This cross polarisation component interferes with th co-polarisation component to distort the signal. So to keep the distortion minimum the value of the cross polarisation must be less as compared to the co polarisation component.

Linear, Circular, and Elliptical Polarizations The instantaneous field of an associated plane wave, traveling in the negative z direction, can be given by

$$\mathscr{E}(z;t) = \hat{a_x}\mathscr{E}_x(z;t) + \hat{a_y}\mathscr{E}_y(z;t) \tag{1.40}$$

The instantaneous components are related to their complex counterparts by

$$\mathscr{E}_x(z;t) = Re[E_x^- e^{j(\omega t+kz)}] = Re[E_{x0}e^{j(\omega t+kz+\phi_x)}] = E_{x0}cos(\omega t + kz + \phi x) \tag{1.41}$$
$$\mathscr{E}_y(z;t) = Re[E_y^- e^{j(\omega t+kz)}] = Re[E_{y0}e^{j(\omega t+kz+\phi_y)}] = E_{y0}cos(\omega t + kz + \phi y) \tag{1.42}$$

E_{x0} and E_{y0} are, respectively, the maximum magnitudes of the x and y components.

A.*Linear Polarization* The phase difference of the linearly polarized wave can be expressed as:

$$\Delta\phi = \phi_y - \phi_x = n\pi, \quad n = 0, 1, 2, 3, ... \tag{1.43}$$

The electromagnetic wave is said to be a *linearly polarized* one, if the vector of the electric field does not rotate while travelling from one point to another. It should be fixed along one particular direction.

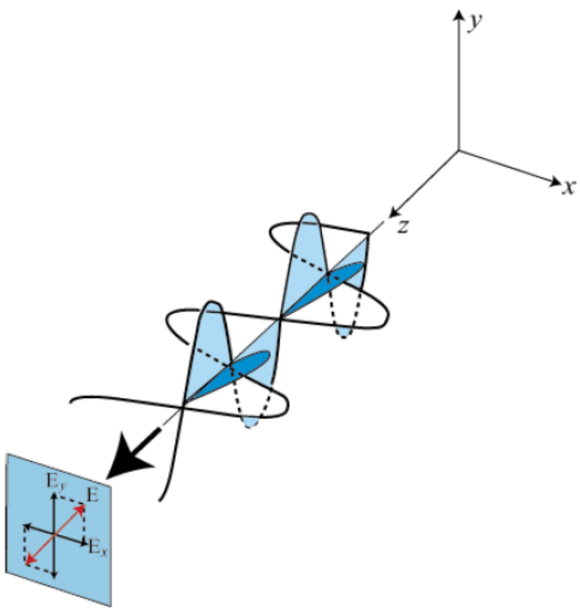


Figure 1.22: Linearly Polarized wave.

B. *Circular Polarization*

If the magnitude of the orthogonal component is similar and their associated phase difference is $\frac{\pi}{2}$ or its odd multiples. Then the resultant wave is said to be *circularly polarized* wave. That is,

$$E_{x0} = E_{y0}$$

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} +(\frac{1}{2} + 2n)\pi, n = 0, 1, 2, ... & for\ CW \\ -(\frac{1}{2} + 2n)\pi, n = 0, 1, 2, ... & for\ CCW \end{cases} \tag{1.44}$$

In other words, if the tip of the electric field vector traces a perfect circle of constant radius while propagating, then the wave will be a circularly polarized one. This has two types, *Left circularly polarized wave* and *Right circularly polarized wave*. To judge the type of polarization, the observer should assume that the wave is coming towards him. If the observer sees the electric field vector coming towards him in clockwise direction then the wave is *Left handed circularly polar-*

ized wave. If the observer sees the electric field vector coming towards him in an anti-clockwise direction then the wave is *Right handed circularly polarized wave.*

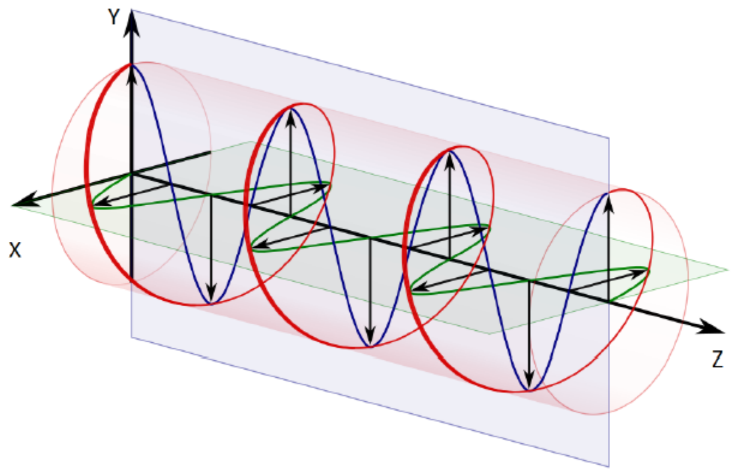


Figure 1.23: Circularly Polarized wave.

C.*Elliptical Polarization*

The most basic definition of the *elliptically polarized wave* is that the wave which is neither linearly polarized nor is circularly polarized, is called the *elliptically polarized wave.* Or it can be stated mathematically as, if the magnitude of the orthogonal component is not similar but have the phase difference of $\frac{\pi}{2}$ or odd multiples of $\frac{\pi}{2}$. Or if the orthogonal component has the phase difference other than of $\frac{\pi}{2}$ or multiples of $\frac{\pi}{2}$.. That is,

$$E_{x0} \neq E_{y0}$$

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} +(\frac{1}{2} + 2n)\pi, n = 0, 1, 2, ... & for\ CW \\ -(\frac{1}{2} + 2n)\pi, n = 0, 1, 2, ... & for\ CCW \end{cases} \tag{1.45}$$

or

$$\Delta\phi = \phi_y - \phi_x \neq \pm\frac{n}{2}\pi = \begin{cases} > 0 & forCW \\ < 0 & forCCW \end{cases} \tag{1.46}$$

If the tip of the electric field vector traces an ellipse while propagating, then the wave will be a elliptically polarized one.

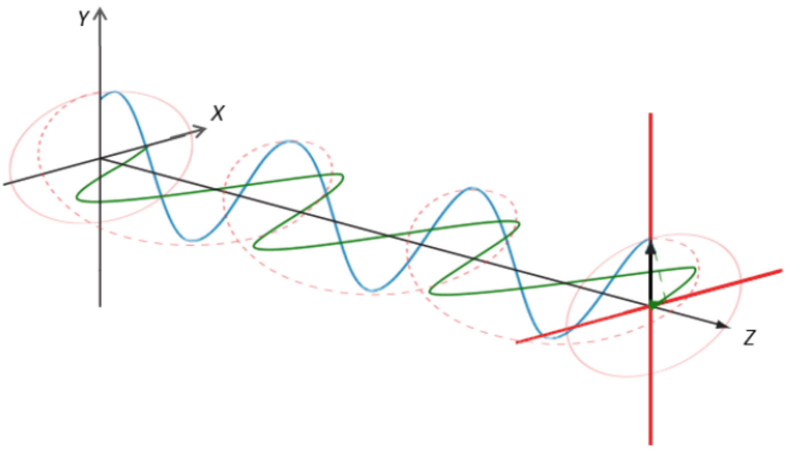


Figure 1.24: Ellipticaly Polarized wave.

This has also two types, *Left elliptically polarized wave* and *Right elliptically polarized wave*. If the observer sees the electric field vector coming towards him in clockwise direction then the wave is *Left handed elliptically polarized wave*. If the observer sees the electric field vector coming towards him in an anti-clockwise direction then the wave is *Right handed circularly polarized wave*.

Axial Ratio The ratio of the major axis to the minor axis is referred to as the axial ratio (AR), and it is equal to

$$AR = \frac{major\ axis}{minor\ axis} = \frac{OA}{OB}, \qquad 1 \leq AR \leq \infty \tag{1.47}$$

So we can conclude from the formula that the

AR=1 for circular polarization;

$1 < AR < \infty$ for elliptical polarization;

$AR = \infty$ for linear polarization.

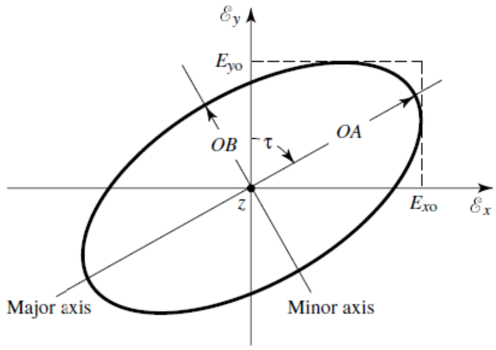


Figure 1.25: Major and minor axis determination.

1.8.14 Polarization Loss Factor and Efficiency

The polarizatio of the EM wave radiated by the antenna plays very important role in almost all communication links. If not adjusted properly situation may arise that our entire communication system may fail. In many circumstances the receiving antenna polarization will not be identical to that of the transmitting antenna.

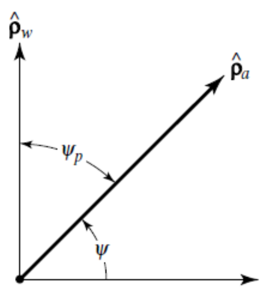


Figure 1.26: Polarization unit vectors of incident wave ($\hat{\rho_w}$) and antenna ($\hat{\rho_w}$), and polarization loss factor (PLF).

This phenomenon is generally referred as a *Polarization mismatch* and it should not be ignored. The power absorbed or extracted by the receiving antenna from the input electromagnetic waves will fail to reach its desired values because of this phenomenon of Polarization mismatch.

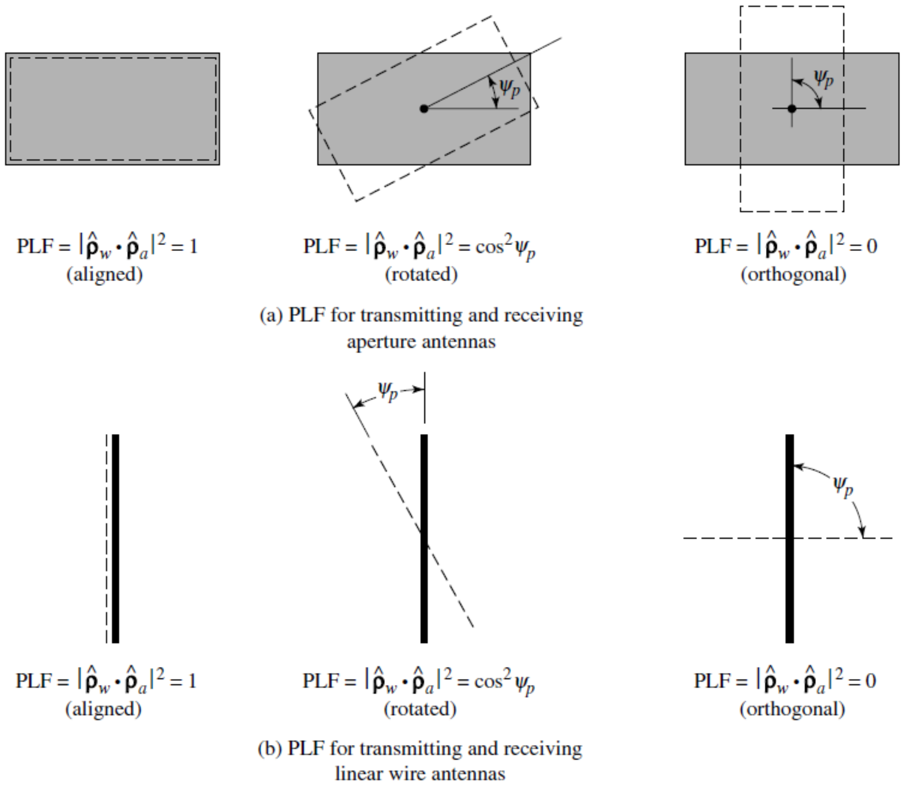


Figure 1.27: Polarization loss factors (PLF) for aperture and linear wire antennas.

Let us assume the electric field if the input signal is given as

$$E_i = \hat{\rho}_w E_i \tag{1.48}$$

The $\hat{\rho}_w$ is the associated unit vector of the incoming wave The receiving antennas electric field polarization state is given by

$$Eai = \hat{\rho}_a E_a \tag{1.49}$$

Where $\hat{\rho}_a$ is the corresponding unit vector The polarization loss factor is then calculated as the square of these unit vector quantities. ψ_p denotes the angular separation between these two vectors.

$$PLF = |\hat{\rho}_w.\hat{\rho}_a|^2 = |cos(\psi_p)|^2 \tag{1.50}$$

If the received antenna is perfectly aligned to its transmitting counterpart, then the PLF factor will be unity due to which the receiving antenna will absorb maximum power. The polarization efficiency is generally stated as as "*the ratio of the power received by an antenna from a given plane wave of arbitrary polarization to the power that would be received by the same antenna from a plane wave of the same power flux density and direction of propagation, whose state of polarization has been adjusted for a maximum received power.*" This is similar to the PLF and it is expressed as

$$p_e = \frac{|l_e.E^{inc}|^2}{|l_e^2||E^{inc}|^2} \tag{1.51}$$

where l_e= vector effective length of the antenna E^{inc}= incident electric fieldwhere

1.8.15 Input Impedance of an antenna:

The input impedance antenna is the impedance or the load observed by the feed line or transmission line when it delivers power to the antenna or radiating element. It is the main parameter of the antenna and it should be given by the manufacturer. The input impedance of the antenna is generally frequency dependent i.e. it varies with frequency. For faithful working of the antenna and to radiate maximum power, complete power must be transferred from transmission line to the radiating element. For this to happen the role of input impedance comes into picture. We know from theory that maximum power transmission is possible if the characteristic impedance of the feed line is matched to the load. Here the load is the input impedance of the antenna. Several means are adapted by the researchers to match these two parameters either by employing quarter wave transformer or by using stubs. The input impedance is a combination of resistance and reactance thus making it frequency dependent.

$$\boxed{Z_a = R_a + jX_a} \tag{1.52}$$

where

Z_A = antenna impedance at terminals a-b (ohms)

R_A = antenna resistance at terminals a-b (ohms)

X_A = antenna reactance at terminals a-b (ohms)

In general the resistive part of Eq.1.52 consists of two components; that is

$$\boxed{R_a = R_r + R_L} \tag{1.53}$$

where

R_r = radiation resistance of the antenna

R_L = loss resistance of the antenna

Assuming that the antenna is attached to a generator with internal impedance, then

$$\boxed{Z_g = R_g + jX_g} \tag{1.54}$$

where

R_g = resistance of generator impedance (ohms)

X_g = reactance of generator impedance (ohms)

The input impedance of an antenna is generally a function of frequency. Thus the antenna will be matched to the interconnecting transmission line and other associated equipment only within a bandwidth.

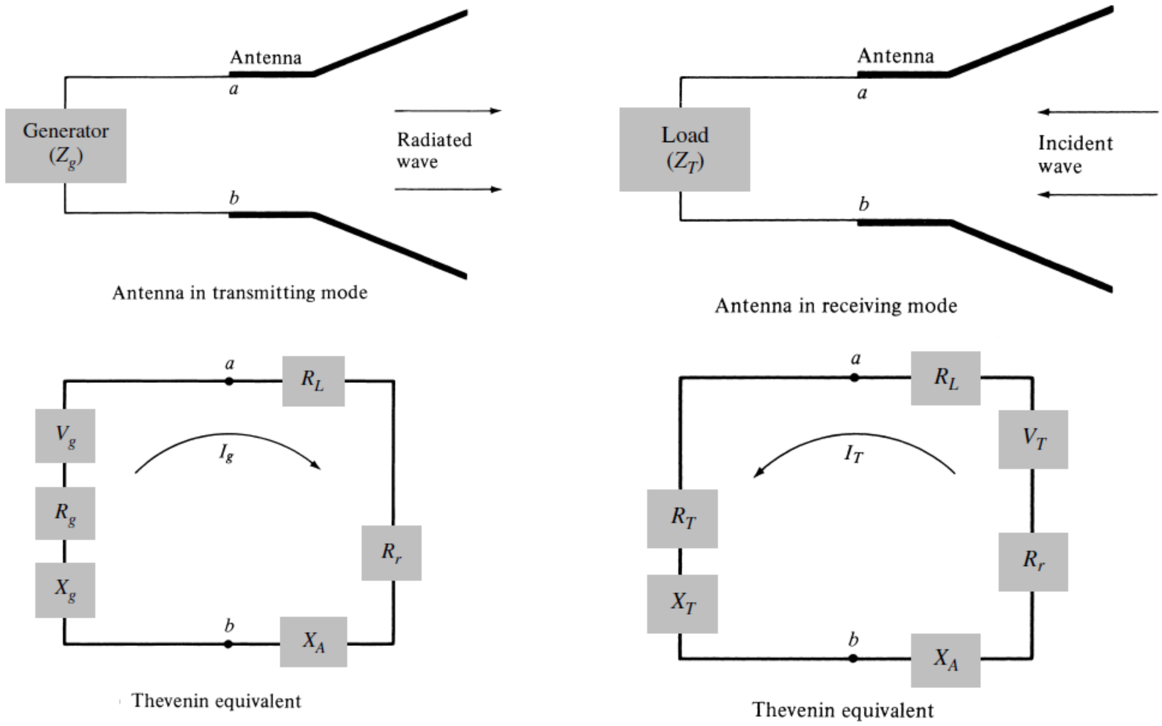


Figure 1.28: Transmitting and Receiving antenna and its equivalent circuits.

1.8.16 Antenna Equivalent Areas

The *effective area (aperture)* of a particular direction is defined as "the ratio of the available power at the terminals of a receiving antenna to the power flux density of a plane wave incident on the antenna from that direction, the wave being polarization-matched to the antenna." If the direction is not specified, the direction of maximum radiation intensity is implied. In equation form it is written as

$$A_e = \frac{P_T}{W_i} = \frac{|I_T|^2 R_T/2}{W_i} \tag{1.55}$$

where

A_e = effective area (effective aperture) (m^2)

P_T = power delivered to the load (W)

W_i = power density of incident wave (W/m^2)

The effective aperture is the area which when multiplied by the incident power density gives the power delivered to the load.

$$A_e = \frac{|V_T|^2}{2W_i}\left[\frac{R_T}{(R_r + R_L + R_T)^2 + (X_A + X_T)^2}\right] \tag{1.56}$$

Under conditions of maximum power transfer (conjugate matching), $R_r + R_L = R_T$ and $X_A = X_T$, the effective area of Eq.1.56 reduces to the maximum effective aperture given by

$$A_e = \frac{|V_T|^2}{8W_i}\left[\frac{R_T}{(R_L + R_r)^2}\right] = \frac{|V_T|^2}{8W_i}\left[\frac{1}{(R_L + R_r)}\right] \tag{1.57}$$

All of the power which is intercepted, collected, or captured by an antenna is not delivered completely to the load, as we have seen using the equivalent circuit of Figure**??**. In fact, under conjugate matching only half of the captured power is delivered to the load; the other half is scattered and dissipated as heat. Therefore to account for the scattered and dissipated power we need to define, in addition to the effective area, the scattering, loss and capture equivalent areas. In equation form these can be defined similarly to Eq.1.55-1.57 for the effective area.

The *scattering area* is defined as "the equivalent area when multiplied by the incident power density is equal to the scattered or reradiated power".It is given by

$$A_s = \frac{|V_T|^2}{8W_i}\left[\frac{R_r}{(R_L + R_r)^2}\right] \tag{1.58}$$

The *loss area* is defined as the "equivalent area, which when multiplied by the incident power density leads to the power dissipated as heat through R_L." It is given by

$$A_L = \frac{|V_T|^2}{8W_i}\left[\frac{R_L}{(R_L + R_r)^2}\right] \tag{1.59}$$

Finally the *capture area* is defined as “the equivalent area, which when multiplied by the incident power density leads to the total power captured, collected, or intercepted by the antenna.”

$$A_c = \frac{|V_T|^2}{8W_i}\left[\frac{R_T + R_r + RL}{(R_L + R_r)^2}\right] \tag{1.60}$$

The total capture area is thus the sum of the other three areas as given below

$$\boxed{\textit{Capture Area} = \textit{Effective Area} + \textit{Scattering Area} + \textit{Loss Area}}$$

Aperture Efficiency

The *aperture efficiency* ϵ_{ap} of an antenna, is the ratio of the maximum effective area A_{em} of the antenna to its physical area A_p,

$$\epsilon_{ap} = \frac{A_{em}}{A_p} = \frac{\text{maximum effectivec area}}{\text{physical area}} \tag{1.61}$$

Relationship between Maximum Effective Aperture A_{em} and Maximum Directivity D_0.

The maximum *effective aperture* A_{em} of any antenna is related to its *maximum directivity* D_0 by

$$\boxed{A_{em} = \frac{\lambda^2}{4\pi}D_0} \tag{1.62}$$

When Eq.1.62 is multiplied by the power density of the incident wave it leads to the maximum power that can be supplied to the load. If there are losses associated with an antenna, its maximum effective aperture of Eq.1.62 must be modified to account for conduction-dielectric losses (radiation efficiency). Thus,

$$\boxed{A_{em} = e_{cd}\left(\frac{\lambda^2}{4\pi}D_0\right)} \tag{1.63}$$

CHAPTER 2

Microstrip Patch Antenna Theory

2.1 Microstrip Patch Antenna Background

The microstrip patch antennas or simply MPA's are the planar antennas [5] which is gaining much popularity in the past decade. It finds variety of applications in many areas due to its numerous advantages [16]. It is especially the main research topics of many researchers across the world. These antennas are assumed to replace the other conventional antennas in the coming years.

It consists of a substrate material of some dielectric constant. The upper layer of this substrate consists of the radiating element known as the *patch*. And finally at the backside it consists of a ground plane. The name microstrip antenna comes due to the use of *microstrip line* which is used to give or supply microwave power to the radiating element [16].

Initially the microwave enginners usually employs *striplines* to fabricate the circuits in microwave devices. It consists of two conductors acting as a ground plane and a strip in the middle of it, for guiding the signal. As the advancement of technology has taken place in the past years, it is replaced by the similar structure known as a *microstrip line*. The main advantage of microstrip line as compared to strip line is that the former can be made by monolithic integrated circuits [1] [21].

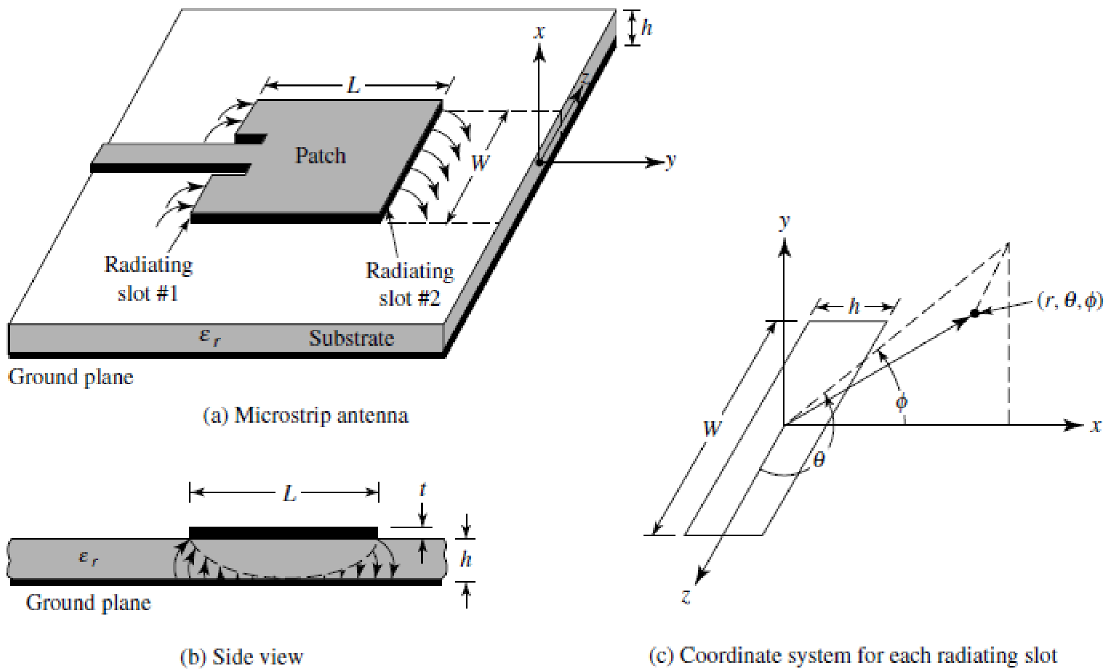


Figure 2.1: Microstrip antenna and coordinate system.

2.2 Feeding Methods

There are large numbers of techniques used to feed microstrip patch antenna.

(a) Microstrip line feed,

(b) Coaxial probe feed,

(c) Aperture coupled feed,

(d) Proximity-coupled feed.

Each method has some merits and demerits. According to our need we can choose any one of suitable technique. The basic function of a feedline is to transfer electrical power from transmission line to patch. There should be accurate impedance matching between feed line and radiating patch. For impedance matching to take place we need extra matching circuitry. Therefore feedline should be designed keeping in mind the matching circuit should be designed with radiating patch. If we increase the thickness of dielectric substrate, it will increase bandwidth but also has the effect of surface wave as well as spurious feed radiation [34].

Two parameters, spurious feed radiation as well as surface wave depend on the structure of the feed line. Spurious feed radiation introduce side lobe in radiation pattern as well as increase the cross polarisation and the surface wave affects the efficiency of antenna.

Out of the above mentioned feeding techniques, Microstrip line feed and Coaxial probe feed are contacting feeding technique because feedline directly connected to metallic patch. Whereas Proximity coupled and Aperture coupled feeding techniques are non-contacting feeding techniques because feedline mutually coupled to metallic patch. In contacting feeding techniques spurious feed radiation is more as compared to non-contacting feeding techniques. So in both microstrip line feed as well as coaxial feed, introduction of side lobe and generate higher order mode cause increase cross-polarization are more compare to aperture coupled and proximity coupled feeding techniques.

2.2.1 Microstrip Line Feed

Microstrip line feed consist of a metal stripline of thickness equal to radiating patch [2]. Its width is much less as compared to the patch. In this method antenna comprises of two metal layers of patch and ground plane on both side of dielectric substrate. This is most basic form of feeding technique and easy to manufacture. The main advantage using this technique is that the impedance matching is very easy by position control only [18]. This technique is contacting technique, so feedline is directly connected to patch [33]. Therefore it introduce more surface wave and higher order mode which gives rise to cross-polarization. Its bandwidth is also very less about 2-5%.

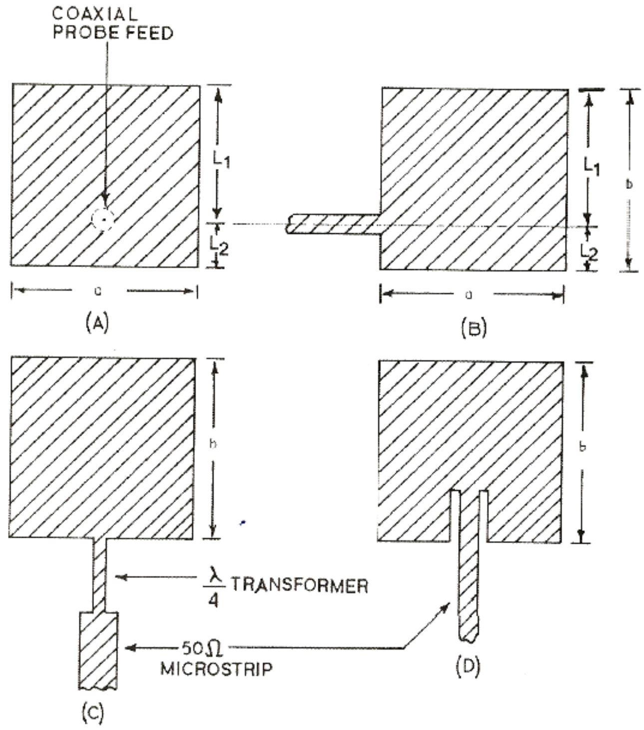


Figure 2.2: a) Co-axial feeding; b), c) and d) Strip line feeding methods.

2.2.2 Coaxial Probe Feed

It is also a contacting feed technique. Coaxial probe consists of two coaxial conductors especially an SMA connector. Inner conductor is connected to metallic patch and outer conductor connected to the ground plane. It is simple in structure. It is however difficult to implement if thickness of substrate is very high. The spurious feed radiation here is less compare to microstrip line feed. It also generate higher order mode and surface wave causes introduction of cross-polarization and side lobe.

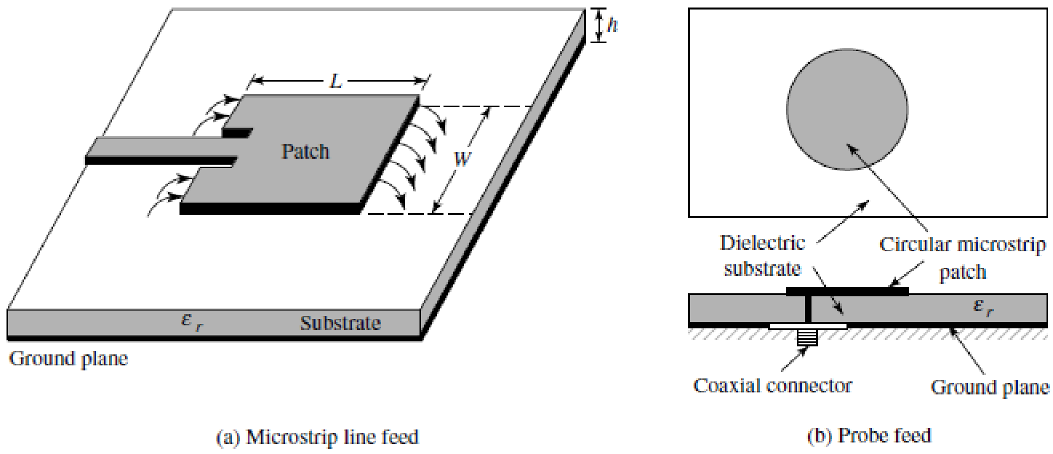


Figure 2.3: Microstrip line feed and probe feed.

Its bandwidth is also very less like microstrip feeding technique. To overcome problems in contacting feeding techniques, non-contacting feeding techniques are introduced which are discussed below.

2.2.3 Aperture-coupled feed

In aperture coupled technique two different substrates are utilised, separated by metallic ground plane. Radiating patch is on the top side of upper substrate and feedline is placed just below the bottom substrate. This technique is most difficult in comparison to others. Bandwidth and field pattern depends on dimensions and dielectric constant of bottom substrate i.e. feedline substrate. Thickness of bottom dielectric substrate is less and permittivity is high as compare to upper substrate to increase the bandwidth and for good field pattern. Thickness of upper dielectric should be less to reduce the generation of fringing field. Field is mutually coupled to the patch from feed line through slot created in ground plane. Different types of shape of slot are used. The circular and rectangular shaped slots are popular. This is a non-contacting technique.

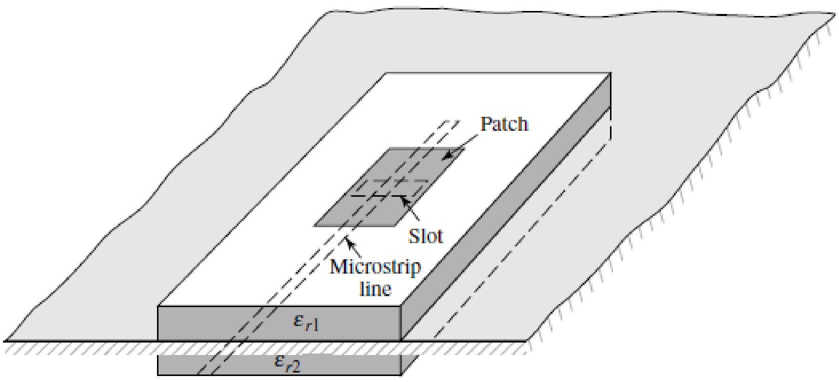


Figure 2.4: Aperture-coupled feed.

Maximum field coupling can be achieved by proper dimension of slot and positioning of slot and feedline. Its bandwidth is very less and fabrication is easy. Feedline is separated from radiating patch because of the ground plane. Therefore spurious feed radiation is very less causing lower cross-polarization and higher polarization purity. From electrical theory of distribution of voltage and current, E-field is max at the corner and H-field is max at the centre. If aperture slot is just below the centre of the patch then H-field is max and E-field is zero. For better impedance matching, feedline is stretched over slots. The extra portion of extended feedline acts as open circuit stub. Stub reduces the reactive component of aperture or slot.

2.2.4 Proximity-Coupled Feed

Proximity-coupled technique is also a non-contacting technique. In this technique also the cocept of two dielectric substrates are used which are separated by microstrip feedline. Energy is mutually coupled to patch from feedline. To increase the bandwidth and improve the field pattern high dielectric constant and thin substrate is used as bottom substrate as compare to upper substrate. Upper substrate should be thin to reduce the fringing field . Spurious feed radiation is less as the feedline is separated from radiating patch.

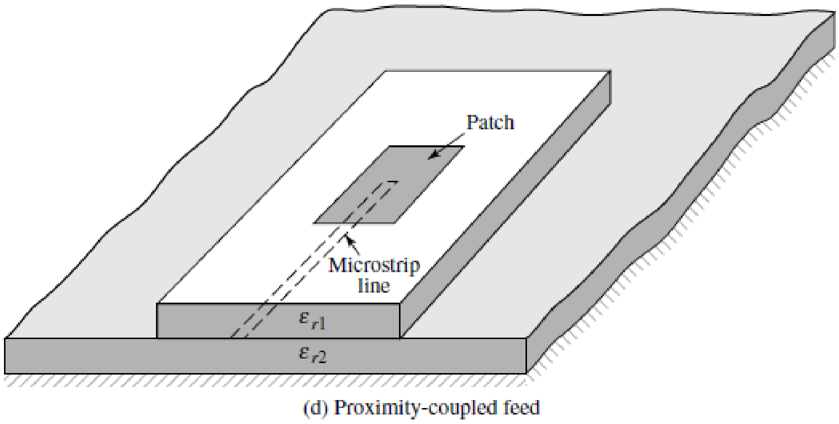


Figure 2.5: Proximity-coupled feed.

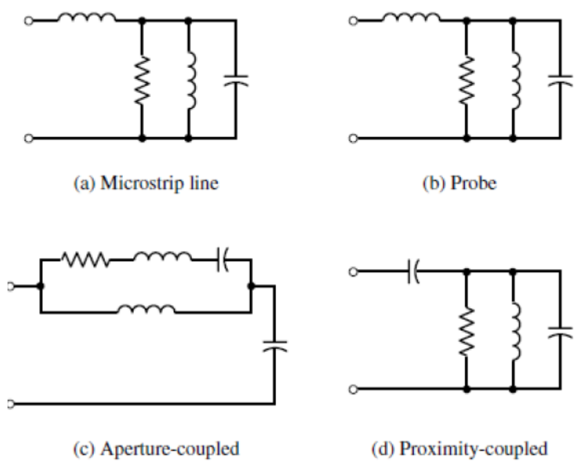


Figure 2.6: Equivalent circuits for typical feeds.

Its fabrication is difficult because of critical management of position of feedline is difficult. Bandwidth of proximity coupled technique is high (approximately 13%) as compare to other techniques. The equivalent circuit diagram of above four techniques is shown in illustrated in the figure below.

2.3 Various microstrip antenna configurations

2.3.1 Microstrip patch antennas

The patch antenna as the name suggest consist of a radiating patch at the top of the substrate [2] [25]. This patch is soleley responsible for the radiation of the electromagnetics wave.

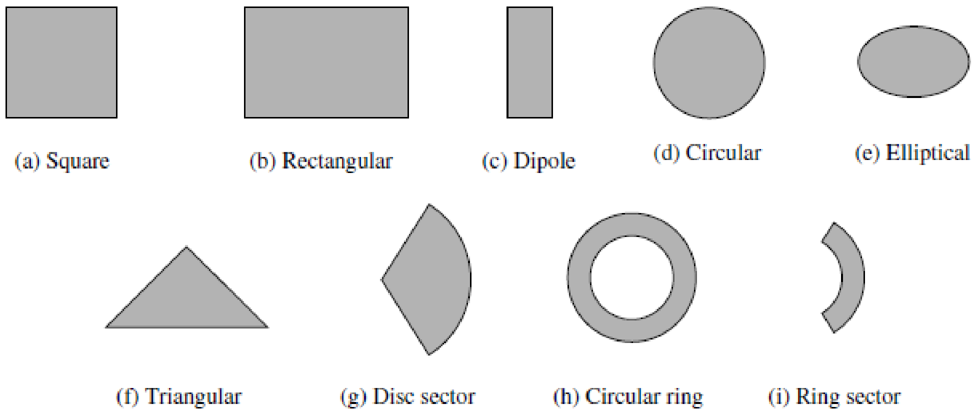


Figure 2.7: Representative shapes of microstrip patch elements.

The radiating element of the antenna may take several shapes. Some of the various configurations are shown in the Figure 2.7. Different shapes has its special purpose and applications.

2.3.2 Microstrip traveling-wave antennas

Microstrip traveling-wave antennas or simply MTA consists of chain-shaped periodic conductors or an ordinary long TEM line which also can supports a TE mode, on a substrate with a ground plane on other side. The open end of the TEM line is terminated in a matched resistive load. Different configurations for MTA are shown in Figure 2.8.

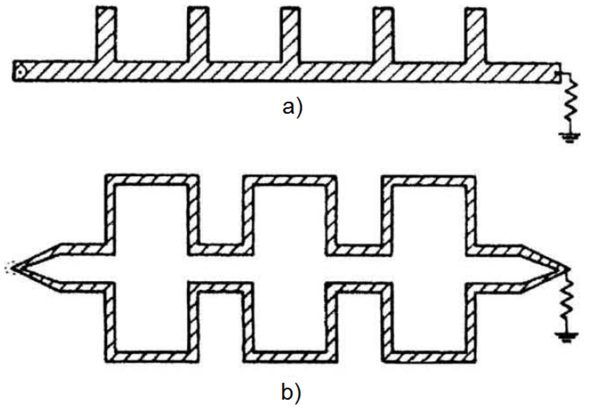


Figure 2.8: Microstrip traveling-wave antennas configurations.

2.3.3 Microstrip slot antennas

A microstrip slot antenna consist of a slot cut in the ground plane area perpendicular to the strip conductor of a microstrip line. The slot is excited by the energy propagating in the strip transmission line. The slot may have the shape of a rectangle, a circle or an annulus as shown in Figure 2.9.

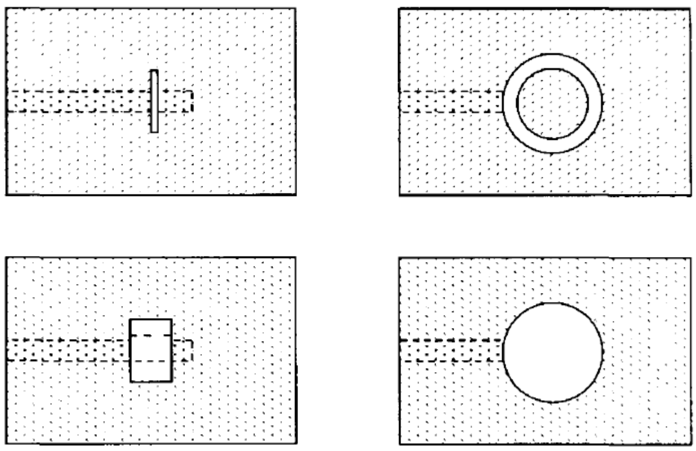


Figure 2.9: Microstrip slot antennas.

2.4 Rectangular Patch Analysis

The rectangular patch antenna is the most widely used antenna configuration [2] [18]. It is very easy to analyze this type of antenna by using both the transmission-line and cavity models, which are almost accurate for thin substrates. The rectangular microstrip patch antenna can be analysed using two famous techniques or models known as *the transmission line model* and *the cavity model.*

2.4.1 Transmission-Line Model

Transmission line model is one of the easiest one for the analysis of rectangular microstrip patch antenna. It provides very basic picture or equivalent model for the patch antennas.

This model usually makes use of the concept of the transmission line. In this model the patch antennas analysis is carried out by assuming the microstrip antenna structure as an arrangement having a transmission line which is feeding some power in two separate symmetrical loads [40]. This is shown in the Figure2.10. The resistive component of the load is nothing but the radiation losses [40].

In c+ase of resonance or when the antenna is operated in its resonance frequency, the imaginary part of the input impedance of the patch cancels each other. Thus the input impedance is purely real or resistive so that complete absorption of power takes place coming from the feed line.

The point where the transmission line or feed line is connected to the radiated element, in order to supply microwave signals, is called the *driving point* of the antenna. And the impedance associated with that point is called the *driving point impedance* or generally input impedance. This input impedance can be easily calculated with the help of this transmission line model. The most famous form in which the driving point impedance is represented is when it is in terms if admittances.

$$Y_{in} = Y_0 \frac{Y_L + jY_0 tan(\beta L)}{Y_0 + jY_L tan(\beta L)} \tag{2.1}$$

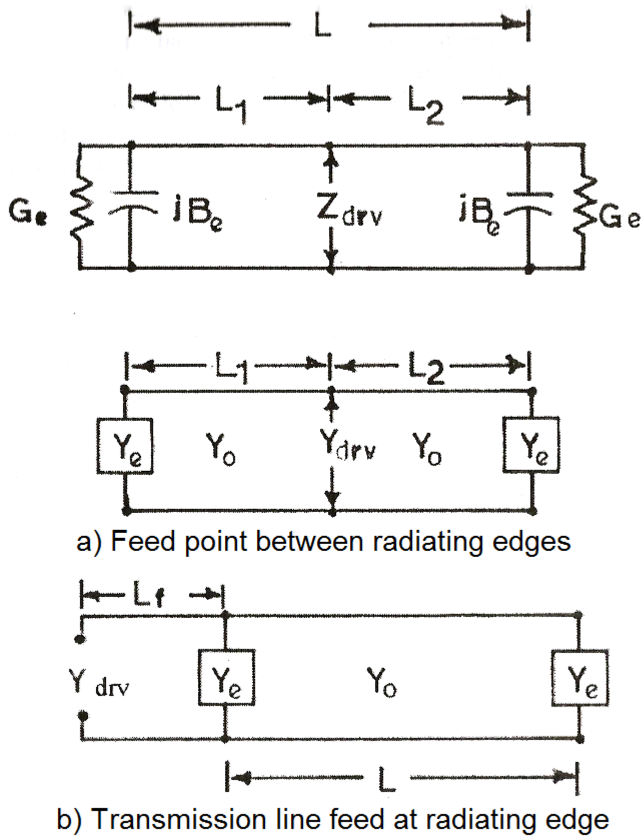


Figure 2.10: The transmission line model of a rectangular microstrip patch antenna.

Thus the input admittance of the antenna is the admittance which is located at the end of transmission line. This line has a chracatreistic admittance of Y_0 having Y_L as the load admittance. So we can visualize that this transmission line of characteristic admittance of Y_0 is feeding complex load having admittance depended on frequencies. It should also be noted that the Y_e represents the radiation loss and is known as *Edge admittance*. The driving point admitance is given by

$$Y_{drv} = frac1Z_{drv} \tag{2.2}$$

Using equation (previous), the driving point admittance $Y_{drv} = 1/Z_{drv}$ at a driving point between the two radiating edges is given by

$$Y_{drv} = Y_0 \left[\frac{Y_e + jY_0 tan(\beta L_1)}{Y_0 + jY_e tan(\beta L_1)} + \frac{Y_e + jY_0 tan(\beta L_2)}{Y_0 + jY_e tan(\beta L_2)} \right] \tag{2.3}$$

The edge admittance Y_e can be expressed as edge conductance G_e and edge susceptance B_e. The transmission line having characteristics admittance Y_0 separates the two loads.

$$Y_e = G_e + jB_e \tag{2.4}$$

A.*Fringing Effect*

The fields at the edges of the patch experience the fringing effects due to the smaller dimensions of the patch and the inputed higher frequency. Fringing is predominant at higher or microwave frequencies near to discontinuous edges of the device. The fringing is also depended upon the height of the substrate. The field lines are shown in the Figure2.11. As we can see that the maximum percent of the line reside in the substrate but also some considerable amount of field also present in air. The filed mostly confined in the substrate because W/h≫1 and the dielectric constant of the substrate $\epsilon_r \gg 1$. Due to the effect of feeding the behaviour of th microstrip line is not only dependent on its physical dimensions but also the air surrounding it, making it look a little wider. So the phenomenon effective dielectric constant ϵ_{reff} is introduced in analysis. It is given by

$$W/h > 1$$

$$\boxed{\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}} \tag{2.5}$$

The effective length of the antenna:

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{2.6}$$

The radiating element generally known as the patch looks greater than its physical dimension due the effect of fringing fields. Thus for further analysis the length of the patch is extendend on either side by delta L which is given by

$$L_{\text{eff}} = L + 2\Delta L \tag{2.7}$$

The resonant frequency at which the input impedance is purely real is given by

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} = \frac{v_0}{2L\sqrt{\epsilon_r}} \tag{2.8}$$

The above equation can be slightly modified if we consider the effect of fringing fields and including edge effects.

$$(f_{rc})_{010} = \frac{1}{2L_{\text{eff}}\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} = \frac{1}{2(L + 2\Delta L)\sqrt{\epsilon_{\text{eff}}}\sqrt{\mu_0\epsilon_0}} = q\frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} = q\frac{v_0}{2L\sqrt{\epsilon_r}} \tag{2.9}$$

where

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \tag{2.10}$$

The actual length of the patch can now be determined by solving Eq.2.9 for L, or

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \tag{2.11}$$

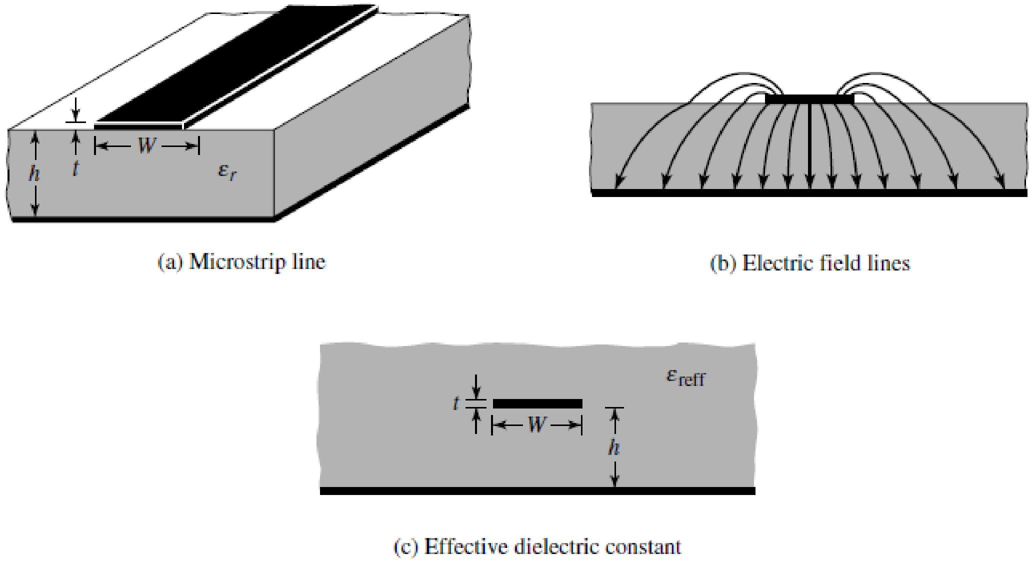


Figure 2.11: Microstrip line and its electric field lines, and effective dielectric constant geometry.

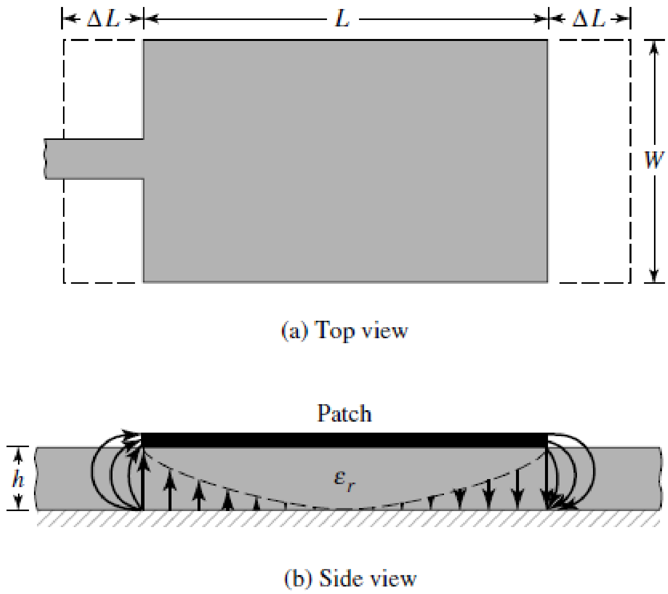


Figure 2.12: Physical and effective lengths of rectangular microstrip patch.

2.4.2 Cavity Model

Although the transmission line is widely used due to its simplicity and lucidity, it often avoided in some accurate analysis because of its disadvantages. Some of them are listed below:

1) The transmission line model works good for finding the input impedance for the thicker substrate. But it is inaccurate when the substrates used are thin. For thinner substrate the calculated and the actual results for this model shows a huge gap.

2) It doesn't give information of the internally excited modes which are not aligned to the feeding line. The mode analysis sometimes is desired for detailed analysis of the antenna.

3) The transmission line model carry out calculations by assuming the current flow in a single direction. But practically the current can flow everywhere in any direction over the entire area of the rectangular element.

In the cavity model analysis the patch antenna is assumed as a cavity surrounded by the conducting walls above and below. And it is also surrounded by the magnetic walls for the open circuit case, so that the accurate calculation of normalised fields takes place which exists within the dielectric.

When the radiating element is given the microwave power from the microstrip line, the upper plane as well as lower plane consists of the charge distribution which is created as a result of the supplied power. The attractive and repulsive mechanism controls these distributions of charges. The force of attraction takes place between the lower end charges of the patch with the opposite charges present in the ground plane. As a result the charge concentration is maintained at the bottom of the radiating element. On the other hand the force of repulsion takes place between the like charges at the bottom of the radiating element which forces the charges to be present at the edges and the top. The whole mechanism is shown in the Figure2.13.

The current density J_b and J_t thus created at both the surface of the patch due to the above discussed movement of charge. In general the attractive mechanism is more as compared to the repulsive one, as the height to width ratio is very small. Due to this at the edges and at the top surface of the patch, the current flow exists.

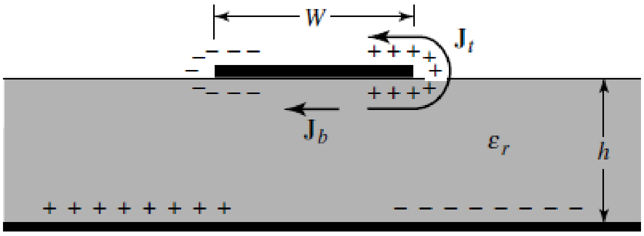


Figure 2.13: Charge distribution and current density creation on microstrip patch.

But it must be noticed here is that, the current flow may be decreased due to the increase in height to width ratio. In this case at the top edge of the patch the current would be negligible failing to create any magnetic field components. Thus the four walls or the conducting surface should be considered as perfect magnetic surfaces which do not affect the magnetic field, which in turn avoids any disturbances of electric field below the patch. The hight to width ratio will be small in every case, so the best approximation can be made that the four sidewalls are magnetic conducting.

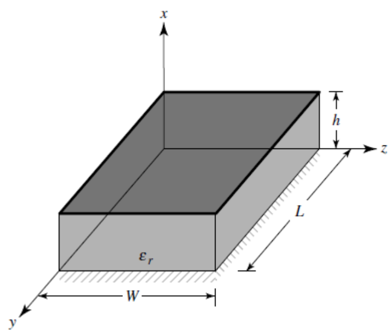


Figure 2.14: Geometry rectangular microstrip patch.

A. Field Configurations (modes)-TM^x

The field configurations within the cavity can be found using the vector potential approach

The wavenumbers k_x,k_y,k_z are equal to

$$\left.\begin{aligned} k_x &= \left(\frac{m\pi}{h}\right),\ m = 0,1,2,.... \\ k_y &= \left(\frac{n\pi}{L}\right),\ n = 0,1,2,.... \\ k_z &= \left(\frac{p\pi}{W}\right),\ p = 0,1,2,.... \end{aligned}\right\} m = n = p \neq 0 \tag{2.12}$$

The resonant frequencies for the cavity can be given by

$$(f_r)_{mnp} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{h}\right)^2\left(\frac{n\pi}{L}\right)^2\left(\frac{p\pi}{W}\right)^2} \tag{2.13}$$

the electric and magnetic fields within the cavity are written as

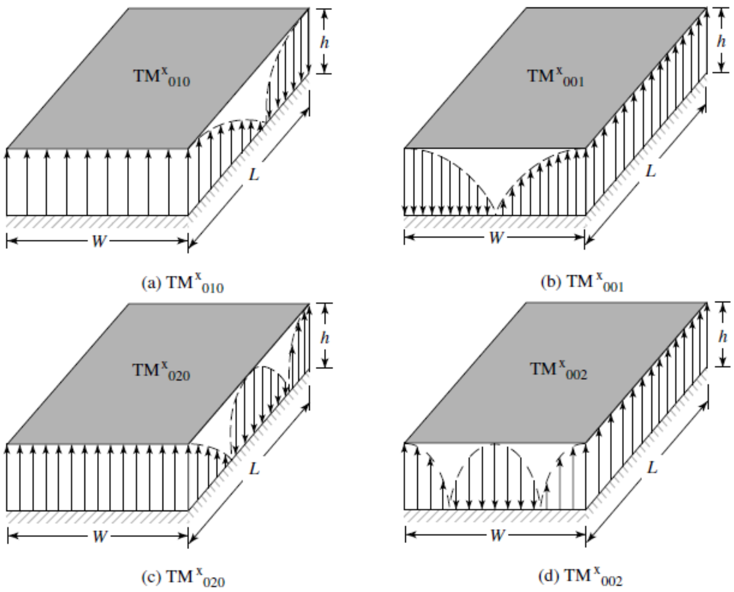


Figure 2.15: Field configurations (modes) for rectangular microstrip patch.

$$\left.\begin{aligned}
E_x &= -j\frac{(k^2-k_x^2)}{\omega\mu\epsilon}A_{mnp}cos(k_x x^{'})cos(k_y y^{'})cos(k_z z^{'})\\
E_y &= -j\frac{(k_x k_y)}{\omega\mu\epsilon}A_{mnp}sin(k_x x^{'})sin(k_y y^{'})cos(k_z z^{'})\\
E_z &= -j\frac{(k_x k_z)}{\omega\mu\epsilon}A_{mnp}sin(k_x x^{'})cos(k_y y^{'})sin(k_z z^{'})\\
H_x &= 0\\
H_y &= -\frac{k_x}{\mu}A_{mnp}cos(k_x x^{'})cos(k_y y^{'})sin(k_z z^{'})\\
E_z &= \frac{k_y}{\mu}A_{mnp}cos(k_x x^{'})sin(k_y y^{'})cos(k_z z^{'})
\end{aligned}\right\} \tag{2.14}$$

2.5 Merits and Demerits of Microstrip Patch Antenna

Advantages

1) Manufacturing of the microstrip patch antenna is easy [1]. Because of the planar structure it can be easily fabricated using printed circuit board technology. Also substrate materials are easily available in the market.

2) The manufacturing or the fabrication cost of this antenna is very low [16] since it requires a single machine to make the shape of the radiating element. Also the coaxial cables can be connected to the patch with the help of 50 Ohm SMA connector.

3) Efficient radiation is possible by the patch antennas. The state of polarisation can also be changes by some slight modifications.

4) It can support both type of polarization i.e Linear and circular polarisation with desirable axial ratio.

5) It can be easily integrated or mounted within the integrated microwave circuitry [3].

Disadvantage

1) The microstrip patch antenna is a narrow band structure [3]. The impedance bandwidth of a antenna is very low. However sever techniques will be discussed in the later sections, to enhance the bandwidth of the antenna.

2) The gain of the antenna is very low i.e. up to 5 to 6 dBi. We can use the array concept here to increase the gain of the overall structure. But care must be taken for the complete isolation factor in between the adjacent antennas. The parameters of the individual antennas should be minimum affected by its adjacent counterpart.

3) If we use strip line feed, spurious radiation occurs which distorts the original radiation pattern. Co-axial probe feed may be employed, but again it makes the antenna useless in the areas where planar structures are demanded.

Despite of having all the demerits discussed, the merits of the microstrip patch antenna outweighs the demerits and makes it a perfect candidate to be used in today's communication equipment.

2.6 Applications of Microstrip Patch Antenna

The microstrip antennas are widely used due to its robust design, satisfactory performance, ease of manufacturing [1], etc. The microstrip patch antennas finds application in defence system especially in missiles, aircraft and in rockets [25]. It is also famous for Satellite related applications [25] [3] [5], in biomedical engineering, etc.

Microstrip antennas has been greatly exploited in government related application and now it is spreading its feathers in commercial filed. This is just because of its easily availability of manufacturing elements such as substrates. In the years to come it is expected that it will replace most of the existing other working antennas. The different areas of application is discussed below:

Mobile and satellite communication systems: As we know in the mobile has become the necessity of every human being and is used in our day to day life. The most desired property of this system is its portability. Thus it requires antenna having low profile [25], light weight, low cost [6] [3]. These all requirements is successfully fulfilled by the Microstrip patch antenna [5]. It has benn designed in various shapes and configuration [3] for use in mobile communication technology.

Satellite communication system often suffers the problem of polarization mismatch. For this the signals must be circularly polarised so that it can be received efficiently by the receiver. It makes use of Microstrip patch antenna for circular polarisation [5], as circular polarization can be easily achieved by using square or circular patch with one or two feed points.

Global Positioning System applications: It has been found that the microstrip patch antennas with high dielectric permittivity substrate are used for GPS. These antennas are use in circular polarization mode and are quite expensive for its positioning purpose. It is specially installed in vehicles and other movable objects at the receiving ends.

Radio Frequency Identification (RFID): Radio Frequency Identification usually makes use of frequencies in the range of 30 Hz to 5.8 GHz. This technique is used in many areas of mobile communication, manufacturing, logistics, etc. Basically RFID system is a tag or transponder and a transceiver or reader.

Worldwide Interoperability for Microwave Access (WiMax): Wimax comes under IEEE 802.16 standrd. It has a range of about 30 miles and the data rate of about 70Mbps. The microstrip patch antennas which are used in these applications consist of three resonant modes at 2.7 GHz, 3.3 GHz and 5.3

GHz.

In Radio Detection and Ranging Equipments (RADAR): Radar is used to find any target by maching use of an echo concept. It usually detects an echo coming from the target to detect it. The microstrip antennas of light weight, low profile are the first choice of the RADAR systems. Moreover it is also helping the defence systems to supply RADARs more quickly due to the bulk manufacturing of the microstrip antennas [6].

Table 2.1: Areas of application for Microstrip Patch Antenna

Application	**Frequency**
Global Positioning Satellite	1575 MHz and 1227 MHz
Paging	931-932 MHz
Cellular Phone	824-849 MHz and 869-895 MHz
Personal Communication System	1.85-1.99GHz and 2.18-2.20GHz
GSM	890-915 MHz and 935-960 MHz
Wireless Local Area Networks	2.40-2.48 GHz and 5.4 GHz
Cellular Video	28GHz
Direct Broadcast Satellite	11.7-12.5 GHz
Automatic Toll Collection	905 MHz and 5-6 GHz
Collision Avoidance Radar	60 GHz, 77 GHz, and 94 GHz
Wide Area Computer Networks	60 GHz

In Rectenna Application: The Rectennas are the antennas having rectifying type of property. It is used to convert the inputted microwave signal to a DC signal. It is basically made of four subsystems such as an antenna, a rectification filter, rectifier and a post rectification filter. It especially demands high directional property antenna for establishing long distance communication links [28].

In Biomedical Applications: It has been found that the use of microwave energy is the efficient way of inducing hyperthermia for the treatment of makignant tumors. The design of the radiating element must be very handy and should be of light weight. Thus the patch antennas finds applications in these areas.

Thus, microstrip antennas for commercial systems require low-cost materials, and simple and inexpensive fabrication techniques. Some of the commercial systems that presently use microstrip antennas are listed in the Table2.1:

CHAPTER 3

Reconfigurable Antennas Literature Review

3.1 Introduction

The antennas plays a significant role in many wireless communication system [26] and also used widely in defence systems [20]. The antennas are made reconfigurable so that they should be operated according to the demands of a particular system [25], to improve the existing functionality, or adapt to the environmental conditions. Out of the other reconfigurable antennas, frequency reconfigurable antennas has found numerous applications.

For the designing of any communicating equipment present in today's world, reconfigurable antennas have become the first choice of the designer. The reconfigurable antennas can come in as a single element or a group of radiating element especially known as *arrays*.

The reconfigurability can be defined as "the ability to change a particular characteristics of an existing design through the means of electrical, mechanical or even optical switches". The reconfigurable antennas has gained much attention in the past years [7] for providing spectrum efficiency and reduction of the overall system's size and cost. The change in the existing characteristics is achieved by redistributing the electric currents. Thus it changes the radiated electromagnetic fields from the apertures.

3.2 Reconfiguration Techniques

According to context of antennas, reconfigurability is the virtue to change a particular radiator's fundamental operating characteristics through electrical, optical, physical, material change [25].

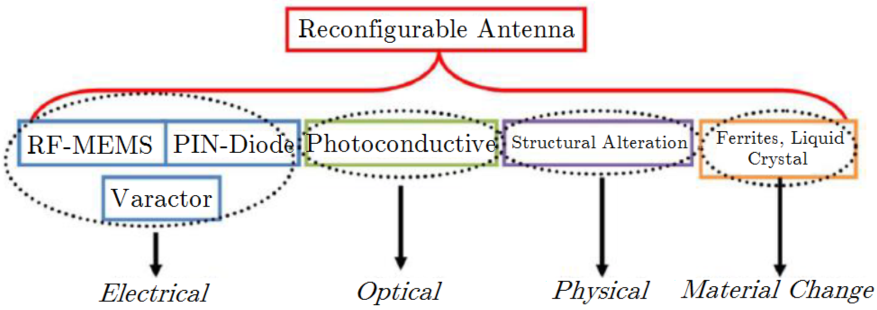


Figure 3.1: Types of reconfigurable antennas.

As discussed earlier the reconfigurability is the ability to change a particular characteristics of an existing design through the means of electrical, mechanical or even optical switches. These techniques are classified as:

1) Electrically reconfigurable antennas: These types of antennas are made to change their performance based on the alteration of electrical current's path. These reconfigurable antennas makes use of electrically operated switches which are quite popular at microwave frequencies. These are PIN diodes [15] [7], varactor diodes [29] [30], etc.

*2) **Optically reconfigurable antennas:*** These antennas are made reconfigurable by the use of optical switches [17]. Optical communication system concept is then come into picture. Since we are aware about the advantages of using optically operated systems, it finds application here also. The non contacting operation of the switches makes the antenna more reliable. It makes use of photoconductive switching elements, photo transistors, etc.

*3) **Physically reconfigurable antennas:*** These antennas are also known as a mechanically reconfigurable antennas. Here the reconfigurability is achieved by altering the physical dimensions of particular antenna.

4) Finally, there are also antennas available which demands material changes which makes use of ferrites or liquid crystals [14].

3.3 Concept of reconfigurability

The reconfigurability concept can be better understood by considering single element design and array design.

The *single element* design consist of a cellular phones, portable wireless communicating equipment or a laptop computer. The antenna used in such type of devices are basically microstrip antennas which may or may not consist of multiple frequency capabilities. Diversity concept may also be used for increasing the portability of reception, but only a single antenna is used for transmission. Due to the limited power, size and cost considerations, the portable device transmission to the access points is the delicate part of the communication system. In addition to this the condition may arise that these devices are to be used in harsh environmental conditions. The reconfigurability technique may act as a boon in such

situations which offers several advantages. This is because the ability of reconfigurable antennas to switch in between the frequencies may be utilised to filter out the signals which are interfering, or the antennas can be tuned to different environment as desired. On the other hand, radiation pattern reconfigurability technique will be very much help full to the antenna so that the radiation pattern can be redirected to the base station and thus use less transmitted power.
However due to the addition of reconfigurability, several undesired changes can occur in the existing design. These are listed as

1) The antenna design becomes complex which will be very difficult to manufacture and installed.
2) Additional circuitry responsible for switching is needed.
3) Several characteristics changes which are not desired.

3.4 Classification of reconfigurable antennas based on the parameter of the antenna to be switched

Reconfigurable antennas can be classified into four different categories.

1)Frequency reconfigurable antennas
In these types of antennas the operating frequency of the radiating element is hopped [26] between different operating frequency bands. These are also called as *frequency agile antennas* [22] [17].
2) Polarization reconfigurable antennas
As the name implies these types of antennas may change their state of polarisation depending upon their requirement. For example at some cases antenna radiates in vertical polarization mode and in other case in horizontal polarization mode [24].

3)Radiation pattern reconfigurable antennas

The antenna radiation pattern may change in these cases. The change may take the form of altering the number of side lobes, nulls, beamwidth of the antennas, etc. [25].

3.5 Methods for achieving Frequency Reconfigurability

The frequency reconfigurable antennas are subdivided into two categories

i) Continuous frequency reconfigurable antennas ii) Switched transitional reconfigurable antennas

In *continuous frequency reconfigurable antennas* the variation in the operating frequency or the transition in between the frequency takes place smoothly. In *switched transitional reconfigurable antennas*, the sudden variation of frequency takes place with the help of different switching element.

These antennas has some operating principle, but they differ from the different switching techniques used. In theory it is proven that the effective length of the antenna is closely associated with the frequency of operation. Thus effective length variation also opens a door for frequency reconfigurability [27]. Number of techniques ahs been devised to change the effective length of the antenna having some merits and demerit.

3.5.1 Reconfigurability by applying switches

The operating frequency of the antenna can be changed by changing its effective length. The length can be altered by attaching or detaching several parts of the antenna with the use of switches such as PIN [23] [15], RF-MEMS [7] [9] [15]

Figure3.2 shows the example of a dipole antenna with photoconductive switch. In this dipole reconfigurable antenna, the switch is operated by an optical ray supplied by laser diode. So when both the switches are closed the operating frequency is 2.16 GHz, and when both the switches are open then the operating frequency is 3.15 GHz.

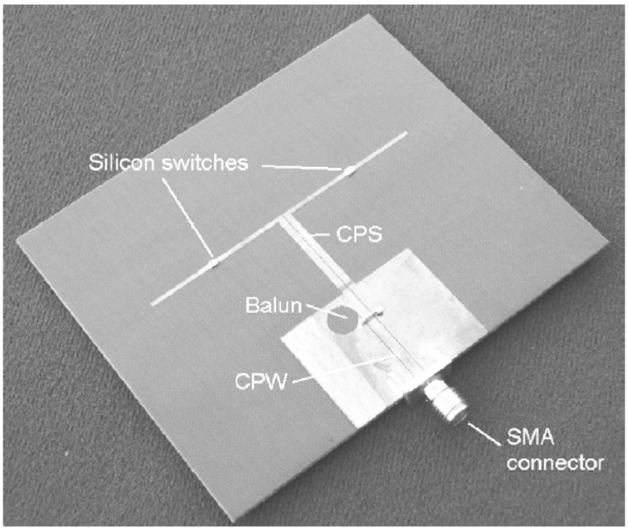


Figure 3.2: Photograph of an optically switched dipole antenna

3.5.2 Variable Reactive Loading

This technique share the similar concept of frequency reconfigurability. All the parameters are same, but it differs from previous technology by the types of switches used. The switches are such that it gives the result of smooth or continuous frequency reconfigurability.The effective length is changed smoothly with the help of reactive element. Figure3.3 shows an example of variable reactive loading which has used RF-MEMS capacitors. The capacitors are mounted on a patch with CPW stubs and given the DC supply of 12V.

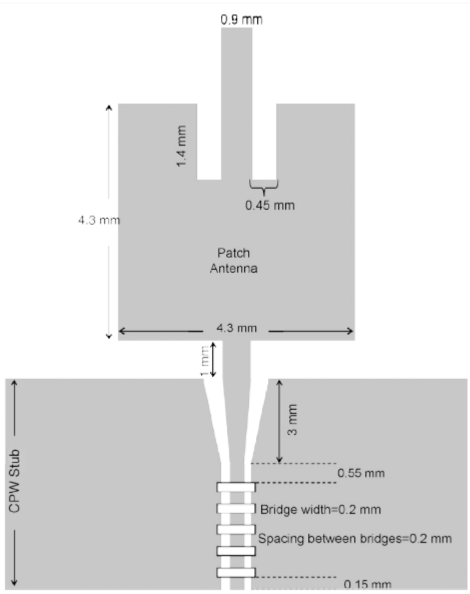


Figure 3.3: Frequency tunable microstrip patch antenna with RF-MEMS capacitors and CPW tuning stub

3.5.3 Structural / Mechanical Changes

Larger shifts in the frequency bands can be achieved by employing the mechanical alteration rather than electrical one. This includes both switched or continuous reconfigurability.

Here the challenge is to design such type of radiator which can be altered mechanically without affecting the other dimensions of the antenna.The example of continuous frequency change is shown in the Figure3.4. It consist of a patch antenna mounted in such a way that the distance between it and the substrate can be mechanically varied. Here initially the patch antenna of 26 GHz is designed. It was having thin layer of magnetic material. The patch is slightly moved away from the substrate. By applying the DC magnetic field the process known as plastic deformation takes place at the boundaries in the points where the feed line is attached.

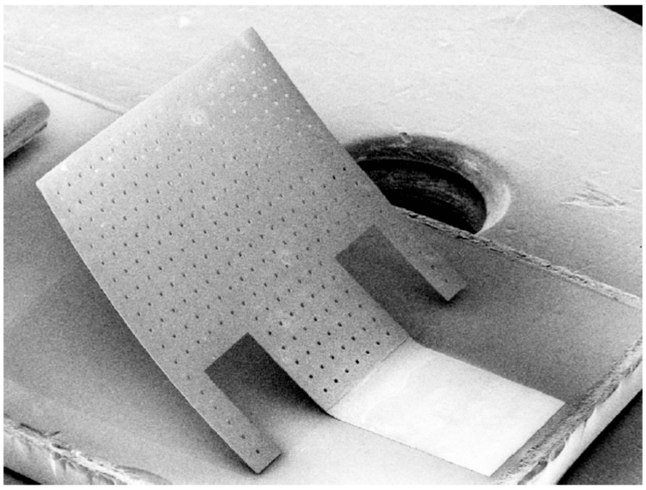


Figure 3.4: Photograph of magnetically actuated reconfigurable microstrip antenna

This varies the patch position at slight angles above the substrate. This change in angle causes the change in operating frequency. Small angles change the frequency without affecting the radiation characteristics. On the other hand large angles results in the shift in frequencies with noticeable change in radiation pattern.

3.5.4 Material Changes

The change in the material characteristics of the substrate used can also cause significant change to tune the antenna at different operating frequency. It can be easily altered by the application of external means. Reviewing the concept of material science, the relative permittivity of the ferroelectric materials is greatly affected by the application of external electric field. On the other hand the relative permeability of the ferrites is greatly affected by the application of external magnetic field. The effective length of the antenna is very much affected by these material changes. And thus shift in the frequency is obtained, as the operating frequency is directly related to the electrical length.

3.6 Methods for Achieving Polarization Reconfigurability

The performance of the communication system can be greatly improved by applying the *diversity* concept. Many diversity techniques are available for improving the communication link. This provides avoidance of interfering signals from the desired signals in varying environmental conditions. This is practically possible by the use of polarization reconfigurability of the antenna.

The polarization reconfigurability can be achieved by changing the convensional current flow on the antennas radiating element. This is achieved by changing the antenna geometry, basic material properties, feed positions, etc. If we use polarization reconfigurability, the antenna is practically shifted from one polarization state to other polarization state. This includes linear, right circular and left circular polarization states.

Though the implementation is quite different as that of frequency reconfigurability, the two shares almost the same concept and procedure to obtain reconfigurability. The mechanism for obtaining the change in geometry, material is almost same as in frequency reconfigurability.

3.7 Methods for Achieving Radiation Pattern Reconfigurability

The behaviour of the electrical current and their rate of change on a radiating element directly affect the radiation pattern distribution. Thus altering the behaviour of the currents to achieve Radiation pattern reconfigurability without giving rise to frequency reconfigurability is a difficult task.

A designer must be aware of what kind of source current required along with their magnitude and phase, so that he can design antennas with a particular radiation pattern. Once the behaviour of the current is studied, a baseline antenna can be designed or selected and it is afterwards altered to obtain the variation in the distribution of currents.

The later task of the designer is to manage not to change the operating frequency while obtaining pattern reconfigurability, since the currents also have some effects on the operating frequency. This is one of the critical task. In some design the designer keeps the input of the feeding arrangement quite isolated from the are to be reconfigured, so that frequency reconfigurability is avoided

3.8 Advantages of Reconfigurable Antennas

1) Cost minimization, makes the system portable, the size of the system is generally reduced as the single antenna is responsible for achieving more than one desired operating frequency bands. And also specific isolation is obtained in between different frequency bands standards [25].
2) Band rejection is quite good and lesser use of front end processing.
3) It can be easily controlled by software means. This is achieved by employing microcontrollers and made automated via FPGA.

3.9 Limitations of Reconfigurable Antennas

1) Additional biasing circuitry or switching circuitry is needed to control the switching element mounted on the radiating patch [4].

2) The power consumption is increased due to the operation of switches and their associated switching circuitry [25].

3) The higher order harmonics is also generated due to the use of non linear switching elements.

4) Fast tuning of the radiation pattern of the antenna is difficult to achieve.

3.10 Area of application for Reconfigurable Antennas:

Very much usefull in cognitive radios

The cognitive radios make use of frequency reconfigurable antennas [17] [19]. While operating in a particular frequency bands, sometimes the signal degrades due to the harsh environmental conditions. This radio then continuously monitors for the frequency which is unused. Thus obtaining better performance and minimises the interference with other frequency bands.

In multi input multi output (MIMO) systems

Multiple antennas are employed in the MIMO system at both the transmitting and receiving ends. With the use of reconfigurable antennas various information can be sent simultaneously. Thus it increases the spectral efficiency.

In satellite communication systems

In applications of dynamic space, for serving better to the new coverage zone, it is quite essential to change or switch the existing radiation pattern of the antenna. The satellite communication system greatly makes use of polarization reconfigurable antennas [17] to change their state of polarization according to the need of particular receiving stations. It is also used to reduce the fading concept. Thus the operation in higher data rate is possible [6].

CHAPTER 4

Bandwidth enhancement techniques of Microstrip Patch Antenna

The bandwidth enhancement techniques is classified as:

1) Intrinsic techniques of enhancement of bandwidth 2) External matching techniques 3) Non contact fed patches

Intrinsic techniques: It also has two subdivisions for bandwidth enhancement

i) Thick substrate material must be used ii) The lower dielectric constant substrate must be used

The above two techniques hen employed, bandwidth enhancement can be obtained up to 10%. Due to the use of thicker substrate materials, the feed line becomes more inductive which has some significant effect on the impedance. The input impedance locus thus becomes inductive. But these types of procedures is basically not suitable for edge type of feeding, to enhance the bandwidth. This is because the feeding structure can give rise to unwanted radiation. By increasing substrate thickness and also using substrate of less dielectric constant, the structure of feed line widens. Thus the overall radiation of the patch is reduced a little which is more noticeable at higher frequencies.

4.1 External matching structures

The external matching structures are used to enhance the bandwidth of the existing narrowband of the order of 15%. But this in turn will solely depend upon the feeding structure and the nature of the substrate material. In several cases the antenna impedance acts as load impedance for the input feed line. The stubs are then used to match this impedance with the characteristic impedance of the feed line for complete power transfer to take place. Usually the impedance of the transmission line used is close to 50 ohms. The input impedance of the antenna though frequency depended, is then adjusted to 50 ohms at that particular operating frequency.

4.2 Non-contacts fed patches

The direct or contact feed structures introduce discontinuity in the current distribution on the radiating element. Thus Non contact fed techniques are suitable for enhancing the bandwidth. In the research it is found that the aperture coupled technique has given rise to wider bandwidth as compared to the proximity feeding counterpart. This is because the aperture technique consists of more than one radiator.

4.2.1 Use of parasitic elements:

If the parasitic elements are installed along with the main radiating element which is known as driven element, the bandwidth can be enhanced. The parasitic elements are not given any supply. Only there are placed near to the driven element. The field gets coupled to the surface of these elements causing currents to flow.

This is because if we use different patch geometries responsible for different resonant frequency, then along with the frequency of radiator, these frequencies also get radiated. Due to this the number of operating frequencies increases which in turn increases the bandwidth. The geometry of the patch is shown in the Figure4.1.

The gap between the driven element and the parasitic one plays very important role as it couples the power from driven element to parasitic elements. Hence it reduces the radius of resonant loop in the impedance locus.

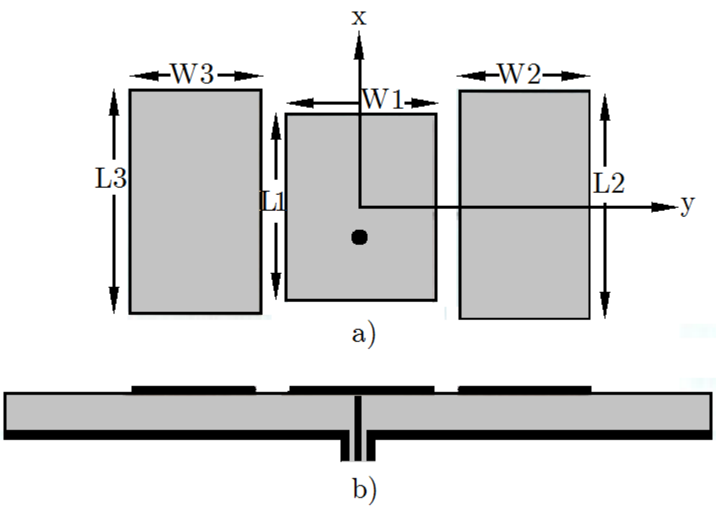


Figure 4.1: Horizontally coupled parasitic patches

4.3 Role of substrates

The other parameter which can change the impedance matching behaviour over the large range of frequencies, is the substrate used in the planar structures. It has been observed that the substrate having small dielectric constant enhances the bandwidth. The other techniques such as employing both the higher and lower dielectric substrate also have shown increment in the bandwidth. The use of lower dielectric substrate along with the foam has also resulted into wideband characteristics.

CHAPTER 5

Design analysis of an Ultrawideband Antenna

5.1 Design of a simple rectangular patch antenna.

While approaching towards my aim of designing the multiband reconfigurable antenna, the first task was to design an utrawideband antenna with the frequency ranging from 3.1 to 10.6 GHz [13]. Initially a simple rectangular patch is designed which after further modification will be later converted to an ultrawideband antenna. This section will emphasize on designing a rectangular patch antenna of 6 GHz and the related design calculation.

5.1.1 Antenna Design:

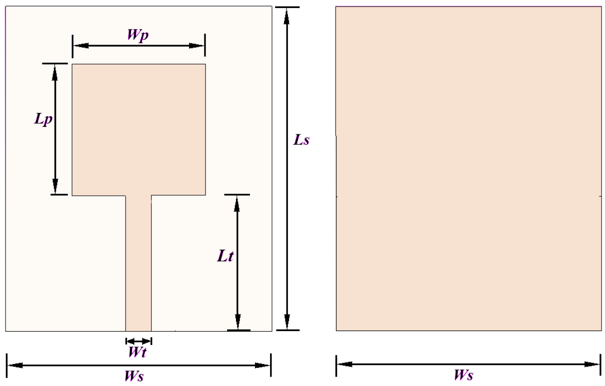


Figure 5.1: Design of antenna with full ground

Parameters	Values(mm)
Ws	30
Ls	35
Wp	15
Lp	14.5
Lt	13.5
Wt	1.45

Calculation:

Given: f=6 GHz, Dielectric Constant ϵ_r=4.3, Loss tangent δ=0.02, h=1.6mm

The width of the patch can be calculated by :-

$$\begin{aligned} W_p &= \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \\ &= \frac{3\times10^8}{2\times6\times10^9\times\sqrt{\frac{4.3+1}{2}}} = 15.35\ mm. \end{aligned}$$

The effective dielectric constant then will be:-

$$\begin{aligned} \epsilon_{reff} &= \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W_p}\right)}}\right] \\ &= \frac{4.3+1}{2} + \frac{4.3-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{1.6}{15.35}\right)}}\right] = 3.75\ mm. \end{aligned}$$

The length of the patch is found out by:-

$$
\begin{aligned}
L_p &= \frac{c}{2f_0\sqrt{\epsilon_{reff}}} - 0.824h\left(\frac{(\epsilon_{reff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W_p}{h}+0.8\right)}\right) \\
&= \frac{3\times10^8}{2\times6\times10^9\sqrt{3.75}} - 0.824\times1.6\left(\frac{(3.75+0.3)\left(\frac{15.35}{1.6}+0.264\right)}{(3.75-0.258)\left(\frac{15.35}{1.6}+0.8\right)}\right) \\
&= 11.45\ mm.
\end{aligned}
$$

The geometry of the patch is shown in Figure5.1 and the associated parameter dimension in the Tabel next to it. As it can be observed that a simple rectangular patch is taken, which is fabricated over a substrate material of FR-4 having dielectric constant ($\epsilon_r = 4.3$) and loss tangent ($\delta = 0.02$) [35]. The rectangular patch is fed by a microstrip transmission line of 50Ω impedance. This type of feed is usually known as a *microstrip line feed.* Microstrip line feed is selected so as to make the design simple and it can be fabricated very easily.

It can also be observed from the Figure5.1 that in this case the ground plane is over the entire back area of the substrate. Several changes will be made in this ground plane in further analysis to get the desired performance.

5.1.2 Simulated results:

The antenna has been designed and simulated using CST microwave studio [43]. As it was discussed earlier the antenna is made to resonate at approximately 6 GHz.

The results after the simulation is observed and is shown in the Figure5.2. It can be seen that the antenna resonates at a single frequency 6.05 GHz. The associated return loss is around -50 dB which is quite acceptable. All the higher and lower frequency return losses is well above -10 dB line which indicates higher return losses at that frequency, and the antenna fails to radiate those frequency.

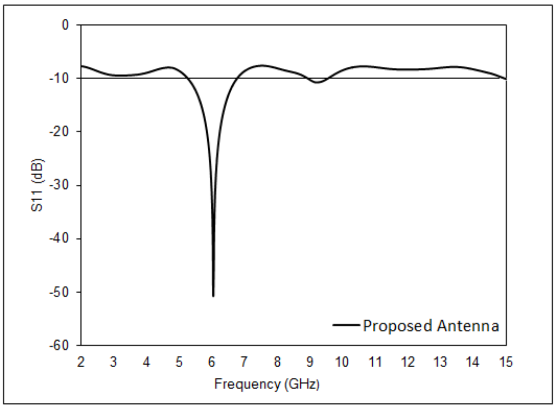


Figure 5.2: S11 plot of the antenna with full ground.

The smith chart of the designed simple rectangular patch antenna is shown in Figure5.3. From the literature we know that the smith chart is usually used to examine the impedance matching property.

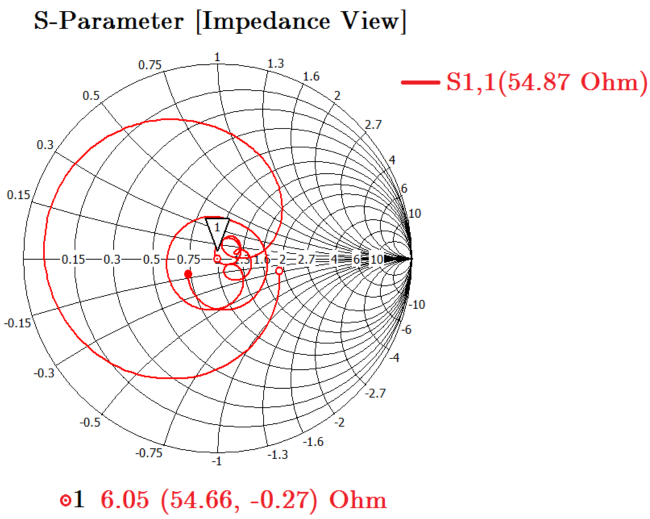


Figure 5.3: Smith Chart of the proposed antenna.

The smith chart shows the normalised input impedance of the antenna for all the frequencies ranging from 2 GHz to 15 GHz. For the impedance matchin to take place, we know the load impedance must be equal to the characteristic impedance of the transmission. So that complete power is transferred to the load. The load in our case is the patch and the transmission line is the microstrip line. So the complete matching takes place only when load impedance is same as characteristic impedance, thus by normalisation, the normalised imput impedance must be equal to 1 with zero imaginary part.

So by observing the smith chart we can see that at 6.05 GHz frequency the normalised input impedance is unity with negligible imaginary part. Thus the complete matching takes place at this frequency. This is the reason why we are getting very less return loss of -50 dB.

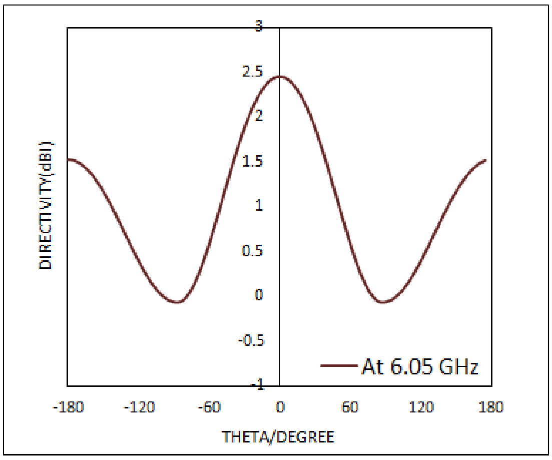


Figure 5.4: Directivity plot of antenna with full ground.

Figure5.4 shows the directivity plot for different theta value by keeping ϕ=90°. The theta value is changed from -180° to 180°. For all these values the directivity is computed and plotted in one graph. We can see that the antenna shows better directivity results. The directivity is maximum in the desired direction as compared to other theta values.

5.2 Modification of the ground plane to achieve Ultrawideband characteristics

5.2.1 Ultrawideband Background

The ultrawideband technology coming under 3.1 to 10.6 GHz which is authorised by Federal Communication Commission [6] [13] has become famous for variety of application in public safety, consumers, etc.. In UWB systems the antenna plays a key role in the entire arrangement.

The antenna can be used in several forms in wireless communication system. Thus it may take forms of conducting wire or may be an aperture. It may be in the form of patch [11], a reflector, or as a lens or either in the form of assembly of radiating elements which is usually known as arrays. To fulfil all the standards and desired system requirements the design of the antenna must be proper.

Over the years, many researches have been carried out for UWB design [13]. The UWB antennas makes use of very short duration narrow pulses [6] of the order of nanoseconds used for wideband communication system, which covers wide range of frequencies in the frequency domain. The antennas should possess non dispersive characteristics for enhancing high data rates. In the past decades different types of antennas are introduced to work as UWB antennas having some merits and demerits.

5.2.2 Planar UWB antennas

In the recent years it has been observed that the planar antennas are mostly suited for UWB applications as compared to others. These planar antennas are supplied by the conventional feeding techniques such as microstrip line feeding or co-axial cable feeding.

Several techniques have been devised by the researchers to obtain the UWB characteristics. Some techniques are discussed below:

1) The radiating element which is the active portion of the antenna is made in various shapes.

2) Slots can be used to modify the existing design for better impedance matching.

3) Use of partial ground technique in which the some portion of the conductive ground plate is removed in order to enhance the bandwidth.

4) By introducing two slots below rectangular or square radiators, impedance bandwidth can be improved. This is because, the slots greatly influence the radiator and ground plane coupling.

5) Finally by improving or modifying structures used for feeding. By altering position of the feed point, the impedance bandwidth can be enhanced. This is because due to the variation of the feed point greatly influences the input impedance of the antenna.

5.2.3 Effect of reduction of the ground plane

For the designing of the UWB antennas the geometry of the patch and the ground greatly influences the characteristics of antennas. Slight modification can play a big role in the final outcome. The assembly of the patch and the ground plane initially forms as an unbalanced design.

The currents which are fed by the microstrip line is spread both on the patch as well as on the ground plane. The ground plane thus unwantedly radiates little bit. Thus printed or planar ultrawideband antenna's performance is affected mostly by the size of the ground plane. So by reducing the ground and making it patial ground, the unwanted radiation is reduced significantly, giving better impedance matching at the wider range of frequency.

5.2.4 Antenna Design

The modification of the existing design is shown in the Figure5.5. We can observe that the only modification done is in the ground plane. The other antenna dimensions remain unaltered. We can see that the ground is not complete but some part is left open. This type of technique is called *partial grounding technique*. We can see that the height of the ground is Lg.

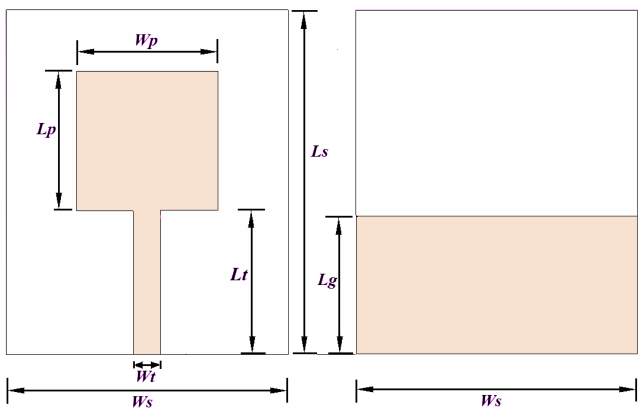


Figure 5.5: Design of proposed partial ground antenna

Design parameters of partial ground antenna.

Parameters	Values(mm)
Ws	30
Ls	35
Wp	15
Lp	14.5
Lt	13.5
Wt	1.45
Lg	12.5

5.2.5 Results related to Ultrawideband Antenna:

The direct result from the CST microwave studio for the ultrawideband antenna is discussed in this section. The S11 plot for three different values of Lg is shown in Figure5.7. For Lg=35mm the S11 is same as discussed in the last section. Lg=35mm means it is full ground condition.

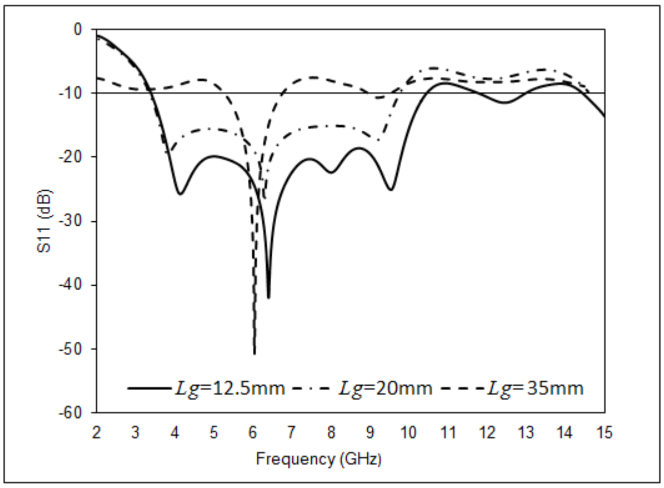


Figure 5.7: Formation of Ultawideband characteristics

Now slowly the valu of Lg is reduced to 20 mm. Tha associated plot is shown by the dash-dot line.

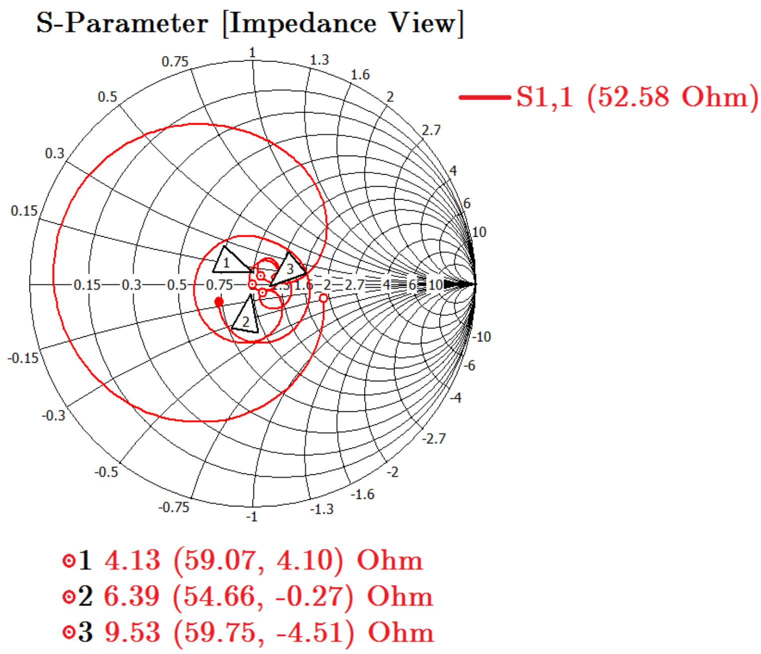


Figure 5.8: Smith Chart of an Ultrawideband Antenna.

We can see that the bandwidth is drastically increasedwith corner frequency approximately 3 GHz to 9.7 GHz. But the standard ultrawideband antenna corner frequency is 3.1 GHz and 10.6 GHz. So further the value of Lg is varied.

The value of Lg is now taken 12.5mm and the S11 plot is analysed. The characteristics similar to the ultrawideband is obtained. This is shown by the solid black line. Thus for this value of Lg=12.5 mm we get the desired value and the parametric analysis is stopped.

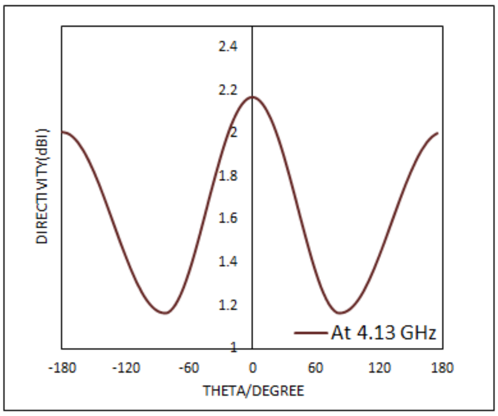


Figure 5.9: Directivity plot of given Ultrawideband Antenna at 4.13 GHz.

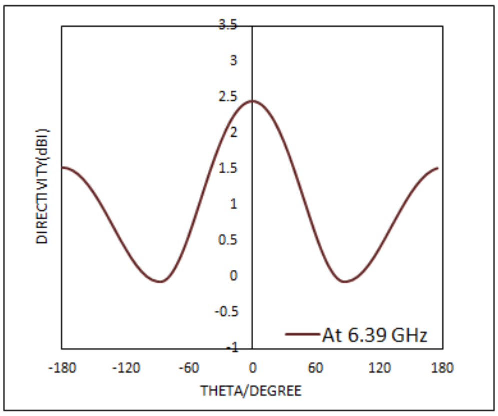


Figure 5.10: Directivity plot of an Ultrawideband Antenna at 6.39 GHz.

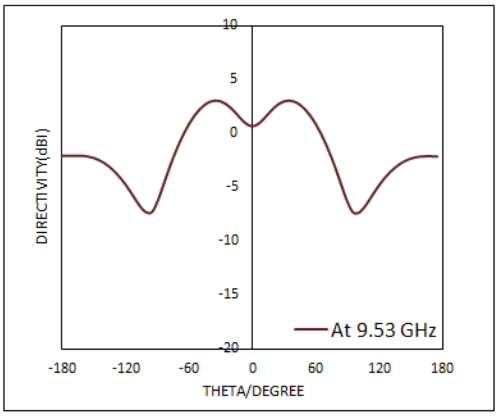


Figure 5.11: Directivity plot of an Ultrawideband Antenna at 9.53 GHz.

The smith chart is also plotted for the designed ultrawideband antenna. The plot shows the input impedance values and location for three different frequencies i.e 4.13 GHz, 6.39 GHz and 9.53 GHz. The input impedance for these three frequencies is examined. We can see that the patch is almost matched to the transmission line at these three frequencies. We cannot say they are perfectly matched since the location of the points are not exactly (1,0) in the smith chart. We can expect these type of results in the ultrawideband case. The middle band however is perfectly matched due to this reason the return loss is very less as it can be observed from the S11 plot.

The directivity plot for three frequencies is plotted. As it is visible that the first two plots are almost same but the values are far different from each other. This can be observed from the vertical scale. All the three graphs show acceptable directivity characteristics, with maximum directivity in the desired direction and relatively less directivity in the undesired direction.

The Co and Cross polarisation is also plotted for the designed ultrawideband antenna. It is usually used to show the desired radiation properties of the antenna.

The polarisation as discussed earlier in this text, is the orientation of the electric field vector with respect to the ground plane. Suppose the antenna is designed to operate in the vertical polarisation. So for this antenna the vertical polarisation is called the Co-polarisation component. So the receiver has to be adjusted to receive this vertically polarised wave.

However due to some spurious radiation, some orthogonal polarisation componets also gets radiated which in the present case is the horizontal polarisation which usually undesired. This type of polarisation is called as Cross polarisation. This cross polarisation component interferes with th co-polarisation component to distort the signal. So to keep the distortion minimum the value of the cross polarisation must be less as compared to the co polarisation component.

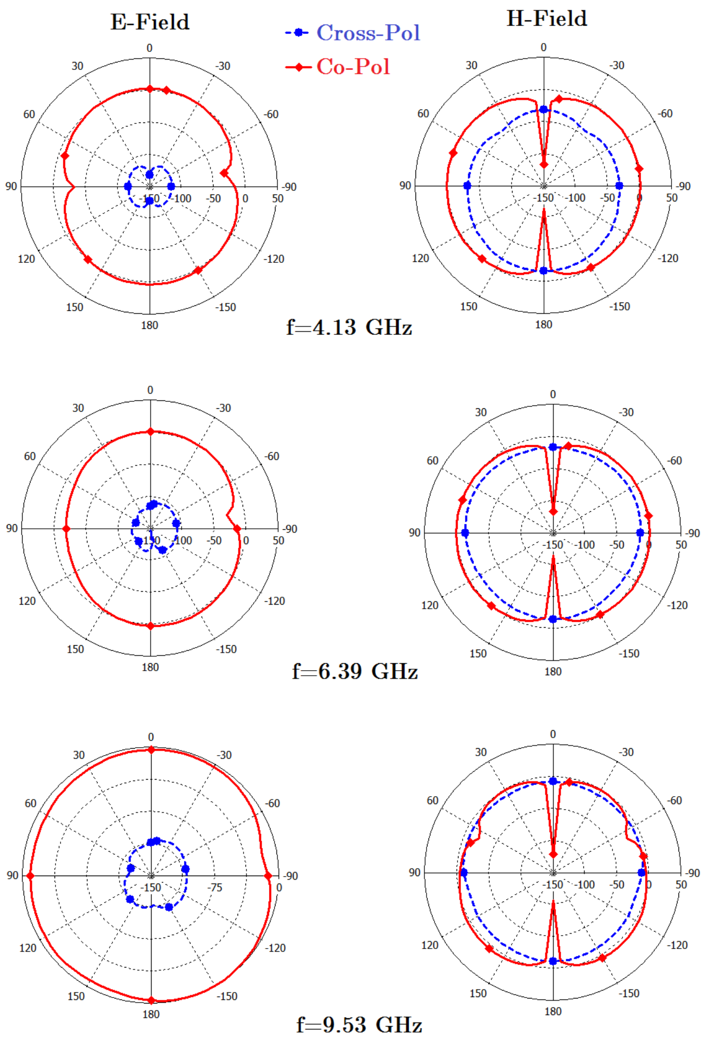


Figure 5.12: Co and Cross Polarization plots of the resultant UWB antenna

The Figure5.12 shows both the components for E-field as well as H-field. With co-polarisation indicated by solid line and cross polarisation by dashed line.

CHAPTER 6

Design steps and analysis of Multiband Antenna for C, X and Ku band applications

6.1 Importance of the triangular slot for obtaining multiband characteristics.

6.1.1 Antenna Design

After the design and analysis of the ultrawideband antenna my next task was to shift the whole frequency of operation towards the higher frequency side so that the antenna can be operated in the standard microwave band application. This is achieved by slight modification of the partial ground plane. It can be seen from Figure6.1 that a small triangular slot has been introduced whose dimensions

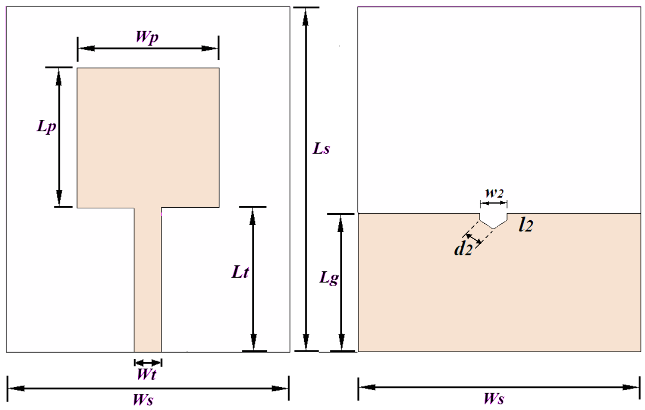


Figure 6.1: Design of antenna with triangular slot.

Design parametrs of antenna with triangular slot.

Parameters	Values(mm)
Ws	30
Ls	35
Wp	15
Lp	14.5
Lt	13.5
Wt	1.45
Lg	12.5
$w2$	3
$l2$	0.75
$d2$	1.8

are specified in the Table6.2. This is the slot which is mainly responsible for the shifting of the operating frequency to the higher sides.

6.1.2 Simulation results:

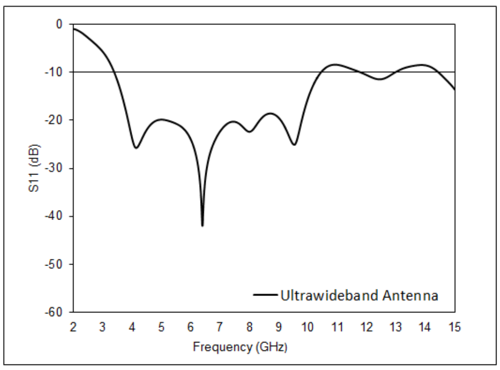


Figure 6.3: Initial Ultrawideband characteristics.

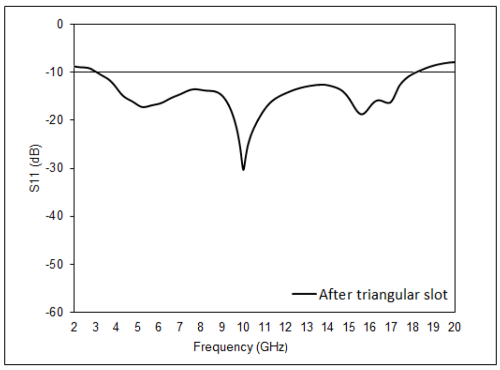


Figure 6.4: S11 plot after cutting triagular slot in the ground plane.

The simulation result of the design is shown in the Figure6.4. Figure6.3 shows the earlier ultrawideband characteristics which is without the introduction of the triangular slot. We can see that the characteristics is restricted to 10.6 GHz. To shift the operating frequency towards the higher frequency a triangular slot is cut. The S11 plot after introducing triangular slot is shown in Figure6.4.

We can observe that the characteristics is still a wide band but the resonant frequency is shifted to higher frequency side. Also the other two bands (left and right to the resonant frequency) also starts forming. In [10] [12] several shaped slots (square ring and trapezoidal) are used to get band notch functions. In the later section we will see that how the return loss is minimised for these resonant frequencies also how the perfect tri band characteristics are obtained.

6.2 Effect of introduction of the left slot in the existing partial ground plane.

6.2.1 Antenna Design

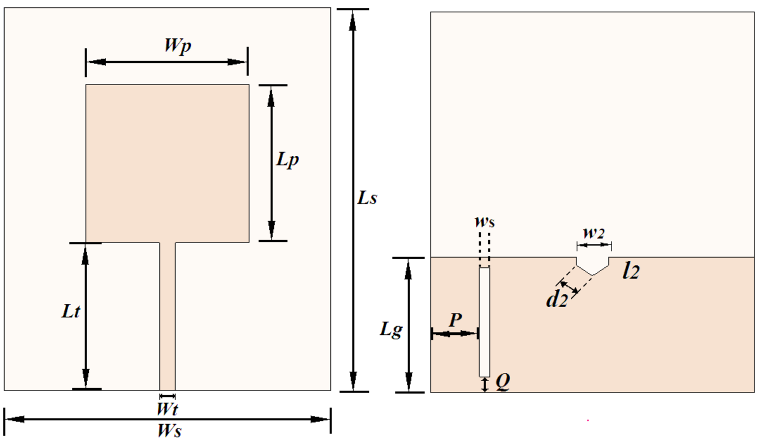


Figure 6.5: Design of the proposed antenna after cutting left slot in the ground plane.

After shifting the ultrawideband characteristics to the higher operating frequency, my next task was to design the tri band antenna which should work effectively in

Table 6.1: Design parameter values of the proposed antenna after cutting left slot in the ground plane.

Parameters	**Values(mm)**	**Parameters**	**Values(mm)**
Ws	30	Ls	35
Wp	15	Lp	14.5
Lt	13.5	wt	1.45
Lg	12.5	P	4.5
Q	1	$w2$	3
$l2$	0.75	$d2$	1.8
Ls	10	ws	1

C, X and Ku band applications. For this to happen the notch must be created for complete isolation between the adjacent band. In this section we will discuss the formation of notch frequencies between first and second bands by the introduction of left slot.

6.2.2 Simulated Results

The S11 plot of the proposed design is shown in the Figure6.6 along with the earlier design's S11 plot. We can clearly compare the two graphs. Without slot plot is shown by the dashed line and with slot is shown by the solid line.

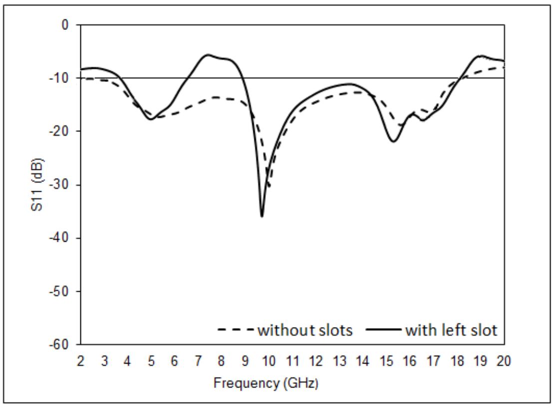


Figure 6.6: S11 plot of the creation of the first notch.

We can observe that the return loss of the frequencies between first and second band is shifted upwards i.e above -10 dB line. Thus the notch is created as desired. All this happened due to the left slot at the ground plane.

We can see that except the notch frequency all the return loss of the other frequencies remain unaltered. And also the resonant frequency is slightly changed which is usually accepted.

Several researchers have worked on the multiband antenna. They usually obtain the multiband characteristics by the formation of the slot in the patch area. This is the unique technique in which the notch is created by the formation of the slot in the ground plane. Which reduces the complexity in the patch area.

This less complexity is very much useful while the designing of the reconfigurable antenna where we have to introduce some switching devices in the patch area. In that case the antenna fabrication will become much easier as we have less complexity in the patch area.

6.3 Effect of the introduction of right slot on the performance of the antenna.

6.3.1 Antenna Design

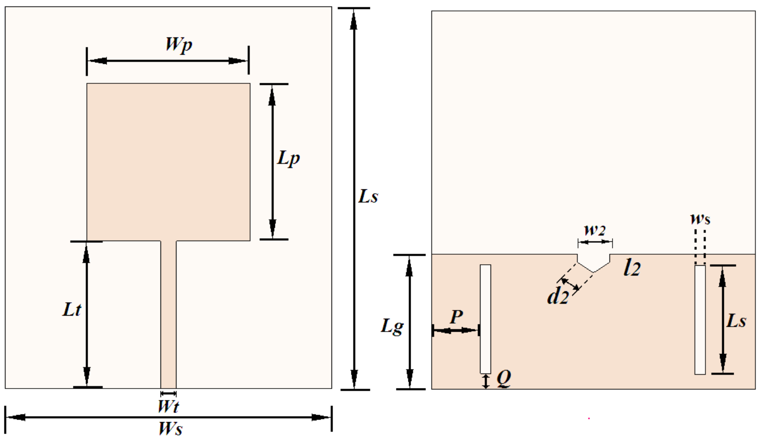


Figure 6.7: Design of the proposed antenna after cutting right slot in the ground plane.

Table 6.2: Design parameter values of the proposed antenna after cutting left slot in the ground plane.

Parameters	Values(mm)	Parameters	Values(mm)
Ws	30	Ls	35
Wp	15	Lp	14.5
Lt	13.5	wt	1.45
Lg	12.5	P	4.5
Q	1	$w2$	3
$l2$	0.75	$d2$	1.8
Ls	10	ws	1

Till now we have achieved the notch in between the first and the second bands.

This is due to the left rectangular slot in the ground plane. To make the antenna a complete tri band antenna the second notch must be created in between second and the third band. Only then we can say that the antenna is a tri band antenna.

For this a symmetrical rectangular slot is crated similar to the previous one with same dimensions. It is positioned in the right of the ground plane. Thus the ground plane geometry becomes symmetrical. The effect of this slot is discussed in detail in the following section.

6.3.2 Simulated Results

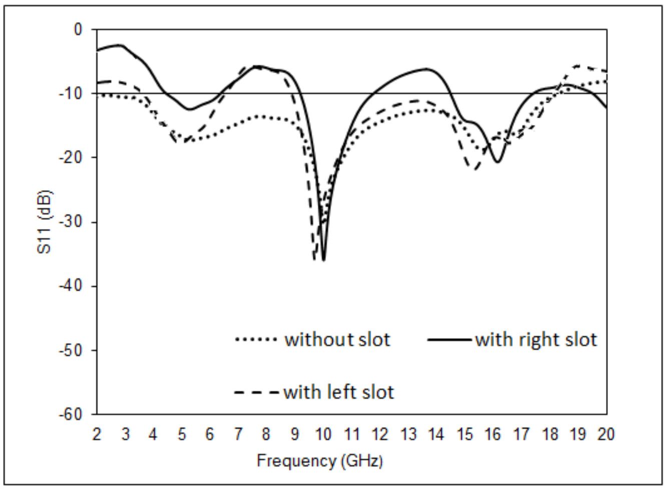


Figure 6.8: S11 plot of the creation of the second notch.

The S11 plot of the proposed design is plotted along with the other two cases i.e withot slot and with left slot and is shown in Figure6.8 . The without slot curve is shown by dotted line, with left slot curve which is discussed in the last section is shown by the dashed line. And finally the right slot curve is shown by the solid line. We can see that the notch is created between the second and the last band. The return loss for these frequencies is well above -10 dB line. And also it can be observed that it is hardly affecting the other frequency component. However it should not be ignored that it is increasing the return loss of the first band. But in the further section, efforts has been made especially to improve the return loss for all the three bands.

Thus, till now we have somehow achieved the multiband characteristics with the antenna operating in three different bands. The return loss is quite large for all the bands. The return loss for all the three bands will be improved by slight modification in the patch area as it will be discussed in the next section.

6.4 Effect of the circular corner cuts in all the four edges of the patch on the S11 characteristics.

6.4.1 Antenna Design

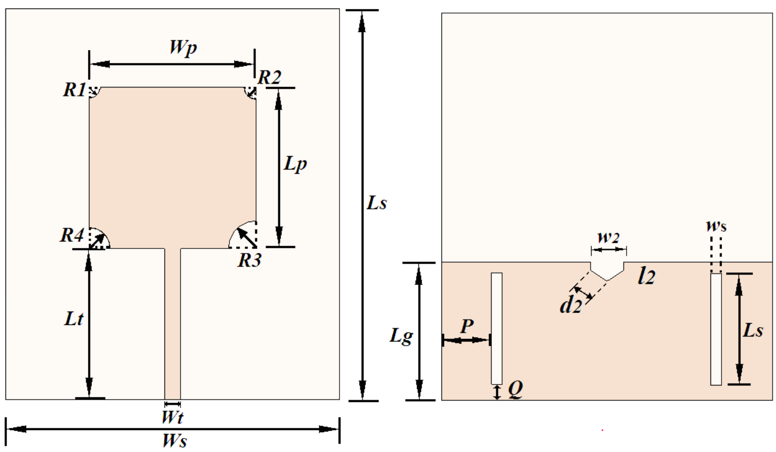


Figure 6.9: Final design of antenna after inclusion of circular corner cuts.

The circular cuts at all the four corners of the patch is introduced. It is shown in Figure6.9. From the figure we can see the radius of all the four corner cuts are not same. They are different. No two corner cuts share the same value of the radius.

The radius are named as R1,R2,R3 and R4.

Table 6.3: Design parameter dimensions of antenna after inclusion of circular corner cuts.

Parameters	**Values(mm)**	**Parameters**	**Values(mm)**
Ws	30	*Ls*	35
Wp	15	*Lp*	14.5
Lt	13.5	*wt*	1.45
Lg	12.5	*P*	4.5
Q	1	*w2*	3
l2	0.75	*d2*	1.8
Ls	10	*ws*	1
R1	1	*R2*	1.1
R3	2.5	*R4*	1.9

6.4.2 Simulated Results

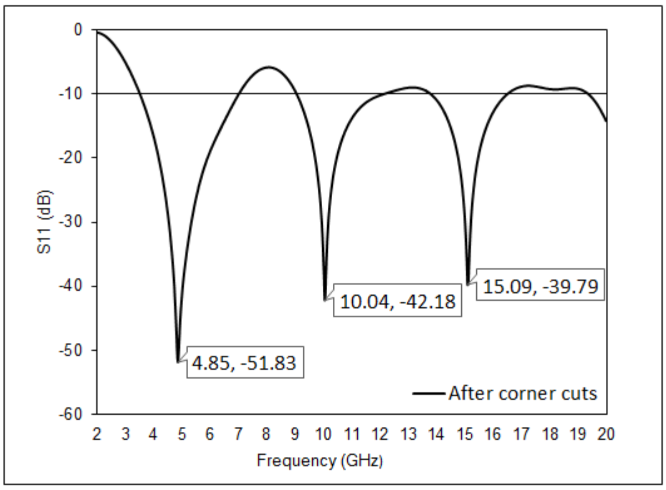


Figure 6.10: Final S11 plot of Tri Band Antenna.

The S11 plot for the design with the circular corner cuts is shown in Figure6.10. We can see that the value of the return loss has been drastically reduced for all the three bands. The final s11 plot of the desired tri band antenna is shown in Figure6.10. The return loss in the range -40 dB to -55dB is obtained.

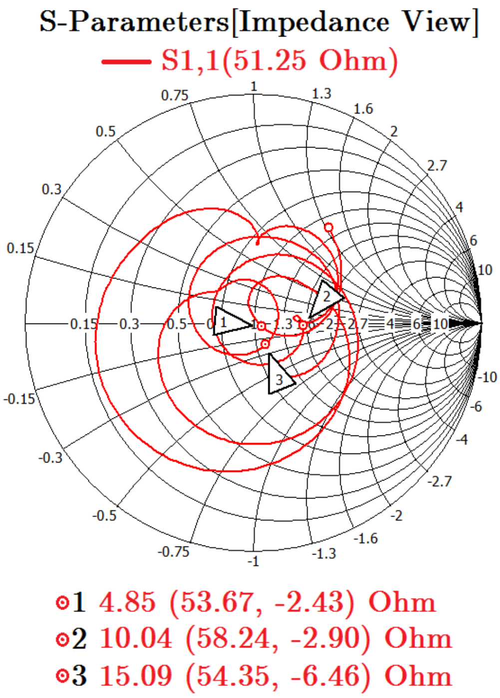


Figure 6.11: Smith Chart of the proposed antenna before inclusion of corner cuts.

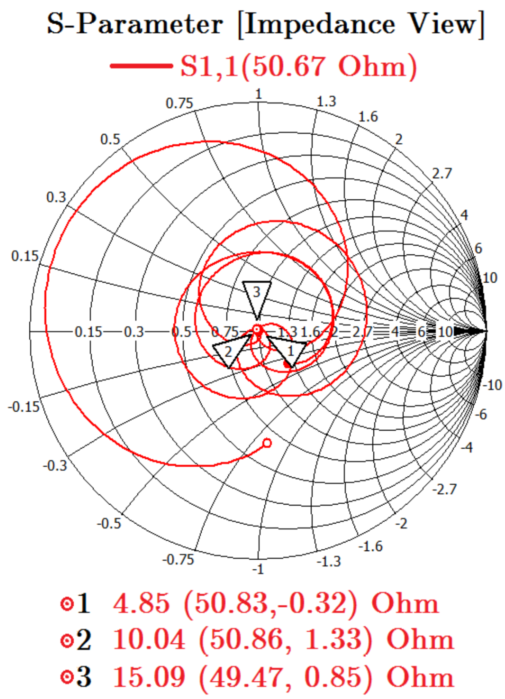


Figure 6.12: Smith Chart of the proposed antenna after inclusion of corner cuts.

The reason why we are getting such a good response can be understood by the smith chart analysis. The smith chart of before corner cuts and after corner cuts is shown in the Figure6.11. Before any corner cuts introduced the input impedance of the antenna is not same to the characteristic impedance of the transmission line. Moreover the imaginary part is negative for all the three bands. This shows that there is some capacitive component in the input impedance of the antenna. Thus complete power is not transmitted to the patch and thus some power gets reflected, thus we are getting more retun loss.

However by the introduction of the corner cuts the capacitive component gets reduced as we can observe from Figure6.12. We can see from the chart that the input impedance of the antenna is nearly equal to the characteristic impedance of the antenna and imaginary part gets nullified with the help of corner cuts. Thus complete power is transmitted and we get the minimum return loss.

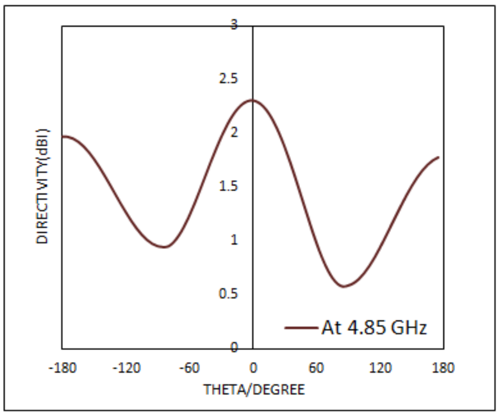


Figure 6.13: Directivity plot of the Tri Band antenna at 4.85 GHz

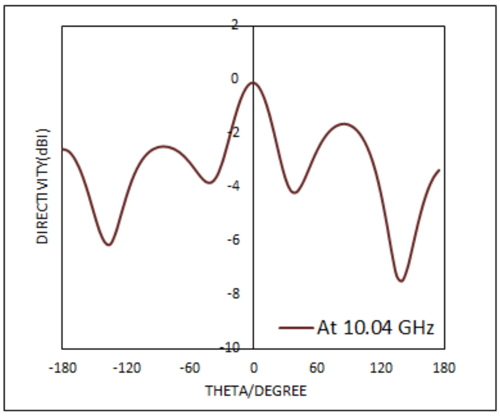


Figure 6.14: Directivity plot of the Tri Band antenna at 10.04 GHz

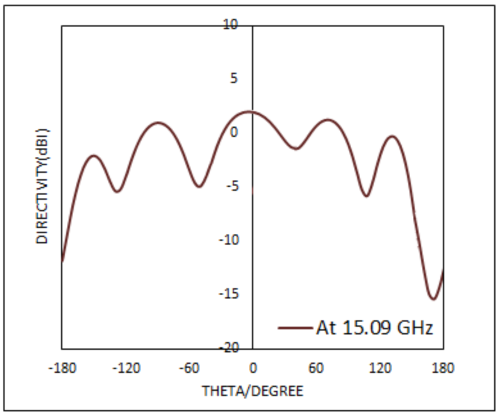


Figure 6.15: Directivity plot of the Tri Band antenna at 15.09 GHz.

The Figure6.13, Figure6.14 and Figure6.15 shows the directivity plot of the triband antenna at three resonant frequencies. We can observe that the antenna radiates well in the desired direction with maximum directivity in that direction and relatively less in the other direction. We can clearly observe that at lower band number of side lobes is less. In the middle band the sidelobes gets increased. And finally at the higher band large number sidelobes are formed. This is common in all the multiband antennas. The main thing we need to consider here is that the directivity is maximum in the required direction.

The realised gain and percentage efficiency is shown in the figure. We can observe that the realised gain is achieved the desirable value at the resonant frequencie and is minimum at the other frequencies. Also the percentage efficiency is in the range 70% to 95%. Peaks are observed at the resonant frequencies. Commonly the efficiency gets reduced at the higher frequencies, in my case also the efficiency is reduced as the frequency is increased, but is at its desired value at the resonant frequencies. This is how finally we obtain the triband characteristics with the desirable return loss.

CHAPTER 7

A Tri Band Reconfigurable Microstrip Patch Antenna Using Shorted Strip Technique

7.1 Inroduction

Up till now the tri band antenna was designed successfully with the desired return loss. The return loss as low as -55 dB is obtained which is very good.

The designed discussed in the last section was a perfect candidate for variety of applications where the antenna is operated in all the three bands simultaneously. It also provides sufficient isolation between the adjacent bands to avoid any interference in between the bands. However due to the increase in demand for more compact antennas which shows multifunctional properties has increased in the past decade. Due to the advancement in the wireless technology a single device can be operated in several frequency bands. For this reconfigurable antennas are the need of the day.

Situation arises where the antenna sometimes needed to be operated in single bands or multiple bands, depending on the application. If the system requires to be operated in single band, then the antenna should be inactive for the remaining bands so as to minimize power wastage. For this case the antenna should operate as single band antenna.

If system requires multiple frequency bands to be received, then the same antenna should used for this case acting as a multiband antenna. Using the same antenna for different application reduces the size of the system. This property is very much desired in the present era of communication. The reconfigurable antennas is finding importance in this area. Several researchers are working in the field of the reconfigurable antenna as these types of antenna is highly demanded in the present world. Thus the triband antenna is converted into a reconfigurable antenna by the application of rectangular parasitic elements which is positioned near to the feeding line. Stepwise analysis has been carried out showing the passing of a particular frequency band and the rejection of the other bands.

7.2 Discussion on antenna operation in the C band

Various reconfigurability techniques has been devised by the researcher for the switching in between the bands. But in this project I have used the concept of band filtering. Microwave filter kind of structure is made over the existing design of the patch. To operate antenna in single band the input is passed first to this filter. We know in simulation software almost infinite amount of frequency component is inputted via the input port. In time domain it looks like an impulse shape. This signal is then passed to an adjustable (switchable) filter that will pass a particular range of frequencies. These frequency is then radiated by the antenna.

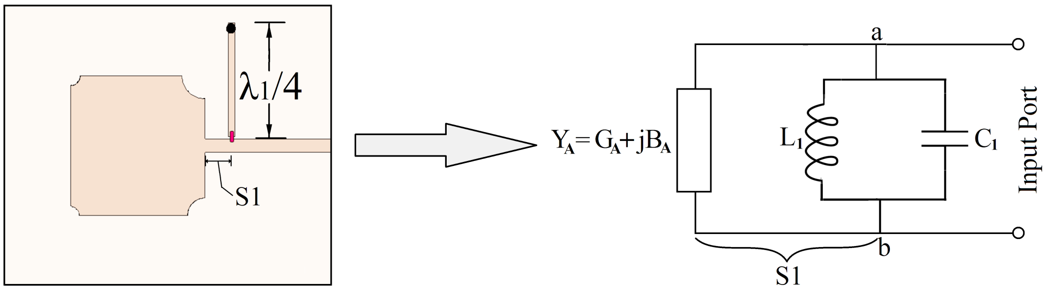


Figure 7.1: Equivalent circuit diagram associated with first parasitic element.

The deign of the antenna and its equivalent circuit is shown in Figure7.5. The parasitic elements acts like a shorted stubs which is used to match the input impedance if the antenna to the characteristic impedance of the transmission line, for a particular frequency. The length of the stubs play a very important role in determining which frequency is to be passed. It is calculated as $\lambda_1/4$ where λ_1 is associated with resonant frequency of the band1.

The antenna acts as a load in this case with admittance Ya. And the stub is equivalent to the LC network, which acts as a band pass filter. Let us assume that the characteristic impedance be rael i.e Z_0. So the associated admittance will also be real i.e G_0.

The admittance between a and b is given by:

$$Y_{abS1}(due\ to\ load\ Y_A) = Y_0\left[\frac{Y_A + jY_0 tan\beta_1 S_1}{Y_0 + jY_A tan\beta_1 S_1}\right]$$

$$= G_{abS1} + jB_{abS1}$$

$$Y_{ab}(due\ to\ the\ stub) = j(B_C - B_L)$$

where β_1 is the phase constant associated by λ_1 and is given by $\beta_1 = \frac{2\pi}{\lambda_1}$. Now combining these two effects to find the total admittance at point a and b we get,

$$Y_{ab} = G_{abS1} + jB_{abS1} + j(B_C - B_L)$$

So for maximum power transfer to load with no reflection,

$$Y_{ab} = G_0 + j0$$

$$G_{abS1} + j(B_{abS1} + B_C - B_L) = G_0 + j0$$

Thus equating real and imaginary parts, we get

$$G_{abS1} = G_0 \; and \; B_{abS1} + B_C - B_L = 0$$

So we can see that for the particular band to be passed, all the imaginary components must be zero. So for a particular band say band1 the length of the stub is adjusted in such a way that L_1C_1 network is formed which cancelles the effect of imaginary component of the load.

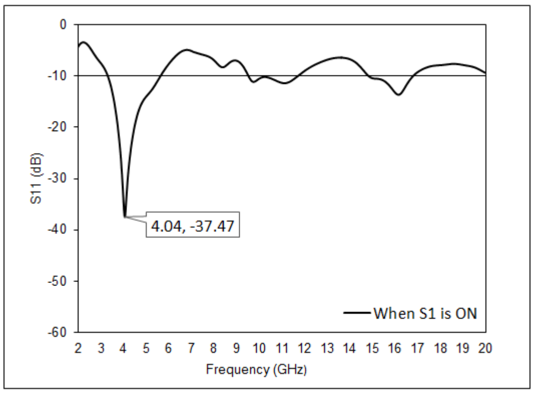


Figure 7.2: S11 plot when antenna operates in the first band.

And the load impedance equal to the characteristic impedance of the feed line so that maximum power transfer takes place for that particular band and not for the other band.

When D1 is ON, the $\lambda_1/4$ rectangular parasitic element gets connected to the line. And this assembly acts as a band pass filter to the input signal which only passes the band 1. Thus the antenna is successfully operated in this band. The related S11 plot is shown above. It can be observed that the resonant frequency is little bit disturbed which is due to the parasitic element introduced. This much shift is accepted.

7.3 Discussion on antenna operation in the X band

Similar rectangular element is designed on the other side of the line. But in this case it will be responsible for the passing of the second band. This rectangular element acts as stub for the impedance matching between the load which in our case is the antenna and the characteristic impedance.

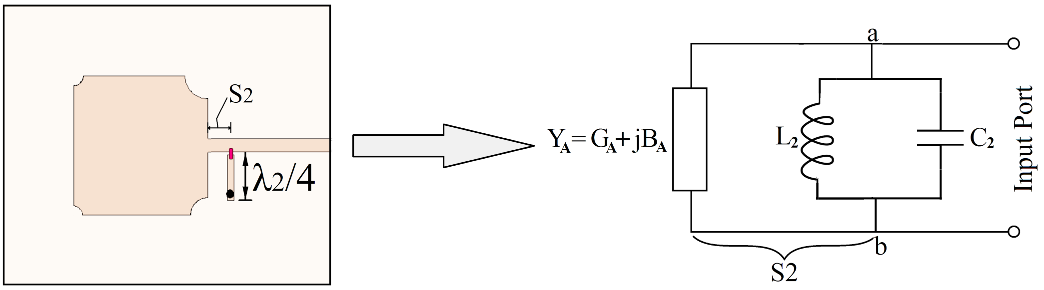


Figure 7.3: Equivalent circuit diagram associated with second parasitic element.

Matching takes place only for the second band in this case. The length of the stubs is taken as $\lambda_2/4$. The stubs is acting as a L_2C_2 network which is a band pass filter for band2. This is because we know that capacitive and inductive susceptance are frequency dependent. Consider the maximum power transfer theorem, the load admittance must be equal to the characteristic admittance G_0 of the load, which is a real quantity.

$$
\begin{aligned}
Y_{abS2}(due\ to\ load\ Y_A) &= Y_0\left[\frac{Y_A + jY_0 tan\beta_2 S_2}{Y_0 + jY_A tan\beta_2 S_2}\right] \\
&= G_{abS2} + jB_{abS2} \\
Y_{ab}(due\ to\ the\ stub) &= j(B_C - B_L)
\end{aligned}
$$

where β_1 is the phase constant associated by λ_1 and is given by $\beta_1 = \frac{2\pi}{\lambda_1}$. Now combining these two effects to find the total admittance at point a and b we get,

$$Y_{ab} = G_{abS2} + jB_{abS2} + j(B_C - B_L)$$

So for maximum power transfer to load with no reflection,

$$Y_{ab} = G_0 + j0$$

$$G_{abS2} + j(B_{abS2} + B_C - B_L) = G_0 + j0$$

Thus equating real and imaginary parts, we get

$$G_{abS2} = G_0 \ and \ B_{abS2} + B_C - B_L = 0$$

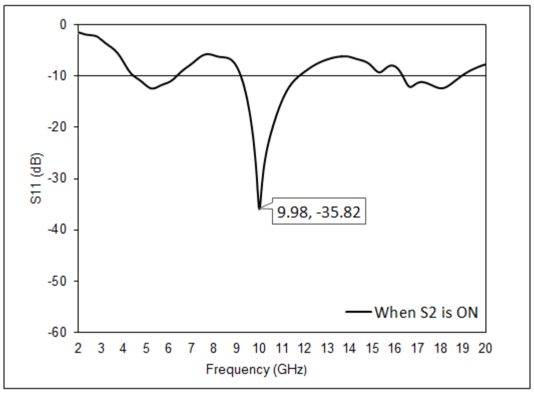


Figure 7.4: S11 plot when antenna operates in the second band.

So the inductive and capacitive susceptance exactly cancels the imaginary part of the load at that particular resonant frequency for maximum power to take place.

When the switch D2 is ON, the $\lambda_2/4$ slot is connected to the line which acts like a band pass filter for the second band. So the antenna faithfully operates in the second frequency band. The return loss obtained is near to -40 dB which is quite desirable also the resonant frequency is slightly changed.

7.4 Discussion on antenna operation in the Ku band

Same procedure is adopted for the third band. Here the length of the rectangular parasitic element is taken as $\lambda_3/4$. We can see that the length of the element decreases as the operating frequency is increased. The stub is positioned at a distance of S3. The equivalent circuit for the antenna is shown in Figure7.5.

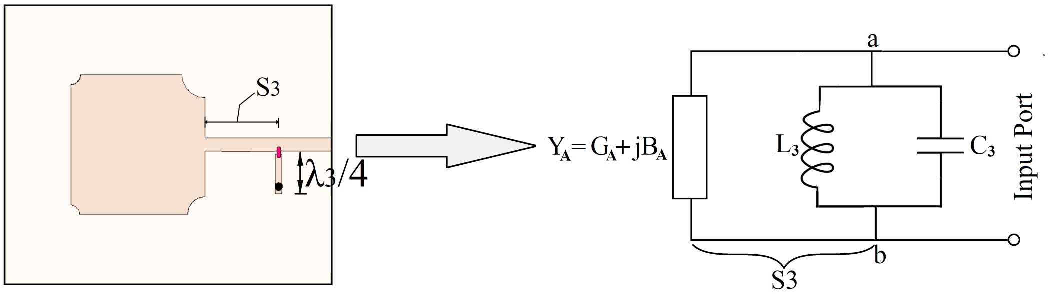


Figure 7.5: Equivalent circuit diagram associated with first parasitic element.

The L_3C_3 network corresponds the stub $\lambda_3/4$ acting as a bandpass filter the third band. This networks cancels the effect of reactive component of the load at that particular third resonant frequency. This can be understood from the following analysis.

Consider the maximum power transfer theorem, the load admittance must be equal to the characteristic admittance G_0 of the load, which is a real quantity. So for maximum power to take place,

$$Y_{abS3}(due\ to\ load\ Y_A) = Y_0 \left[\frac{Y_A + jY_0 tan\beta_3 S_3}{Y_0 + jY_A tan\beta_3 S_3}\right]$$

$$= G_{abs3} + jB_{abs3}$$

$$Y_{ab}(due\ to\ the\ stub) = j(B_C - B_L)$$

where β_1 is the phase constant associated by λ_1 and is given by $\beta_1 = \frac{2\pi}{\lambda_1}$. Now combining these two effects to find the total admittance at point a and b we get,

$$Y_{ab} = G_{abS3} + jB_{abS3} + j(B_C - B_L)$$

So for maximum power transfer to load with no reflection,

$$Y_{ab} = G_0 + j0$$

$$G_{abS3} + j(B_{abS3} + B_C - B_L) = G_0 + j0$$

Thus equating real and imaginary parts, we get

$$G_{abS3} = G_0 \; and \; B_{abS3} + B_C - B_L = 0$$

Thus the stub $\lambda_3/4$ is used for impedance matching between the load and the characteristic impedance of the feed line.

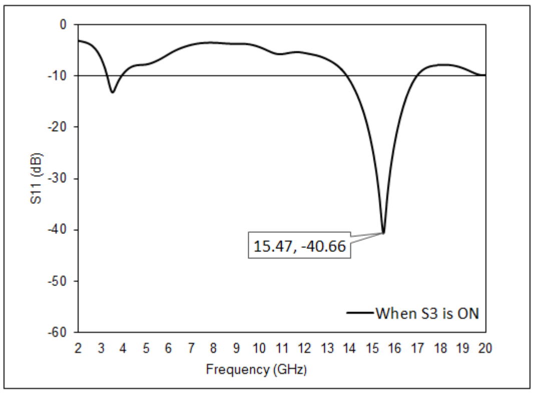


Figure 7.6: S11 plot when antenna operates in the third band.

When the switch D3 is on the associated $\lambda_3/4$ stub is connected to the feed line. This acts as a band pass filter for the third band and the antenna is successfully operated in this band. The return loss again here is -40 dB.

Note that the position of the rectangular parasitic element or so called stubs is determined by the parametric analyisis.

7.5 Final proposed antenna design

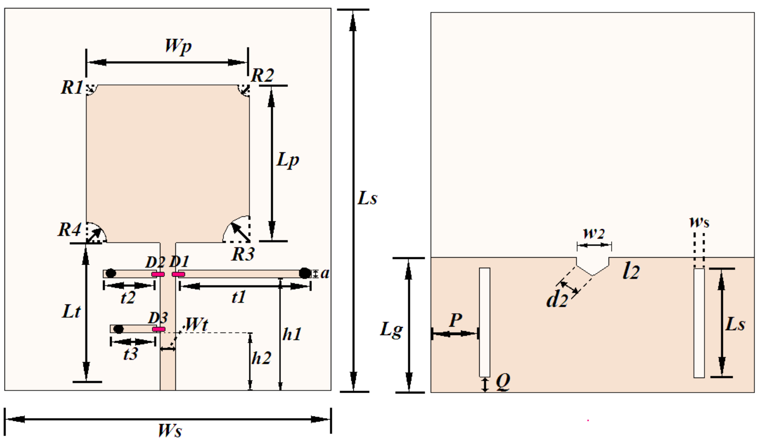


Figure 7.7: Design of Tri Band Reconfigurable antenna.

Table 7.1: Design parameter dimensions of of Tri Band Reconfigurable antenna.

Parameters	**Values(mm)**	**Parameters**	**Values(mm)**
Ws	30	Ls	35
Wp	15	Lp	14.5
Lt	13.5	wt	1.45
Lg	12.5	P	4.5
Q	1	$w2$	3
$l2$	0.75	$d2$	1.8
Ls	10	ws	1
$R1$	1	$R2$	1.1
$R3$	2.5	$R4$	1.9
$t1$	11.6	$t2$	4.6
$t3$	4.1	$h1$	10.6
$h2$	5.6		

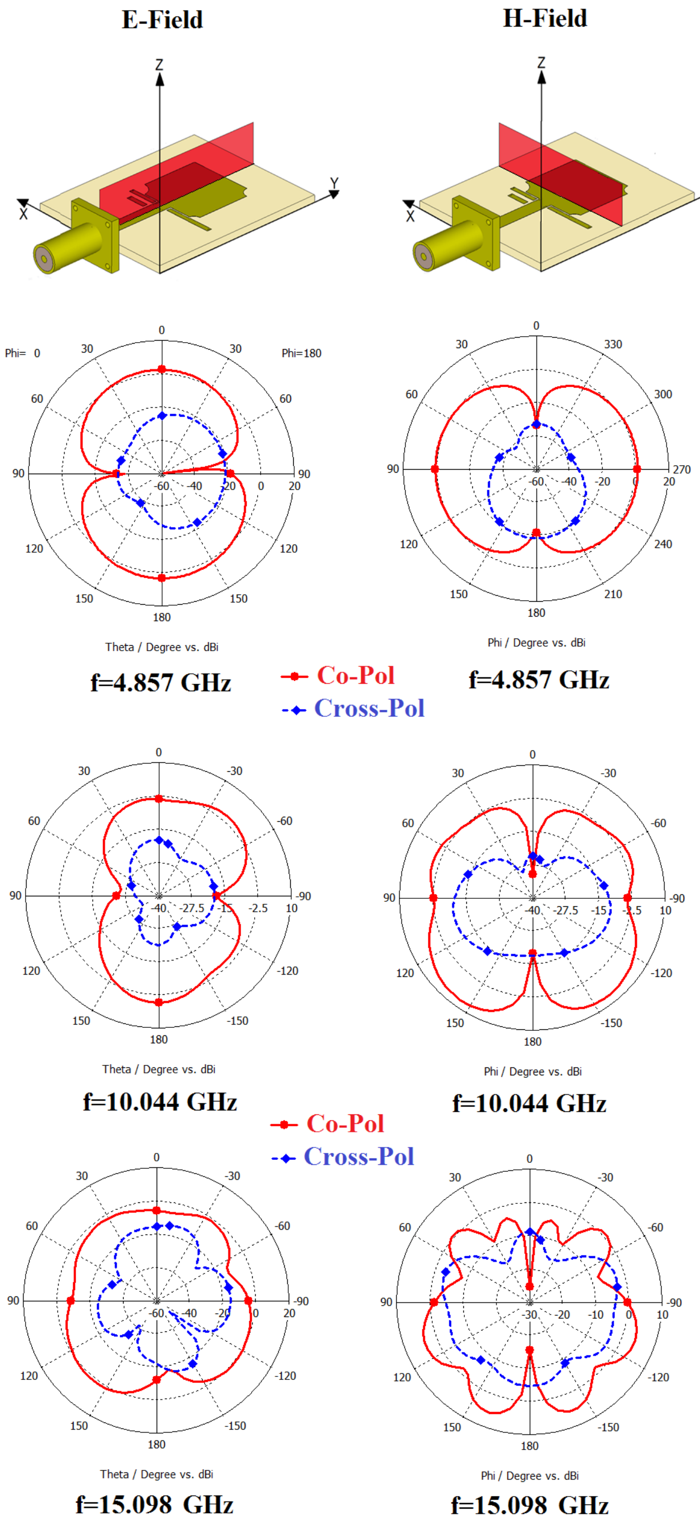


Figure 7.8: Co and Cross polarisation of Tri Band Reconfigurable antenna.

The final design if the antenna is shown in Figure7.7. All the three discussed cases has been summarized here. We can see that the parasitic element gets connected to the feed line whenever desired with help of switches.

The Co and Cross polarisation is also plotted in Figure7.8 for the Tri Band Reconfigurable antenna. Suppose the antenna is designed to operate in the vertical polarisation. So for this antenna the vertical polarisation is called the *Co-polarisation*. However due to some spurious radiation, some orthogonal polarisation componets also gets radiated which in the present case is the horizontal polarisation which usually undesired. This type of polarisation is called as *Cross polarisation*. This cross polarisation component interferes with the co-polarisation component to distort the signal. So to keep the distortion minimum the value of the cross polarisation must be less as compared to the co polarisation component.

CHAPTER 8

Conclusions and Future Directions

8.1 Concluding Remarks

In the previous sections, detailed study of the design of the antenna was discussed. The design discussions on each and every aspect has been carried out in this text. Initially how a 6 GHz antenna is deigned was seen and its characteristics was simulated. Later this design was converted to an ultrawideband design giving somewhat exact ultrawideband characteristics. This was obtained by only by removing the part of the ground plane this ground plane was given the name *partial ground.*

But the design was not limited to the ultrawideband one. It is then converted into a Tri Band antenn by the introduction of triangular slot and two rectangular slots in the ground plane. The antenna showed minimum return losses at the three bands namely C,X and Ku bands. This antenna gave perfect impedance matching property in all the three resonant frequency and their associated bands. Since this Tri band antenna was limited only for certain applications, it was decided to better convert it into a switchable or reconfigurable antenna.

A unique technique of achieving reconfigurability has been employed. The use of parasitic elements which are shorted to ground made the antenna a reconfigurable one. A single parasitic element is capable of band pass filtering a single band at a time. These elements are connected to the feed line with help of switches such as PIN diode which are usable at microwave frequencies. A point should be noted that the discussion in this text is only on the design of the antenna, but not the type of switching employed. We can assume that it is a generalised design having possibilities of incorporating all types of switching techniques such as electrical or optical techniques.

However by the use of such elements the original characteristics has been little bit disturbed. The resonant frequencies of the antenna was little bit shifted. These shift is quite negligible and hence should not be taken into consideration. Also the return losses has been slightly increased.

In the whole project work the basics related to the antennas was studied in depth. In this text also all the concept has been discuused. In the design of the Tri Band reconfigurable antenna also, the function of each and every cuts and slots was discussed and analysed. Wherever needed the parametric analysis has been carried out. Thus finally the end product was as desired giving better results.

8.2 Scope for Further Study

Although the antenna designed has all the desired properties and application, there is always a scope for further improvement.

The proposed design consist of the substrate made up of FR-4 material. This material is selected because it is easily available and cheap. However FR-4 material shows good behaviour upto 10 GHz frequency, but its performance degrades there after. It is not recommended at higher frequencies. Thus this antenna can be modified with the use of substrate made up of materials such as RT Duroid, Rogers 4350, etc. which are capable of operating efficiently at higer frequencies.

The unique feature of this project is that the switching takes place in the feeding line area which is away from patch geometry. This allows us to extend this project towards implementing reconfigurable array antennas. Only a power divider network is needed to supply power to the array element. Switching will take place near to the feeding arrangement which will not disturb the array. The advantage of using array configuration is that we will get better gain and efficiency. The gain of this proposed design is quite low. So this array configuration will enhance the gain of this antenna.

Other technique to enhance the gain of this antenna is to use *Frequency Selective Surface (FSS)*. The Frequency Selective Surface (FSS) are the periodic structures of small elements which are arranged in 2D. These are totaly passive elements without any power supplied to them. These surfaces acts as reflector for some frequencies but it is almost transparent to other frequencies. If these surfaces are designed according to the desired resonant frequencies of the antenna and if it is placed at the back of the antenna with some specific distance from the antenna, it will reflect the fields associated with the three resonant frequencies. These field add up with the existing fields of the antenna giving better directivity and gain. Note that these surface acts similar to reflectors in the parabolic antenna case.

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