Transparent Microstrip Patch Antenna Using Indium Tin Oxide for Telecommunication Applications

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DECLARATION

We, hereby declare that this research is based on the results found by ourselves. Informationfound by other researchers have mentioned in reference. This thesis has not been previously submitted for any degree.

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ABSTRACT

Transparent microstrip patch antenna has been the main focus of this thesis work. The use of transparent antennas for stealth and telecommunication purpose has been the incitement of this research. Lately the urge for high data rate communication, very fast speed and shorter distance have triggered engineers and scientists to work in the large scale of frequency range. On the other hand top mobile manufacturing companies are giving significant effort to build transparent devices which is a good sign for stepping into the promising futuristic works. These facts have been the main motivation of this research. Such antennas are being assembled on the materials which are highly conductive, discreet and conformal. Moreover which has the quality to delivery decent antenna performance on glass in the latest generation communication like 3G,4G or 5G. Our proposed microstrip patch antenna offers a good solution for the multiband areas in the frequency range of 0-35GHz which we have noticed by comparing other researches done before. In this research, we have investigated the result of the patch antenna using indium tin oxide (ITO) with glass substrate. Parametric studies in this work has been calculated and simulated by CST microwave studio. This contention has shown the radiation parameters, S-parameters of the transparent microstrip patch antenna.

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CHAPTER ONE

INTRODUCTION

1.1 Project Background

The popularity of mobile communication systems has increased remarkably during the last decade and the market demand still continues to increase. As a basic part of these systems, antenna is one of the most important design issues in modern mobile communication systems. If we consider both commercial and military applications wideband, multiband and low profile antennas are great demand for modern wireless communication system. Which has influenced the research on antennas in many directions. Traditionally each antenna operates in a single or dual frequency bands, that is why different antenna is needed for various applications [1,5]. But it causes limited space and place problem. In order to overcome these barriers the idea of multiband antenna has appeared which is a single antenna that can operate in different frequency bands. Moreover the main advantage of multiband antenna is the simplicity of its design. Overall we can define a multiband antenna as a system which operates at a separate or an unconnected frequency bands but not at the transitional frequencies among the bands. And the frequency range we have used in this study is approved by federal communication commission (FCC).

We all know that the transparent market extend well beyond displays. We have seen led displays, transparent USB drives and even mobile phone prototypes. Mobile phone companies are already working on making transparent mobile phones and have already made progress. Device now-a-days especially cellular devices have multiple antennas for different purpose such as Bluetooth, wi-fi, GPS, GSM and many more. As antennas are one of the most integral parts of a cellular device the evolution of antenna has been very obvious: smaller, lightweight and most importantly effective. Lately the cellular devices consist of novel antennas that do not protrude from the device, forcing designers to look more into the aesthetics of the antenna [1]. Many well-known cellular companies are already developing completely flexible devices and working on transparent cellular phone. Newer and innovative solutions for antenna need to come forward to keep up with the demand. So the idea of transparent antenna is not surprising at all.

Indium-tin oxide (ITO) is the most popular transparent semiconducting oxide thin film related to the high optical transmittance in the visible and near infrared regions, and also high reflectance in the infrared region. It has been vastly used in different electronic devices, display devices and even infrared reflectors. Indium-tin oxide (ITO) has a very low electrical resistivity which is less than 60Ωm and has wide electrochemical window. Because of high optical transmittance, electric conductivity and band gap (> 3.5 eV) ITO is widely used in many optoelectronic devices such as photovoltaic cells, monitors of ATMs, ticket vending machines and gas censors. Besides, characteristics of oxide thin films are very stable for electric conductivity and transmissions.

The designing of antennas for small mobile devices is becoming difficult not only for limited space but also because it influences other parts inside the device, which lessen the efficiency of the antenna as well. Designing a transparent antenna using transparent conductive films such as Indium tin oxide (ITO) force the transmission of electrical currents while not abolishing the optical transparency. Moreover transparent and flexible antennas are good way to remove the limited space problem as it can be installed on the surface or the display window without being much visible. Moreover the intrusion from the other electric parts can be concealed because of the location of the antenna. In this study we have discussed and designed a transparent microstrip antenna for transparent futuristic mobile device using CST microwave studio simulator software.

1.2 Objective

The objectives of the research are as follows:

1.2.1 Design and simulate the multiband antenna using ITO.

1.2.2 Investigate the performance of the multiband antenna in terms of return loss, VSWR, gain and radiation pattern.

1.3 Scope

The scopes of the research are stated below:

1.3.1 Design and simulate the UWB antenna using ITO operating at 0 up to 35 GHz using CST Microwave Studio.

1.3.2 Investigate and observe the performance of these antennas through several parametric studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Basic Concept of Antenna

Before we get into the main study it is important to understand what is the fundamental of an antenna and how a microstrip patch antenna works as our main work in this thesis is to design a microstrip fed planar monopole antenna for multiband operation. Basically an antenna is an electromagnetic radiator which creates electromagnetic field. The main job of antenna is to convert electromagnetic radiation in space into electrical currents in conductor or vice versa. It mainly depends on whether the antenna is transmitting or receiving the signal.

There are several types of antenna under three main categories which are omni-directional, directional and semi-directional antenna.

Omni-directional antennas are designed in such a way that they can radiate in all directions. It is very easy to install for its horizontal pattern. These type of antennas can deliver large communication distances but coverage under the antenna is very poor which is one of the main drawbacks of omni-directional antenna.

Directional antennas are designed for diverting the RF energy to specific direction to further distances. So we can cover long areas but effective beamwidth decreases. For the point to point links these antennas are used. Sometimes it is needed in the base stations where a sector needs to be covered separate antennas. Panel antennas are the examples of directional antenna.

Semi-directional antennas operate in a constricted fashion and are designed to provide a directed signal over a large area. This is also known as microstrip antenna.

If we want to design an antenna, we need to understand the basic parameters that characterize the antenna or define how that specific antenna will work and which will be the usage. Those parameters are frequency, frequency bands, gain, VSWR, return loss, polarization, impedance, bandwidth, efficiency, effective area or aperture, substrate, field regions, s-parameters, ground plane, directivity and radiation pattern. We will discuss this thoroughly in this thesis which will help us to understand the design of our proposed transparent microstrip antenna.

2.2 Microstrip Patch Antenna

The use of microstrip patch antenna is increasing day by day as it can be printed quite easily on the circuit board. And not to mention it is widely spread in the mobile phone market. These microstrip patch antennas are easier to fabricate, have low profile and most importantly low cost. Microstrip patch antennas have many geometrical shapes and dimensions but rectangular and circular designs are the most popular and have been used in many applications. They are highly used for their simple design and affinity with the printed circuit technology.

A simple microstrip patch antenna consists of a radiating patch and a ground plane. The radiating patch on one side is set with a dielectric substrate. A rectangular microstrip patch antenna has rectangular patch with a substrate thickness (h), permittivity (εr) and with width (W) and length (L) over a ground plane. The length (L) of the patch is usually $\lambda_O/3 < L < \lambda_O/2$ and the thick of the patch is very thin ($t << \lambda_O$) [1,3]. There is a simple rectangular microstrip patch antenna shown below in the figure no.1 which will specify the transmission line, substrate and ground plane of the microstrip antenna.

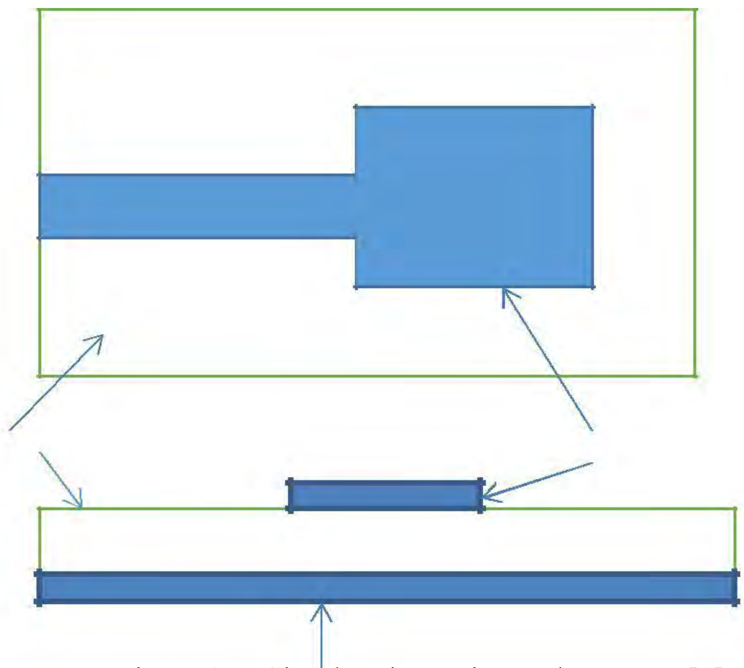


Figure 2.1: Simple microstrip patch antenna [1]

The patch of a microstrip patch antenna is generally made of copper or gold. On the surface of the dielectric substrate feed line and the radiating patch are basically photo etched. Due to the fringing fields between the patch edges the microstrip antenna primarily radiate. Just for its fringing fields the patch is electrically bigger than its physical size. Rectangular microstrip patch antenna is a very simple design considering its geometric structure but the electromagnetic field is complex. Calculating all the parameters need thorough analysis and accurate calculation. The main advantage of a microstrip patch antenna is its lightweight and simple design. But the drawbacks are the narrow frequency bandwidth, deceptive feed radiation, poor polarization purity, limited power capacity, tolerance problem and the excitation of surface waves.

2.3 Different Types of Microstrip Patch Antennas

Microstrip patch antennas can be classified based on their physical parameters. Different types of patches have different purposes. There are square, rectangular, circular, dipole, printed and elliptical configurations. Some of the configurations have show below in figure 2. There are different slots in patch antenna configuration such as A-slot, U-slot, H-slot, E-slot patch antennas. They are used for different frequency bands.

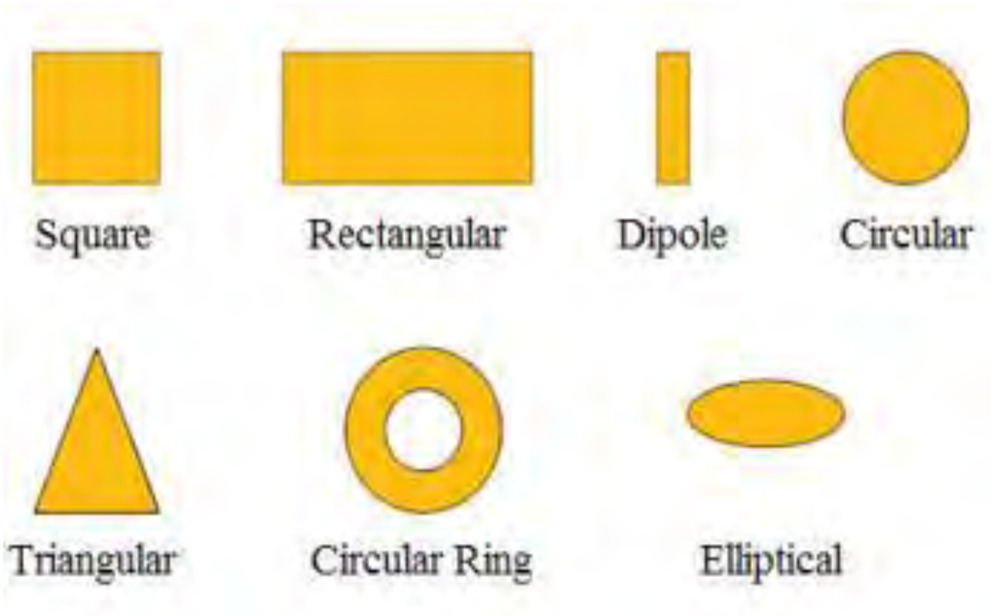


Figure 1.2: Configuration of different types of patch antennas [1]

2.4 Feeding Techniques

Two types of feeding method can be classified for microstrip patch antenna. One is contacting and the other is non-contacting. In contacting feeding method patch is fed with RF power using the coaxial line [23]. On the other hand in non-contacting method patch is not directly fed with power rather, power is passed through electromagnetic coupling.

In order to increase the quality of the antenna input impedance feeding techniques are very important. There are various types of feeding techniques such as microstrip line feed, inset feed, coaxial feed, aperture coupled feed and proximity coupled feed. Different types of feeding techniques are used in different application according to the requirements [1, 23].

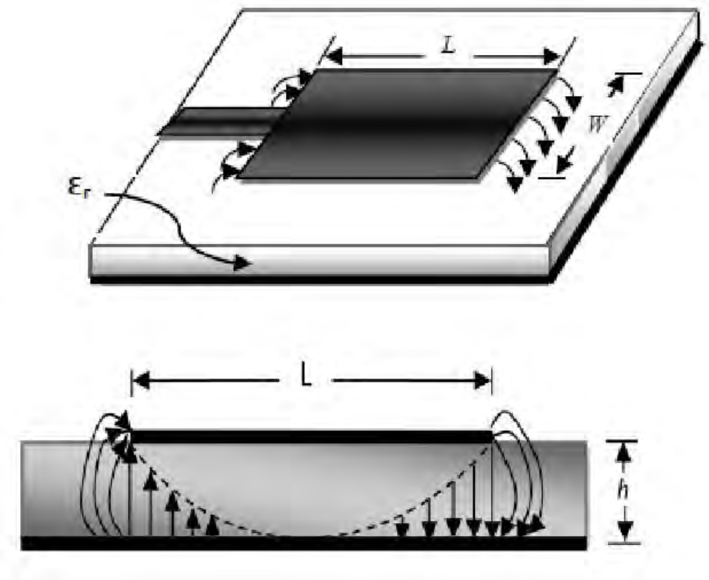
2.5 Frequency

To understand the frequency at first we have to go through electromagnetic waves. This electromagnetic wave is basically an electric field that travels away from antenna. These waves are periodic and vary with position and time. Basically the frequency is the measurement of how fast the wave is oscillating. We use this frequency terms when we discuss about at which wavelength the antenna is operating or which range we are using. Moreover the power of an antenna at which it can transmit is divided into frequency regions or frequency bands [2, 3, 11].

2.6 Fringing Effects

Fringing fields play an important role on the performance of a microstrip patch antenna. As the dimension of the patch is finite, the fields at the edges of the patch go through fringing. The amount of fringing is measured by the dimension of the patch and the height of the substrate. So the higher the substrate, the greater the fringing is. In the microstrip patch antennas the electric field in the center of the patch is zero. Because of fringing effect the microstrip patch antenna looks greater than its physical dimensions.

29].



(a) Electric field lines (top view) (b) Electric field lines (side view)

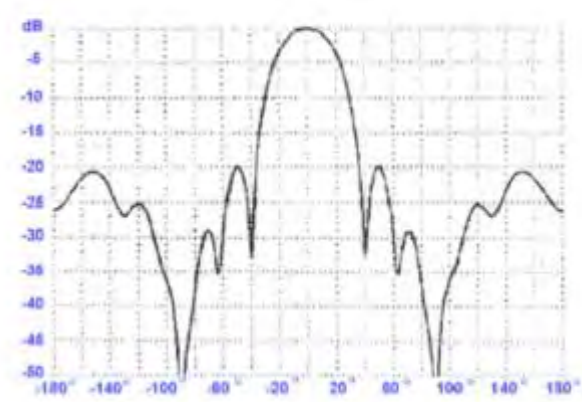
Figure 2.3: Electric field lines for microstrip patch antenna [1,3].

In figure 3 we can see along the width and thickness there is no field variation. While designing a microstrip patch antenna it usually cut by 2-4% to get the desired resonant frequency.

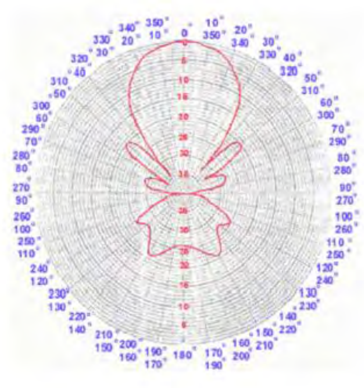
2.7 Radiation Pattern

A radiation pattern looks into the variation of the power radiated by the antenna. It describes the respective strength of the radiated field in different direction at a constant distance. Radiation pattern also exposes the receiving properties of the antenna. It is a three dimensional pattern but measured in two dimensional slices on the vertical and horizontal planes. These patterns are showed in ether rectangular or polar format. In rectangular format it is difficult to visualize the behavior of a microstrip antenna from different direction. Polar format is vastly used. Polar co-ordinate system can be divided into two category, one is linear another one is logarithmic [1, 25, 29].

Radiation pattern can be classified into two ways, absolute radiation pattern and relative radiation pattern. Absolute radiation patters looks into the absolute unit of field strength or power. On the other hand relative radiation patter is presented in relative units. In order to calculate the patch antenna properly it is required look through the source of the radiation of the patch of edge of microstrip and the ground plane [1,2, 29].



(a) Rectangular format [1,3]



(b) Polar format

Figure 2.4: Different types of radiation pattern [1,3].

2.8 Return Loss

Return loss is one of the most important parameters and key measurements for antenna. It characterizes the performance of overall system and shows if the antenna will give specific and expected frequency range or not. The return loss indicates the effectiveness of an antenna to deliver the power from the source to the antenna. Return loss basically means the loss of reflection. In telecommunication system return loss is the loss of the power in the signal that reflected by the disconnection in a transmission line. This disconnection is known as impedance discontinuity. This process is responsible for two signals to come on the cable, one of them goes to a direction another goes to the opposite. They cancel and add at different points. These cancellation and addition can happen to the receiving end of the cable where we can loss all the data. This is why the concern rises about the return loss in the transmission line [1-3, 25, 29].

It is usually expressed as a ration in dB. It is also known as S11 parameter. As this parameter shows the measurement of power that reflected from the antenna, if S11= 0 dB, that means nothing actually radiated from the antenna; all the power got reflected from the antenna. When the S11=-10 dB that means if the power delivered to the antenna is 3 dB then -7 dB will be the reflected power. The ration of the reflected power and incident power is represented as Γ.

$$\text{Return Loss} = -20 \log_{10}\Gamma \text{ (dB)} \qquad \textbf{(1)}$$

$$\Gamma = \text{Reflected power / Incident power.} \qquad \textbf{(2)}$$

For the sake of good transfer power the ration should be high. Otherwise resonances could appear which could come up with a frequency ripple.

2.9 Directivity

One of the fundamental parameters of antenna is its directivity. It represents the radiation pattern of the antenna and shows how directional it is. For example if an antenna radiates in all direction equally that means it has zero directivity. The shape of the radiation pattern is solely responsible for the directivity of the antenna. Directivity can be smaller than unity even it can be zero.

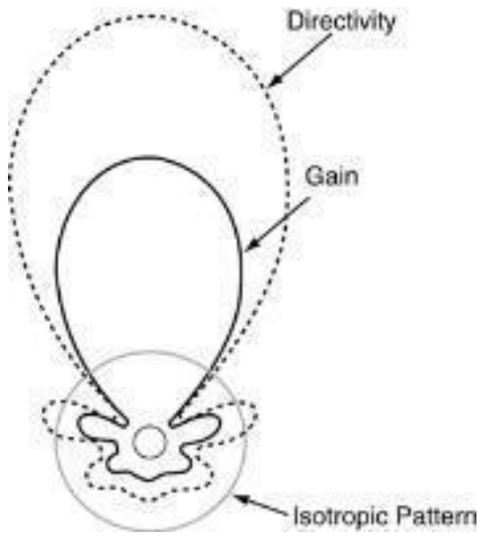


Figure 2.5: Directivity of an antenna [1,29]

2.10 Gain

It represents the antenna performance basically. The definition of antenna gain is close to that of directivity. The main difference is that gain is depended on both efficiency of antenna and the directivity. It is usually expressed in dB. It depends if our desired gain should be high or low. If we know from where we are getting our signals then the antenna gain can be high, on the other side if we have less idea about the location of the signal the gain should be low. For example, wi-fi and television antennas have gain on the other hand GPS and cellular antennas have low gain [29].

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

Where, G= gain and D= Directivity.

2.11 Bandwidth

Bandwidth refers to the range of the frequency over which a specific antenna can radiate properly or receive the energy. According to IEEE Bandwidth definition: "the range of usable frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard".Bandwidth can be the determining factor to decide an antenna. It is technically represented in terms of VSWR (voltage standing wave ratio). In narrowband antennas bandwidth is shown as the frequency difference over the center frequency of the bandwidth. And for the broadband antennas it is the ratio of the upper to lower frequencies of the desired operation. The measurement of bandwidth can be shown in the given equation below.

Bandwidth of a narrowband = $\frac{(fH - fL)}{fC} * 100\%$ (4)

Where,

f_H= upper frequency

f_L= lower frequency

f_C= center frequency

2.12 Antenna Efficiency

Efficiency is very important for an antenna as we must make sure that the antenna uses all the power and energy properly which has obtained by the source. It looks into the measures of the losses in the antenna structure and the losses in the terminals. Basically it is the ratio of the total power radiated through the antenna to the total input given to the antenna. It is quite obvious that no antenna can have 100% efficiency considering its irrepressible losses. Several mismatches between the transmission line and the antenna with dielectric or conductivity losses are responsible for the lacking of efficiency [1, 2, 29]. When the efficiency is high, that indicates the antenna will radiate maximum of the delivered power in its terminal. But when the efficiency is low, then all the power will be absorbed as antenna losses at its terminal or it can be reflected away because of impedance mismatch.

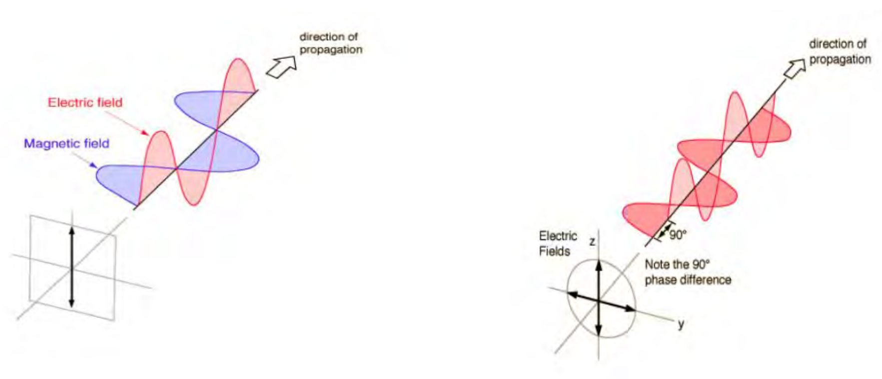
2.13 Polarization

Polarization is one of the fundamental factors and an important design consideration. Both RF antennas and electromagnetic waves are said to have polarization. By antenna polarization we understand the radiated fields generated by the antenna. This generated fields are the properties of electromagnetic wave. This wave looks into the matter of time varying direction and magnitude of the electric field vector. Antenna polarization needs to be matched with the radiated field orientation for the sake of receiving the maximum field intensity to the electromagnetic wave. If the polarization of the receiving and transmitting sides do not match with each other then there will be polarization mismatch and power loss as well. So in order to avoid the power loss polarization needs to be in the same direction. The Polarization Loss Factor is also known as polarization efficiency, antenna mismatch factor, or antenna receiving factor. All of these names refer to the same concept. Antenna polarization can be divided into three side linear, circular and elliptical [19].

When the electric and magnetic fields of the antenna is traveling in a single or same direction that indicates they are perpendicular to each other then it is considered as linear polarization. If the electric field parallel to the earth then it is horizontally polarized. On the other hand, when the electric field is perpendicular to the earth then it is vertically polarized [19].

When the electric or magnetic field vector rotates around a circular path and at the same time remains constant in length then it is defined as circular polarization. There can be clockwise and counterclockwise polarization. In clockwise polarization the wave is right handed circularly polarized (RHCP). In the same way, in counterclockwise polarization the wave is left handed circularly polarized (LHCP). In this circular polarization the two orthogonal components have same amplitude and properly ninety degree out of phase. Interesting part of circular polarization is RHCP waves will reflect as a surface and act like LHCP. The main disadvantage of this RHCP is it can prevent signal fading effects from the reflected wave barricading the desired waves. That's why GPS signals from satellite are usually RHCP [19, 29].

If the tip of the electric or magnetic field can trace the elliptical locus in space then it is considered as elliptical polarization. Like circular polarization the electromagnetic field has two perpendicular components and they are out of phase by 90 degrees but the magnitude is not the same. Although the phase offset and magnitude ratio are constant, It can be defined by its major and minor axis amplitude.



(a) Linear polarization (b) Circular polarization

Figure 2.6: Different types of polarization [1, 19]

2.14 Substrate

Many substrates can be used while designing a microstrip patch antenna. Basically their dielectric constants are in the range of 2.2 <εr < 12 [3]. An antenna radiates in the initial phase because of the patch edge and ground plane. When the dielectric constant is ticked the lowest tangent is available. The loss tangent indicates the quantity of electrical energy which is usually converted to heat by dielectric. And this is responsible for the maximization of the antenna efficiency [17].

Higher dielectric constant is required in microwave circuitry because they can reduce coupling and unexpected radiation. But they are not efficient enough and get smaller bandwidth because of the high losses. But to compromise between a decent circuit design and performance higher dielectric constant is needed.

CHAPTER THREE

CHARACTERISTICS OF INDIUM TIN OXIDE

3.1 INTRODUCTION

Indium Tin Oxide is a ternary composition of three parts of indium, tin and oxide. Indium tin oxide is ordinarily experienced as an oxygen-soaked piece with a plan of 74% In, 18% O_2, and 8% Sn by weight. Oxygen-immersed organizations are typical to the point, that unsaturated arrangements are named oxygen-insufficient ITO. Indium tin oxide (ITO) is a popular n-type transparent conductive oxide material. In this material tin acts as dopant in the indium oxide lattice and as a substitute on the indium sites to bind with the interstitial oxygen. ITO is widely used in optoelectronic devices like gas sensors, photovoltaic cells and liquid crystal displays because of its very high electrical conductivity, high optical transmittance and wide band gap. Besides these above mentioned devices we have seen in the recent studies that ITO can be patched in the antennas too. In this chapter we will discuss more about the background of ITO and it is physical and chemical characteristics which helped us to develop our proposed microstrip antenna.

3.2 History and Background

Transparent conductive films can be traced back to 1907. K. Badeker first fabricated cadmium oxide by thermal oxidation back at that time. For the last thirty to forty years the most dominant transparent conductive film have be indium tin oxide, tin oxide, zinc, oxide. These materials have been mass produced for a long time without any development. After that there has been many significant works on developing these thin films in japan. After that in US several efforts have been made to improve the device performance by developing the transparent conductive films. Many program held at NREL from 1985 and onwards. In the 1990s, several programs took place in AT&T lucent technologies and recent startup program in Northwestern University.

3.3 Deposition of ITO

There are many ways to produce these conductive thin films like ITO. There are various specific methods of producing ITO such as magnetron sputtering, chemical vapor deposition (CVD), spray pyrolysis, electron beam evaporation, ion-beam sputtering, vacuum evaporation etc. The choice of deposition is taken by looking into different matters like the quality and reproducibility of the film, ease, cost and homogeneity over a wide cross section. These processes have their own pros and cons.

Among these sputtering is the most expensive form of deposition. It is closely related to thermal evaporation which also can be done by following several techniques. In this process accelerated ions from excited plasma knocks the molecule out of the target material. And deliquesce it on the substrate apart from the fact that it is original or modified. When the chemical reaction happens in this modification during the transition then it is called reactive sputtering. Most ITO sputter sources are made of hot pressed 90% In2O3 : 10% SnO2 [8,11].

Spray pyrolysis looks into the fact of thermal decomposition. This is interesting and attractive at the same time because no vacuum process is needed. Alcoholic solution of anhydrous indium chloride is the source of ITO spray here and carrier gas is the tin chloride with nitrogen. The whole process is held at 400 degrees of Celsius [8]. It is simply a trade of between the conductivity and transmittance of the ITO films.

Thermal evaporation consists of vaporizing a solid at a very high temperature and condensing it again at a cooler substrate. 90% In – 10% Sn alloy is used as the source of the substrate. Heat is increased by the knocking the electron and ion beam. Substrate temperature is being raised to 300-400 degree of Celsius to achieve the high conductivity and transmittance of ITO [8].

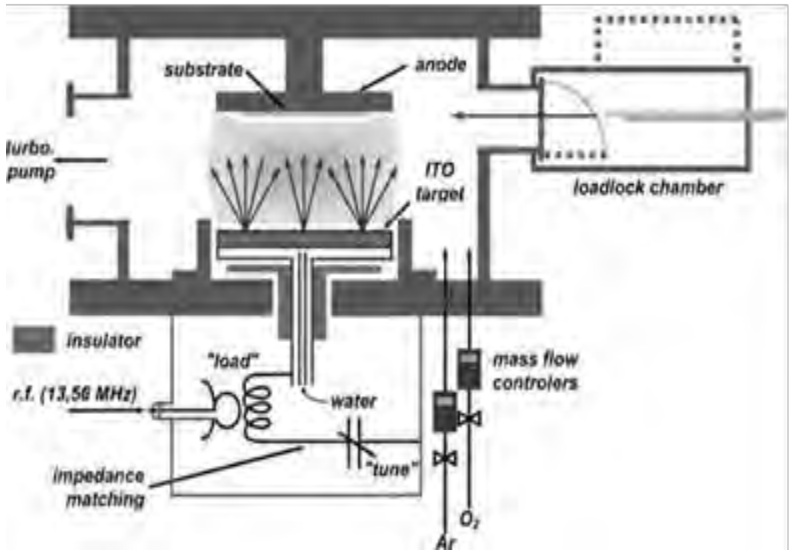


Figure 3.1 : Diagram of r.f sputtering machine [3,5].

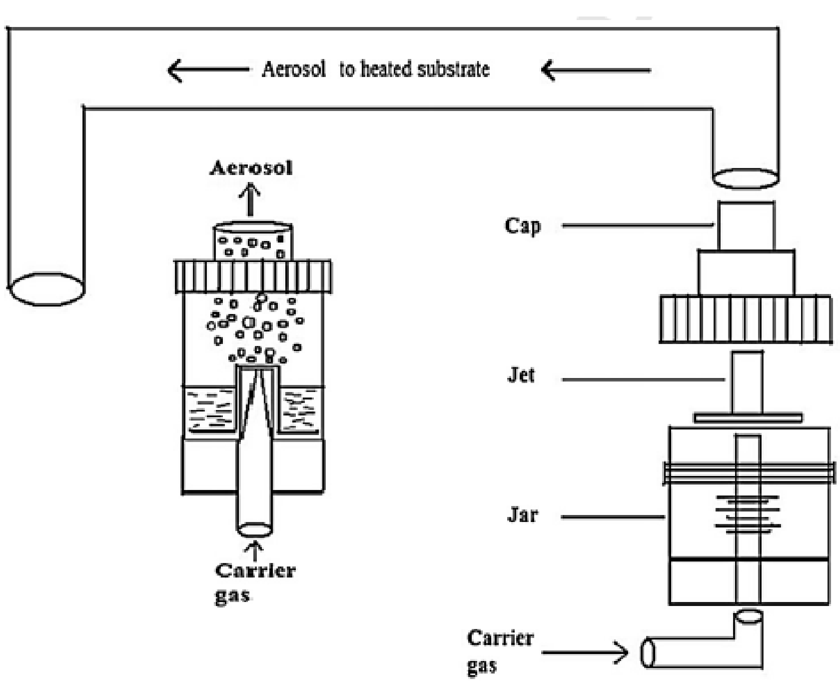


Figure 3.2 : Schematic digram of spray pyrolysis process [13]

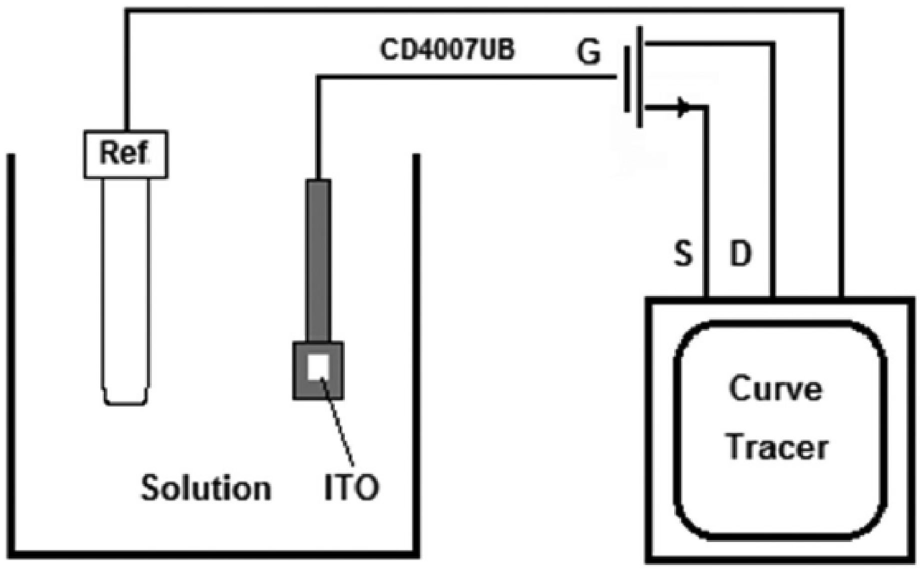


Figure 3.3 : Schematic diagram of CVD architechture [9] .

3.4 Physical Structure and Properties of ITO

Indium Tin Oxide is formed by doping indium oxide and tin which substitutes In3+ atoms from the bixbyte structure of indium oxide. Tin forms a bond with oxygen and makes tin oxide or tin dioxide. And it has a valency of +2 and +4 [8]. This valency is directly connected to the conductivity of the ITO films. Tin dioxide acts as a n-type donor which releases electrons to the conduction band. The higher conductivity of ITO is basically from the higher carrier concentration, hall mobility. It should be mentioned that ITO has lower mobility than Indium oxide because of ionized impurities and carrier concentration. ITO has a high band gap of 3.75eV. This high bandgap has led them to obtain a very high transmittance [8-12]. In the following figure 3.4 we can see that the valence band and the conduction band is upwards and downwards respectively. When the density of the electrons is increasing then the free electrons can be exhibited [8]. These upwards and downwards structure comes from the fact that naturally ITO is degenerate. Which leads the energy band gaps to become narrower.

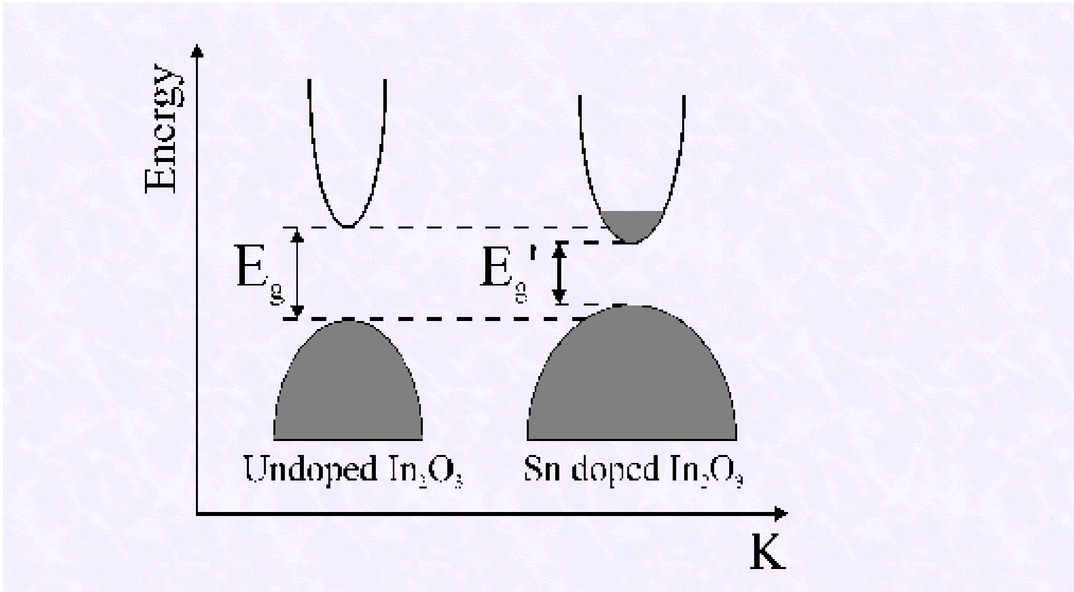


Figure 3.4 : Parabolic structure of indium oxide after doping [8] .

In the following table we will show some of the properties of Indium tin oxide in various deposition process.

Deposition Technique	Thickness[A]	Hall Mobility μH[cm2V-1s-1]	Carriers N[cm-3]	Resistivity P[Ωcm]	Transmittance Tr[%]
r.f sputtering	7000	35	6e20	3e-4	90
r.f sputtering	5000	12	12e20	4e-4	95
r.f sputtering	4000	25	3e20	8e-4	-
Magnetron Sputtering	800	26	6e20	4e-4	85
d.c sputtering	1000	35	9e20	2e-4	85
Reactive evaporation	2500	30	5e20	4e-4	91
Ion beam sputtering	600	26	2e20	12e-4	-
Spray pyrolysis	3000	45	5e20	3e-4	85

Table 3.1 : Electrical and Optical properties of ITO deposited in various techniques [8].

Film	Film thickness, nm	Sheet resistance Ω	Global conductivity S/m	Transmittance in visible spectrum
Cu1	1000	.01	59.59×10^6	REFLECTING FLIM
Cu2	10	8.3	12.05×10^6	45%<T<64%
ITO	1000	8.6	0.12×10^6	69%<T<86%
ITO/Cu/ITO	85/13/85	4.7	1.6×10^6	28%<T<61%

Table 3.2 : Physical characteristics of ITO [3]

3.5 USES OF INDIUM TIN OXIDE:

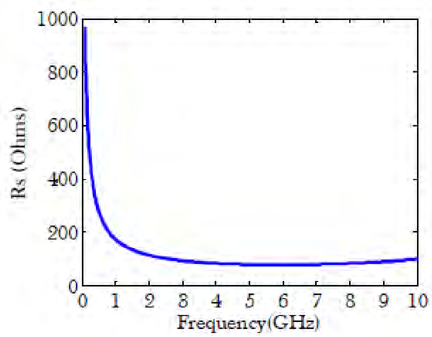
Uses of ITO to provide better efficiency in solar cells played an important role in nanotechnology. Ito provides low costing, ultra-lightweight, flexible cells for wide range of applications. Indium tin oxide (ITO) is an optoelectronic material that is connected broadly in both research and industry. ITO can be utilized for many applications, for example smart windows, polymer-based gadgets, thin film photovoltaic, and architectural windows. Also, ITO thin films for glass substrates can be useful for glass windows to preserve energy. Thin films used as conducting electrodes and transparent electrode that's why ITO thin films used primarily for coatings anti-reflective and for liquid crystal displays (LCDs). ITO is often used to make transparent conductive coating displays such as liquid crystal displays, flat panel display, touch panels and other applications. ITO is also used as anode (hole injection layer). Because of degenerate behavior as n-type semiconductor and a band gap of around 3.5 to 4.3 eV, ITO is used as better level of transmittance in visible points and the unique electrical conductivity which has made ITO more efficient [9-12].

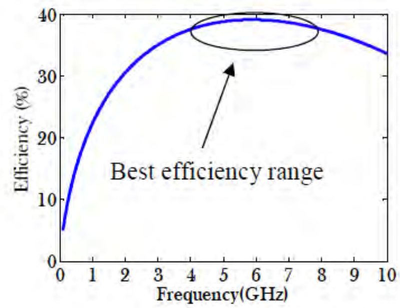
3.6 Challenges with Optically Transparent Antennas

Research of transparent conductors in such a way to study the importance of these material-science constraints the effect of antenna design. Many issues during designing of thin-antenna using thin-film conductors (transparent), including skin depth losses, surface losses and ground losses are investigated [7,11]. Transparent-conducting-oxide depositions need for high optical transparency and because of this reason skin-depth losses occur which reduces antenna efficiency. Ground plane patch antennas reduce efficiency as well and cause ground-effect losses. These above issues are related with low conductivity of transparent conducting oxides. Conductivity ,approximately 8×10^5 S/m for indium tin oxide, increases the surface resistance of the micro strip patch antenna and the result causes lower efficiency [7,11]. During many projects, the scientists and researchers faced many issues to produce the perfect antenna for nano-satellite or satellite applications.

ITO has variety of uses, such as for flat panel designs, touch panel controls, solar cells and electromagnetic shielding. Although they are excellent materials for these applications, TCs are not being used for the transmission of RF signals. Some preliminary designs have shown promising results [26] while others have concluded that more research is needed before a working antenna can be implemented [32]. Even though ITO is the material of choice for most TC applications, many other TCs are available and little research has been done on the effectiveness of each material as a transparent conductor. These materials include semiconducting oxides of tin, zinc and cadmium and metals such as silver, gold and titanium nitride. [33] Transparency of material at optical wavelengths, conductivity and thickness of deposition are essential parameters to consider for antenna design.

Various ITO patch antennas holding the conductivity of σ=281319 S/m built at a range of frequencies from 100 MHz to10 GHz, laid on a glass substrates of εr=6 are investigated at a deposition thickness of 1.2 µm. It was found that at frequencies below 2 GHz ITO antennas are impractical, barely reaching 20% efficiency [7].





(a) surface resistance (b) efficiency range

Figure 3.5 : ITO wih 1.2µm from 100 MHz to 10 GHz [7]

3.7 Caution

Unfortunately Indium tin oxide is harmful for human body. It causes mid irritation in human body because of respiratory tracts that's why it should not be inhaled. Exposures in a long term may cause chronic effect. Studies with animal result shows that if injected in body it causes negative effects in kidney, lung and liver.

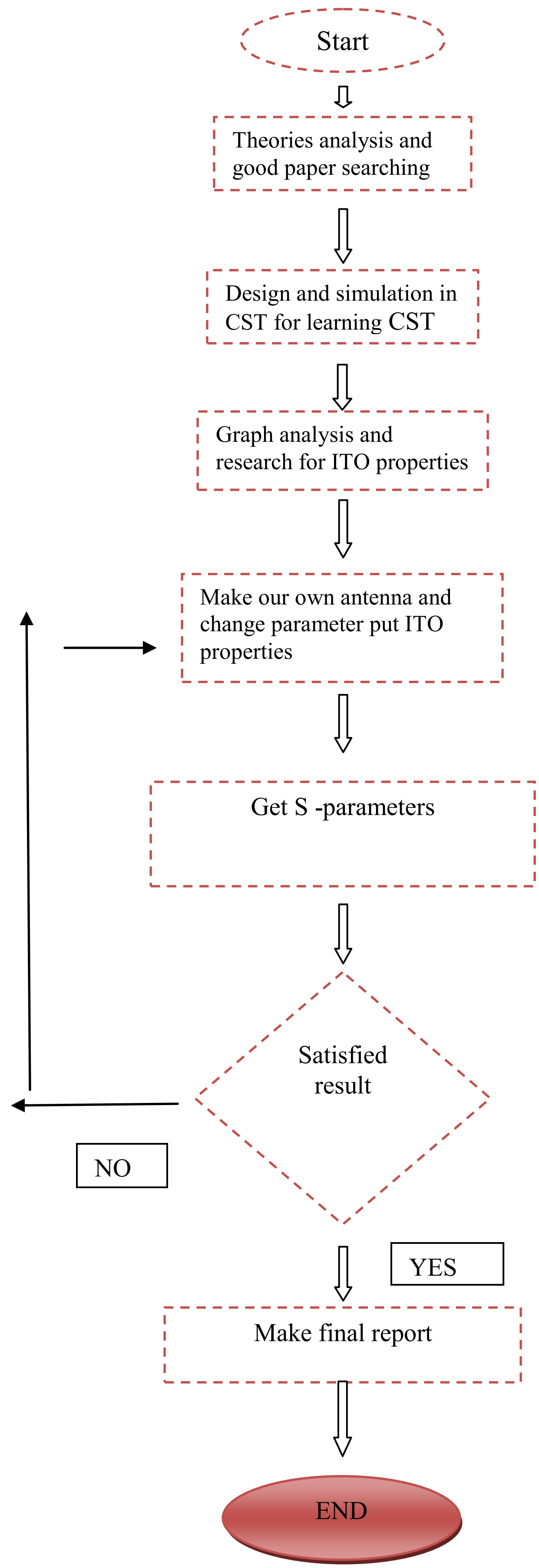
Process of mining, production and reclamation workers often get exposed with indium tin oxide. Workers in the US, China, and Japan have been diagnosed with cholesterol clefts because of under indium exposure. Lung disease was developed through exposures with indium tin oxide dusts. The very first patient is a worker worked with wet surface grinding of indium tin oxide who suffered from interstitial pneumonia. The patient's lung was filled with indium tin oxide related particles.

CHAPTER 4

METHODOLOGY

4.1 Introduction

In this chapter we explained the methodology and data analysis of the project in details. We started this project with previous year's research and many principal theories are the main references for our transparent microstrip patch antenna. In our previous chapter we discussed about it thoroughly. We have used CST (Computer Simulation Technology) microwave studio software for designing antenna as well as data analysis. Following figure shows the steps of our work.


Start
Theories analysis and good paper searching
Design and simulation in CST for learning CST
Graph analysis and research for ITO properties
Make our own antenna and change parameter put ITO properties
Get S -parameters
Satisfied result
NO
YES
Make final report
END

4.2 Microstrip Patch Antenna

Microstrip patch antenna isknown as printed antenna. This antenna operates in microwave antenna frequencies. The antenna was invented by Robert E Munson in 1972.

A microstrip patch antenna is consist of

1. Patch (metal)
2. Dielectric Substrate
3. Ground Plane

Theshape of thepatch may vary in different microstrip patch antennas.Different shapes such as rectangular, circular, T shaped, L shaped, U shape, O shaped, E shaped, triangular etc.

The antenna feeds with different mechanism. Among them the most common are:

1. Coaxile Cable Feed
2. Microstrip Line Feed
3. Aperture Coupled Feed
4. Proximity Coupled Feed
5. Coplanar Waveguide Feed

Advantages of Microstrip Antenna

Fabrication of a microstrip antenna is easy with low cost and less size. The antenna can be integrated with microwave circuit. This is very easy to feed the antenna.

4.2 Antenna Specification

Antenna performance depends on its resonant frequency, operating frequency, radiation efficiency and return loss. Over a glass substrate we have designed our proposed antenna and ground plane using Indium Tin Oxide (ITO). Indium Tin Oxide (ITO) is a transparent material due to its high conductivity. Electrical conductivity of ITO is 100000 S/m and permittivity is 4. Permittivity of glass substrate is 4.82. The defined specification is as shown in Table4.1

Parameter	Specification
Frequency	0-35GHZ
Impedance	50Ω
Return loss	≤-10dB
-10dB Bandwidth	20%-25%

Table 4.1: Defined Antenna Specification [3]

For prototype designing low dielectric constant of the substrate is used and it gives higher efficiency and bandwidth and reduction in the patch size. We needed higher dielectric material like ITO. Substrate thickness is another important parameter because it helps to increase the fringing field at patch periphery.

4.3 Antenna design

Our proposed antenna is a self-complementary design and it has wide frequency band of 0GHz to 35GHz. The antenna has three parts. They are:

1. Substrate
2. Antenna (front view)
3. Ground (Back view)

Impedance calculation:

Feed line width W=2.8

Substrate Height H=1.6

Substrate (glass) permittivity $\varepsilon_r = 4.8$

$$\frac{W}{H} = \frac{2.8}{1.6} = 1.75 \geq 1$$

Dielectric constant ε_{eff}:

$$\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}[1+12(\frac{H}{W})]^{-.5}$$

$$=\frac{4.8+1}{2}+\frac{4.8-1}{2}[1+12(\frac{1.6}{2.8})]^{-.5}$$

$$= 2.9+1.9(1+12(\frac{4}{7})$$

$= 3.577 = \varepsilon_{eff}$

Characteristic impedance Z_{o}:

$$=\frac{120\pi}{\sqrt{\varepsilon eff}\ [\frac{w}{h}+1.393+\frac{2}{3}\ln\frac{w}{H}+1.44]}\Omega$$

$$=\frac{120\pi}{\sqrt{3.577}\ [\frac{2.8}{1.6}+1.393+\frac{2}{3}\ln\frac{2.8}{1.6}+1.44]}$$

$$=\frac{120\pi}{\sqrt{3.577}\ (1.75+1.393+.7733)}$$

$$=\frac{120\pi}{\sqrt{3.577}*3.916}$$

$$=\frac{120\pi}{7.40}$$

$= 50.94\ \Omega$.

This is very important that the characteristic impedance is needed to be approximately 50 Ω [1,2]. Otherwise the microstrip antenna will not work. Therefore we had to keep characteristic impedance around 50 Ω.

The dimensions of the proposed antenna have been shown in the following figures 4.1 and 4.2:

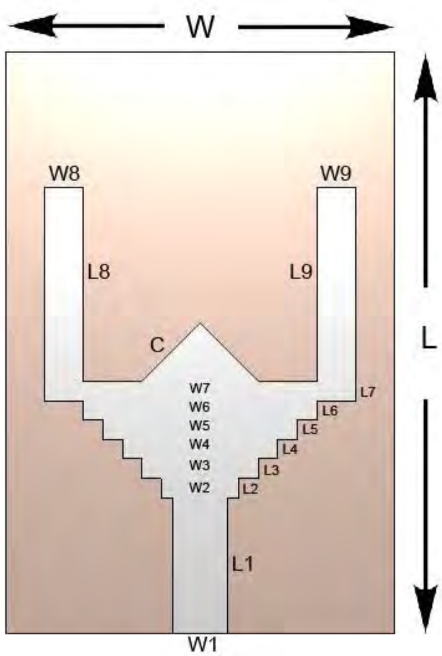


Figure 4.1: Patch

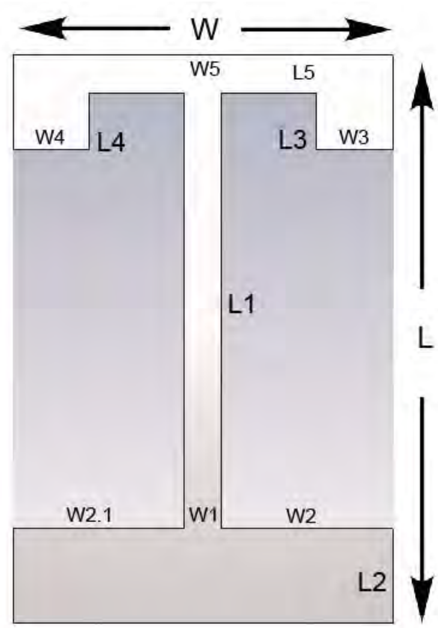


Figure 4.2: Ground Plane

The angular shaped plan C (Figure 4.1) is actually a cylindrical model with radius = 3mm, segment = 4 and thickness = 0.035mm. The glass substrate has width, W = 20mm. Length, L = 30mm and thickness =1.6mm.

The values of the above dimensions have been given in the table below:

Length	L1	L2	L3	L4	L5	L6	L7	L8	L9
Value (mm)	12	1	1	1	1	1	1	10	10

Table 4.2: Antenna parameters for patch (Figure 4.1)

Width	W1	W2	W3	W4	W5	W6	W7	W8	W9
Value (mm)	2.8	4	6	8	10	12	16	2	2

Table 4.3: Antenna parameters for patch (Figure 4.1)

Length	L1	L2	L3	L4	L5
Value (mm)	15	5	3	3	2

Table 4.4: Antenna parameters for ground plane (Figure 4.2)

Width	W1	W2	W2.1	W3	W4	W5
Value (mm)	2	9	9	4	4	20

Table 4.5: Antenna parameters for ground plane (Figure 4.2)

4.4 Simulation and Design Process

We have used CST (Computer Simulation Technology) software for modeling and simulation. This software is efficient enough to do computational solutions for electromagnetic design and analysis .we found this 3D software is user friendly and easy to choose appropriate method for design.

Design Process

Our proposed antenna is supposed to work within the frequency range of 0-35 GHz.

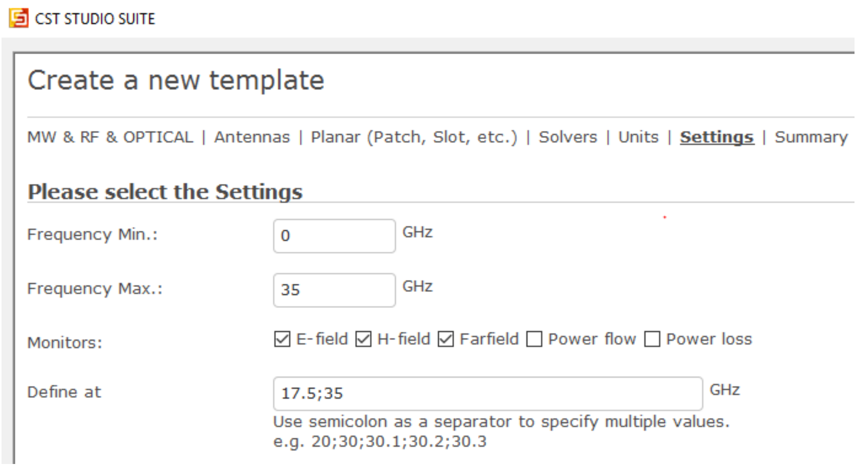


Figure 4.3: Frequency selection in software

In the following picture we can see the CST microwave studio tab on computer. Here we have indicated the frequency range and we have selected the options of electric and far-field which we will notice after simulation.

After selecting the frequency range and other settings are needed to be measured so that we can design the antenna structure part by part such as substrate, patch and ground plane. In this part we can choose the brick which is a basic step to build structure of the antenna.

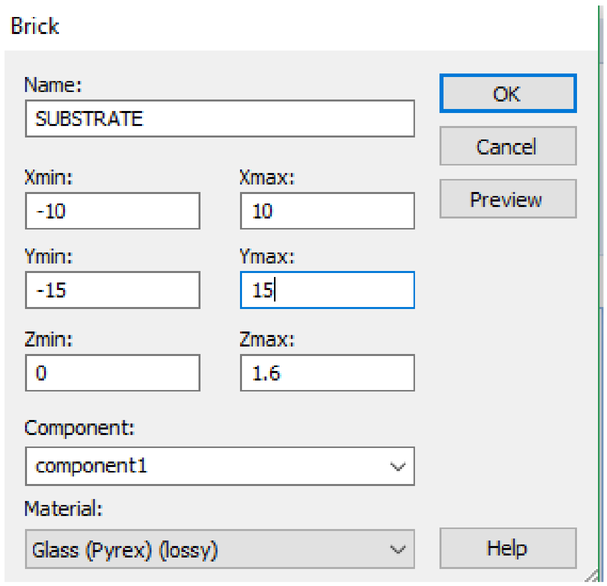
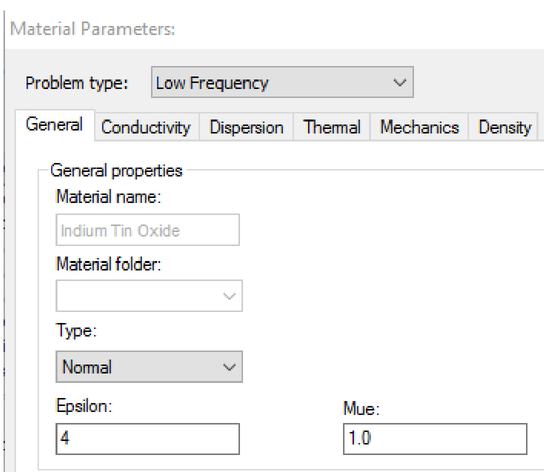


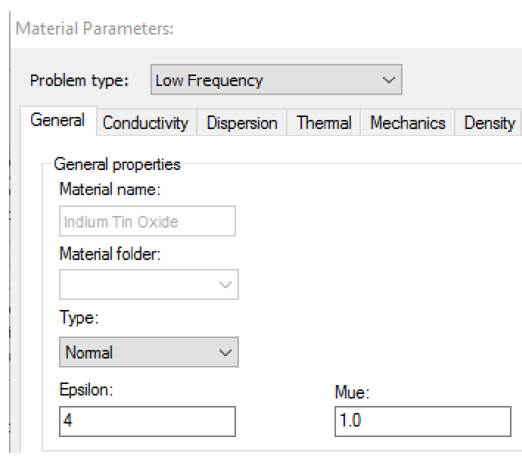
Figure 4.4: Brick window

On the above figure we can see the brick window. A microstrip antenna is consist of three major components which are substrate, patch and ground plane. As mentioned we will build these three components in the brick window. For example we showed one formation to build a component. Here we put name, parameters (width, length and thickness) and material of the component. X, Y and Z axis represents width, length and thickness respectively.

Now we are going to choose the material of the substrate. We select the material from the material library of the software. The material we are using in substrate is glass (pyrex, lossy). In a similar way, we will make the patch and ground plane using Indium Tin Oxide. But in CST material library, the default Indium Tin Oxide (ITO) properties are measured in THz frequency range. On the other hand our proposed antenna is working in a frequency range of 0-35 GHz. Therefore we had to create new ITO with conductivity 100000 S/m, Mue = 1 and Epsilon = 4. These properties have been measured in GHz frequency range [1,3,5].



(a) Putting electric conductivity



(b) Putting electric permittivity

Figure 4.6: Creating ITO in material library using ITO properties measured in 0.1-20 GHz range [17]

Antenna structure construction:

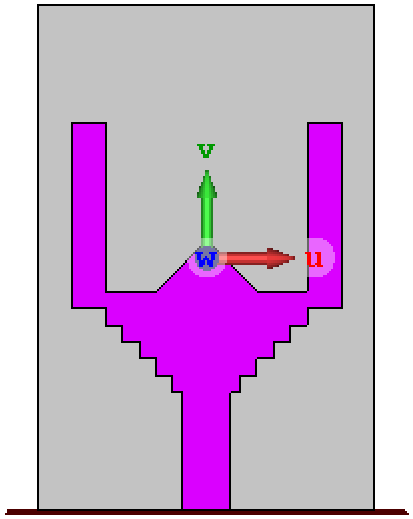


Figure 4.7: Patch over the substrate

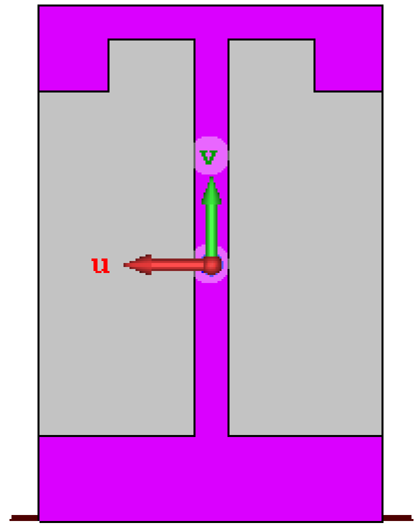


Figure 4.8: Ground plane over the substrate

On the above two figures we can notice the patch and ground plane over the substrate of our proposed antenna. We have used microstrip line feed antenna in our proposed which will channel the current flow into the antenna.

Simulation and result:

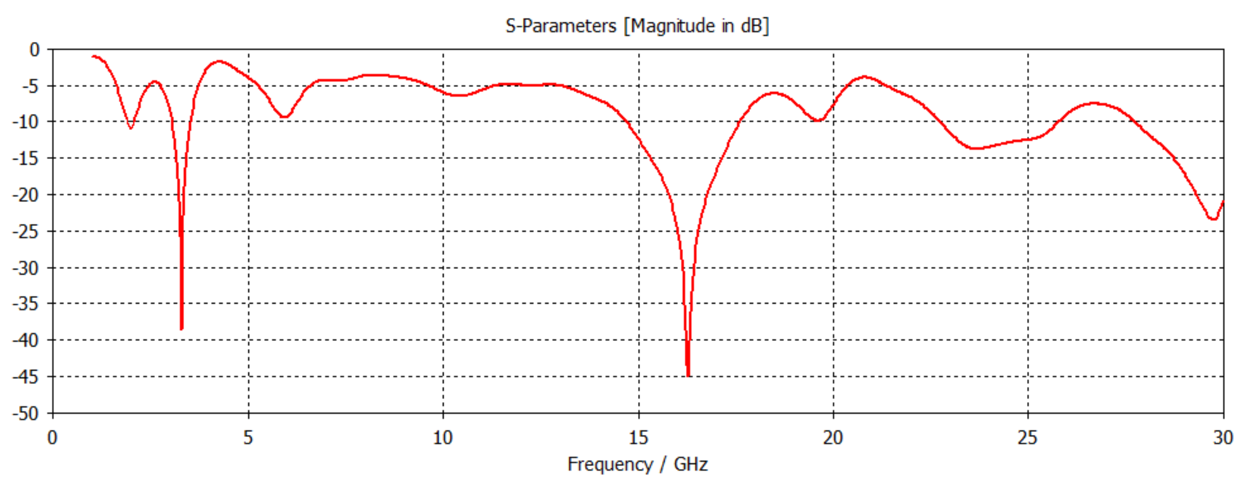


Figure 4.9: S11 parameters of the simulation.

On the following figure 4.9 we can see the simulation result after measuring ground plane, patch and substrate.

4.5 Return loss

Frequency vs. Return loss graph resulted from our proposed antenna is given below:

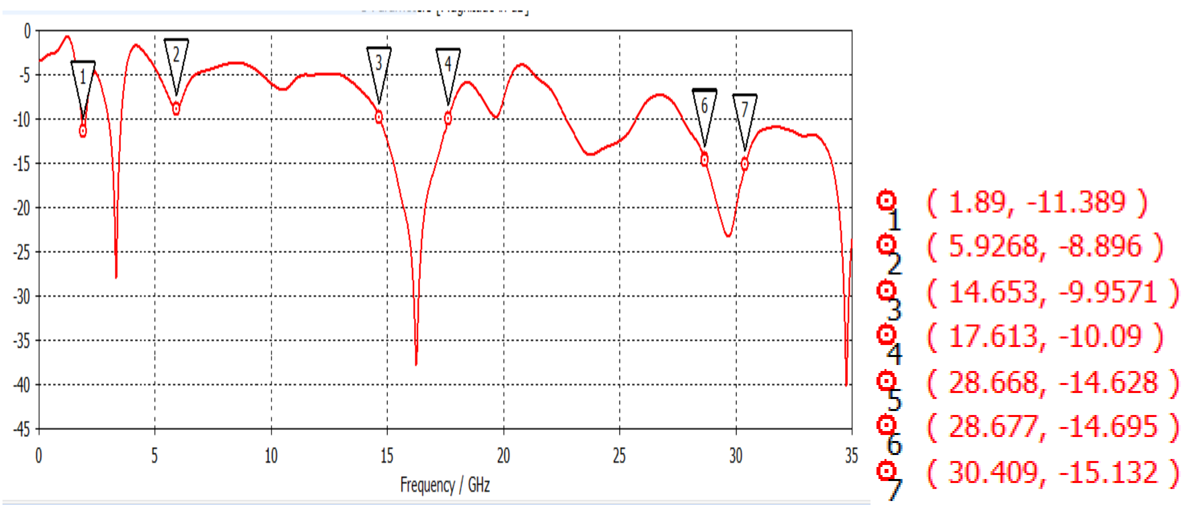
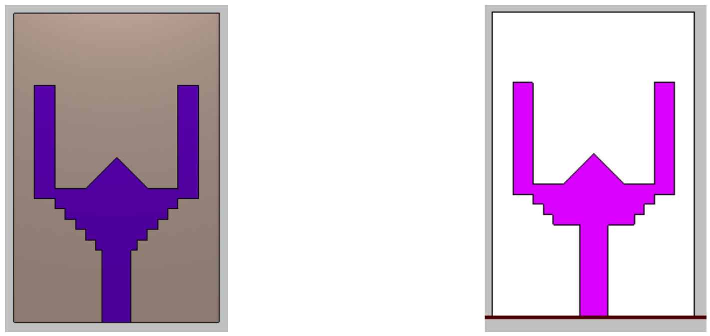


Figure 4.10: Frequency vs Return loss

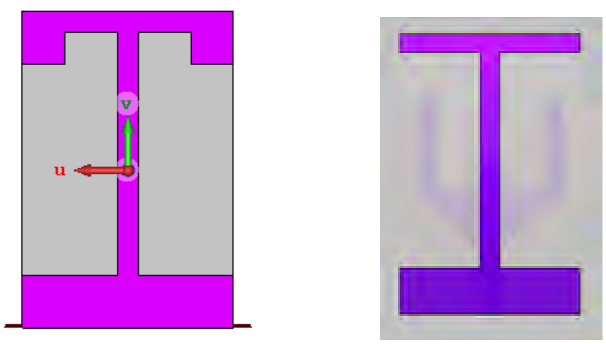
At our target frequency bands we have found few resonant below 10db return loss. We have found frequency bands at range 1.9-2 GHz, 5.9-6 GHz, 14.5-17.5 GHz and 28-30 GHz. 1.9 GHz range is used in PCS technology, 5.9 GHz is used in WLAN. There are lots of military radiolocation and defense use in the range of 15 GHz. 28-30 GHz frequency band is used in 5G technology which is FCC approved.

We chose the peak of the resonant for the desired frequency bands and investigated how deep the peaks are and noticed the return loss. For example in the peak 1 mentioned in figure 10 frequency 1.89 has a return loss of -11.389 dB.

For this satisfactory result, we had to change our design for several times. Few examples are given below to make understand that how does a design can affect resonant.



(a) Proposed antenna patch (b) Change in patch



(c) Proposed ground plane (d) Change in ground plane

Figure 4.11: Different parameters for patch and ground plan to compare result

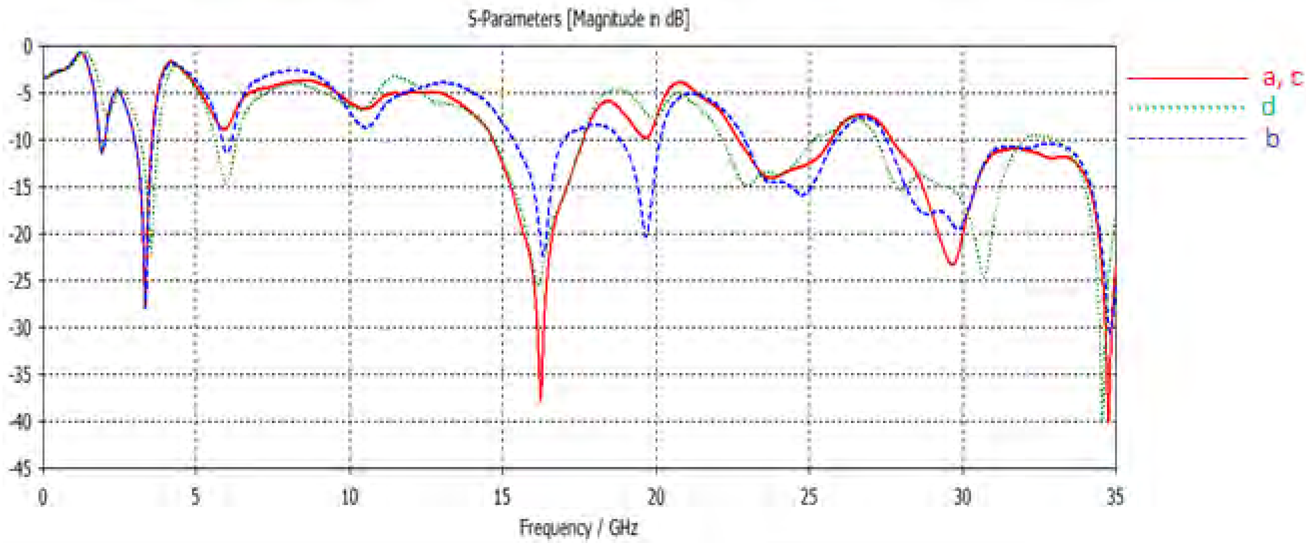


Figure 4.12: Compared result from different designs

In figure 4.9 we can see the resulted resonant of different designs of our proposed antenna. If we look at the graph we can see on the **b** line there is not much of a change till 15GHz comparing the **a** line but after that we found noticeable change. Proposed antenna (**a**) has a good result in 15GHZ and 30GHZ. Now in antenna **d** we changed the ground plane and could not see any good result between 15GHz and 30 GHz and that is why we chose the proposed antenna (**a**).

4.6 Radiation Pattern

A radiation pattern looks into the difference of the power that radiated by an antenna and shows the direction path from the antenna. This difference as a function of the angle is observed as antenna's far field.

Beside the return loss measurement radiation pattern is also important because we need to know in which direction the pattern is radiating well. We measured radiation at 1.9 GHz, 5GHz, 15.5 GHz and 30 GHz have been plotted in figure bellow:-

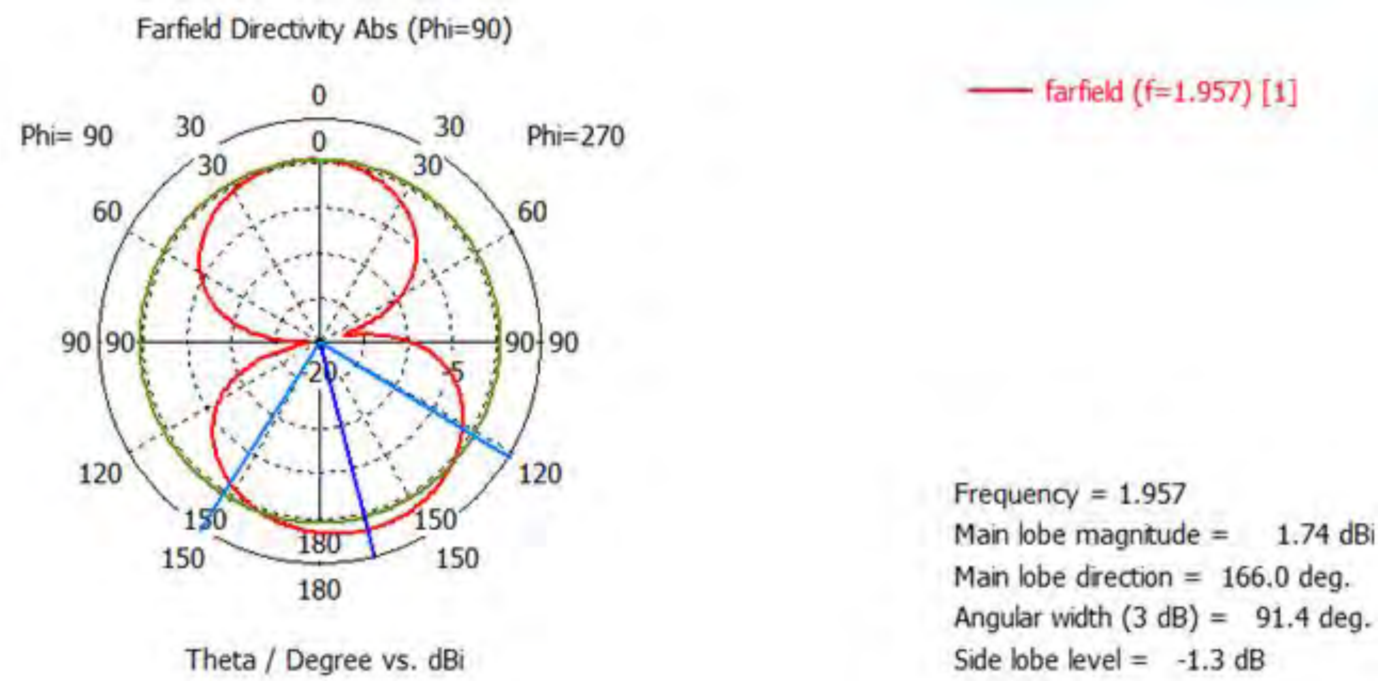


Figure 4.13: Radiation pattern for Phi Ø=90º in 1.9 GHZ

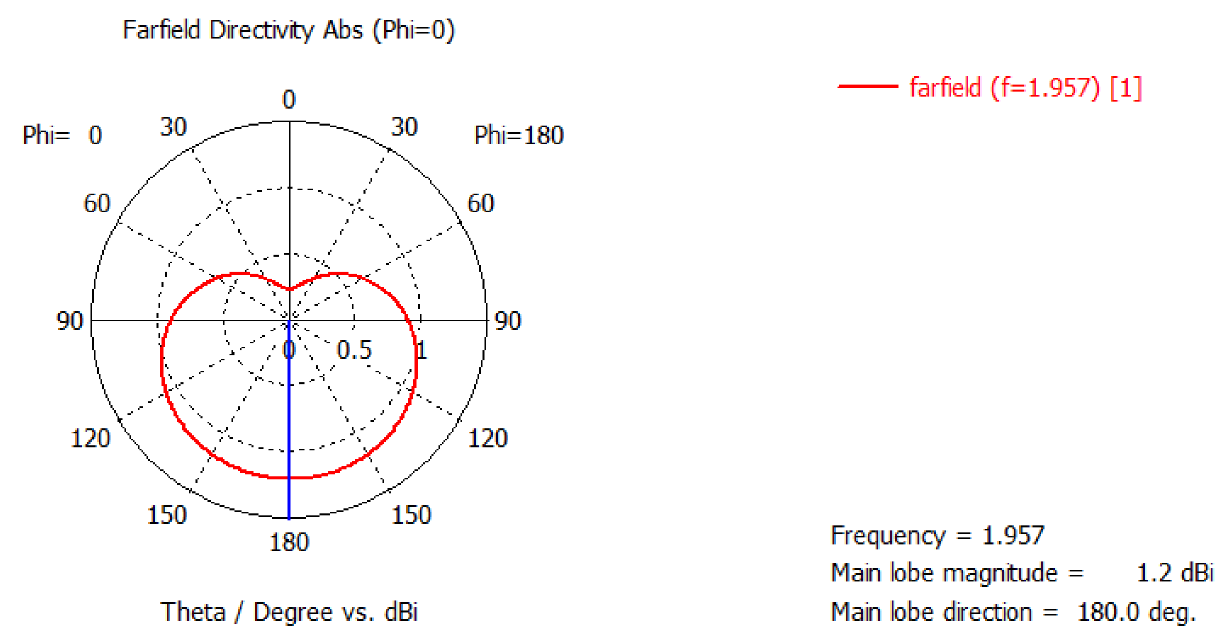


Figure 4.14: Radiation pattern for Phi Ø=0º in 1.9 GHZ

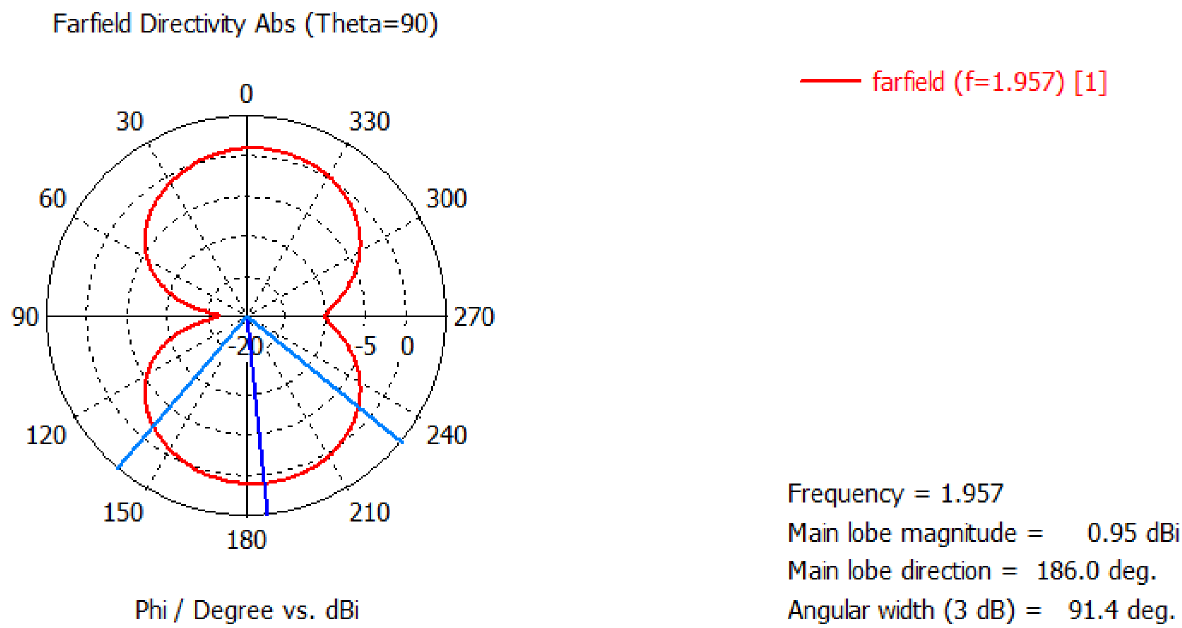


Figure 4.15: Radiation pattern for thetaθ = 90º in 1.9 GHz

The radiation pattern of this figure is satisfactory. At 1.95GHz our antenna is totally Omnidirectional. This bandwidth is used in PCS (personal communication service). PCS is a wireless phone service similar to cellular phone service. It provide all in one wireless phone, paging, messaging and data service.

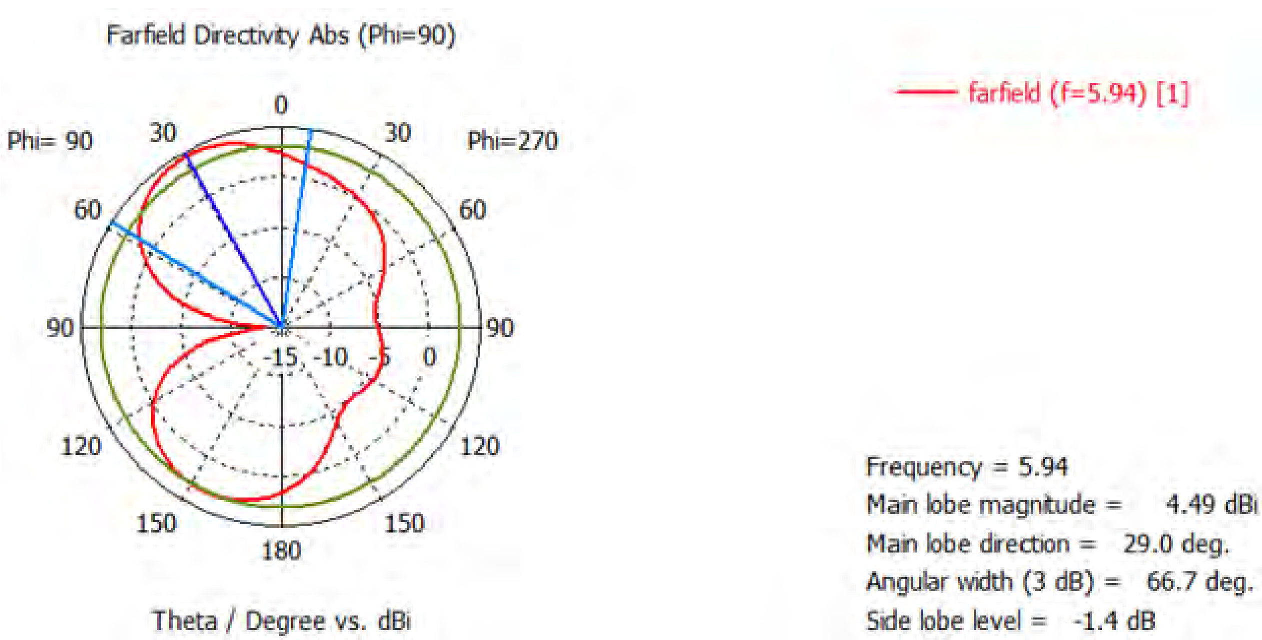


Figure 4.16: Radiation pattern for Phi Ø=90º in 5.94 GHz

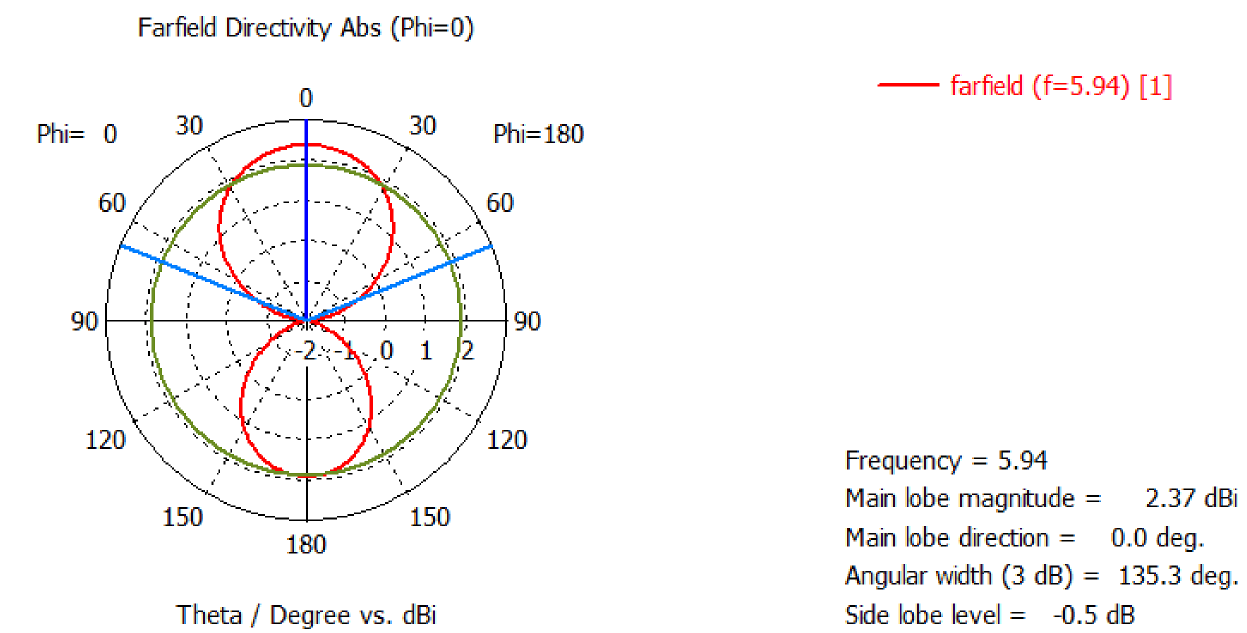


Figure 4.17: Radiation pattern for Phi Ø=0º in 5.94 GHz

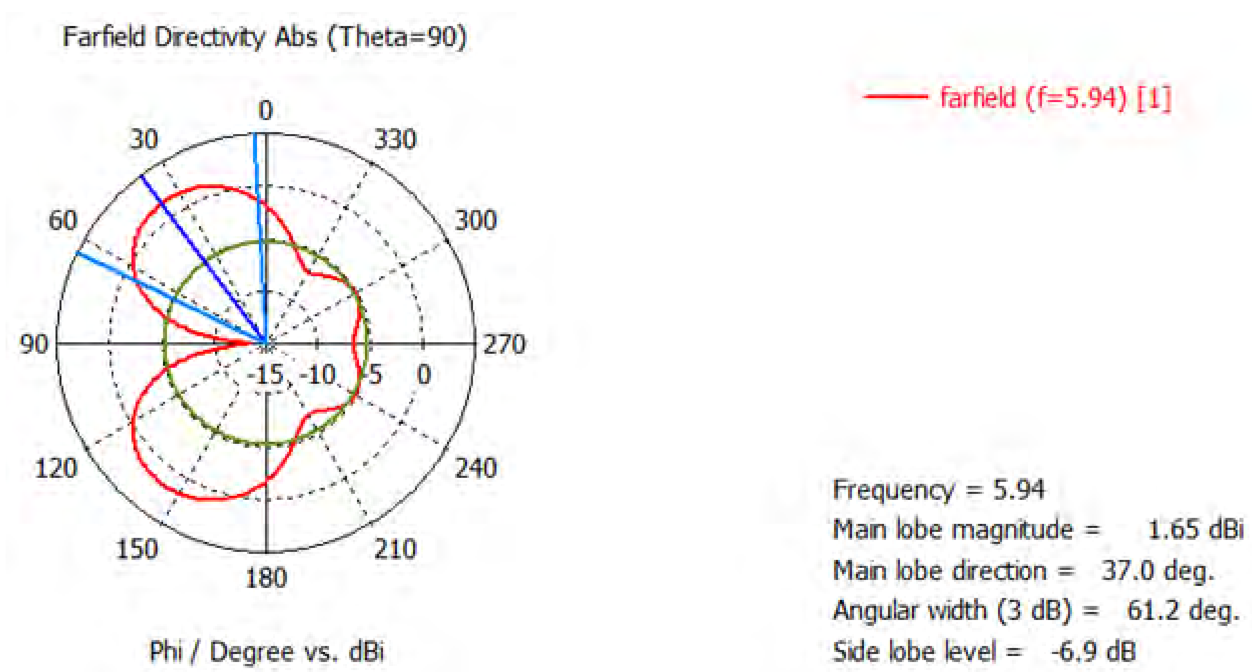


Figure 4.18: Radiation pattern for thetaθ = 90º in 5.94 GHz

For frequency 5.9 GHz we notice the energy in radiation pattern is directly above omnidirectional antenna when they are oriented horizontally.

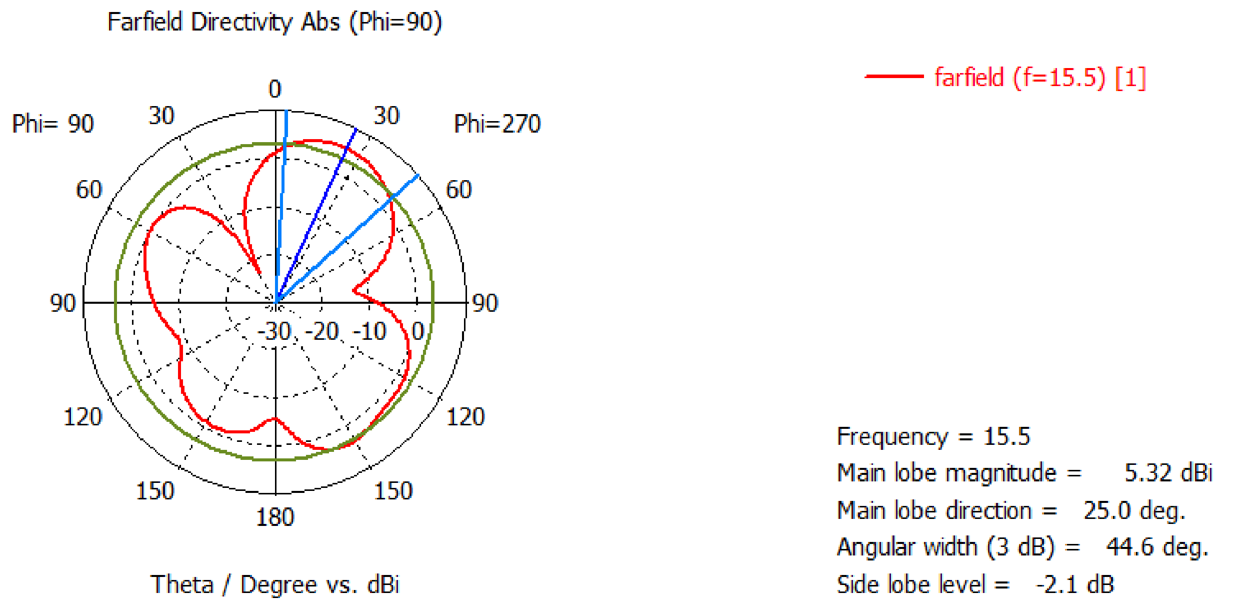


Figure 4.19: Radiation pattern for Phi Ø=90º in 15.5 GHZ

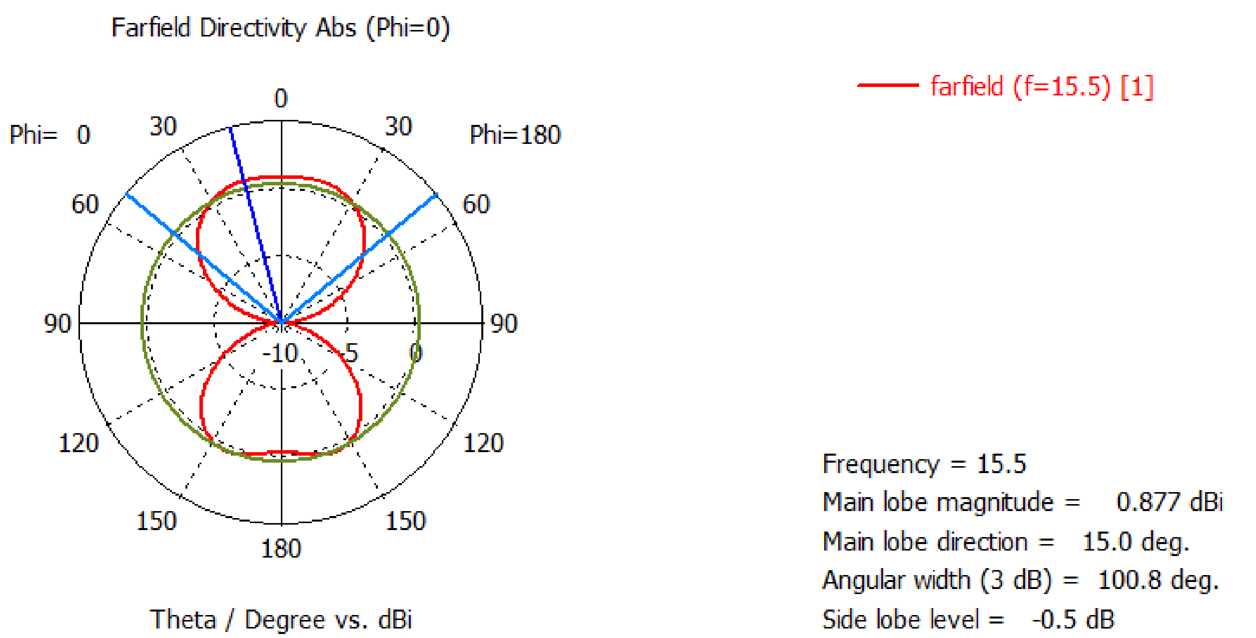


Figure 4.20: Radiation pattern for Phi Ø=0º in 15.5 GHz

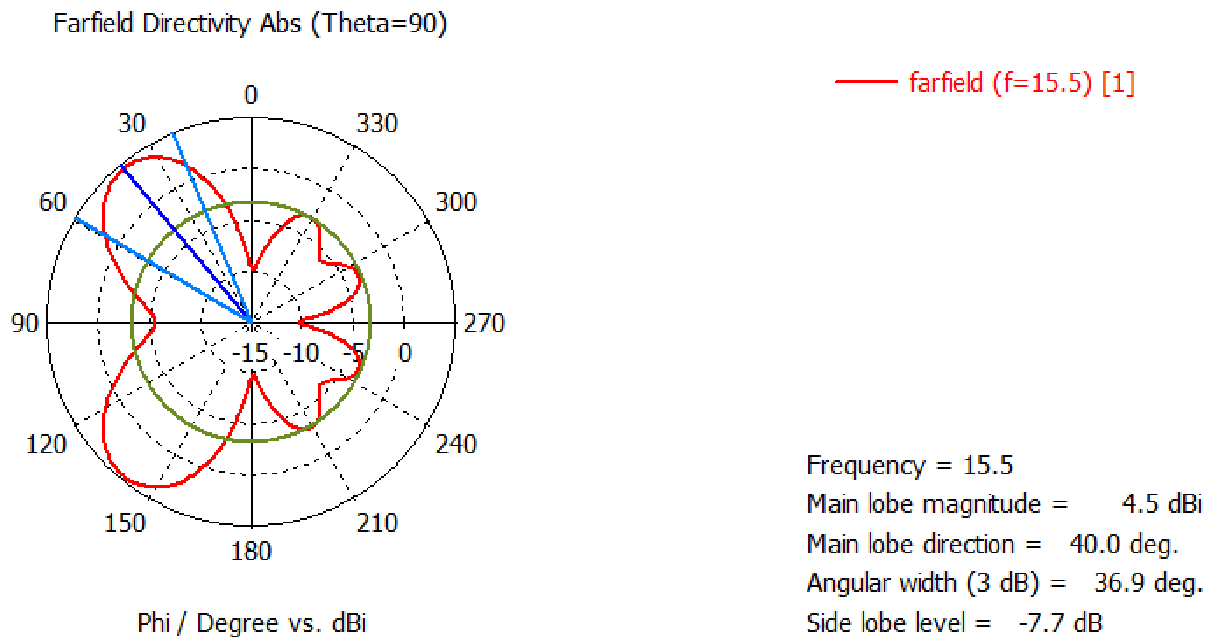


Figure 4.21: Radiation pattern for thetaθ = 90º in 15.5 GHz

We can see that at 15GHz our antenna is directional and almost all portions are covered by our radiation pattern.

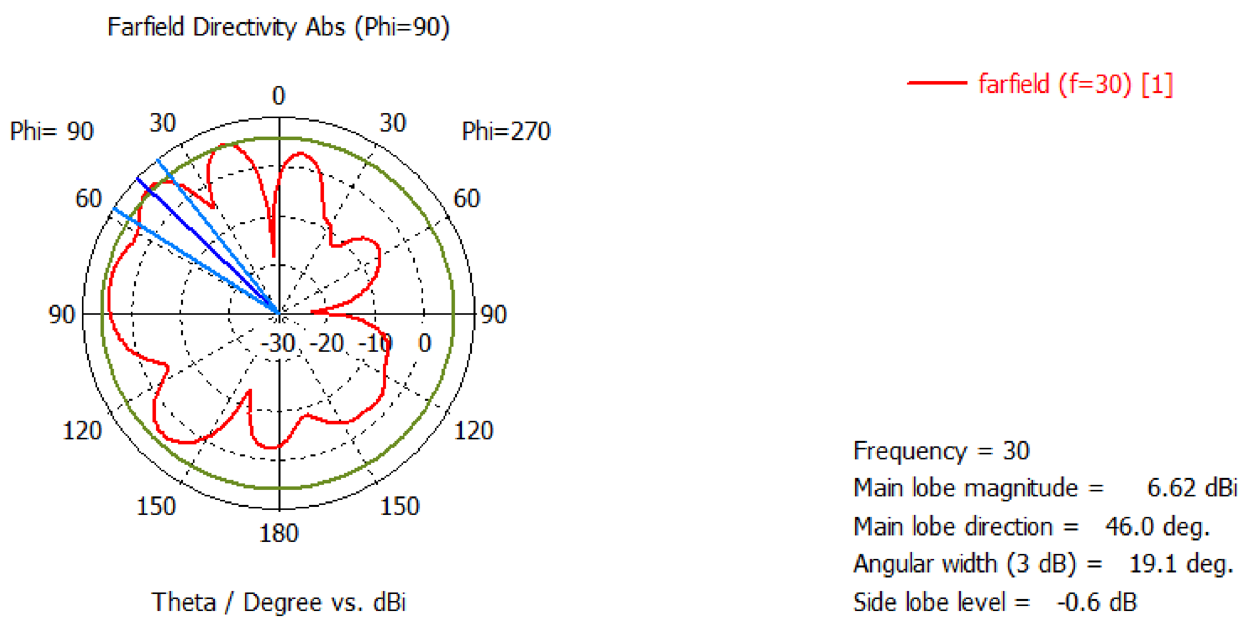


Figure 4.22: Radiation pattern for Phi Ø=90º in 30 GHZ

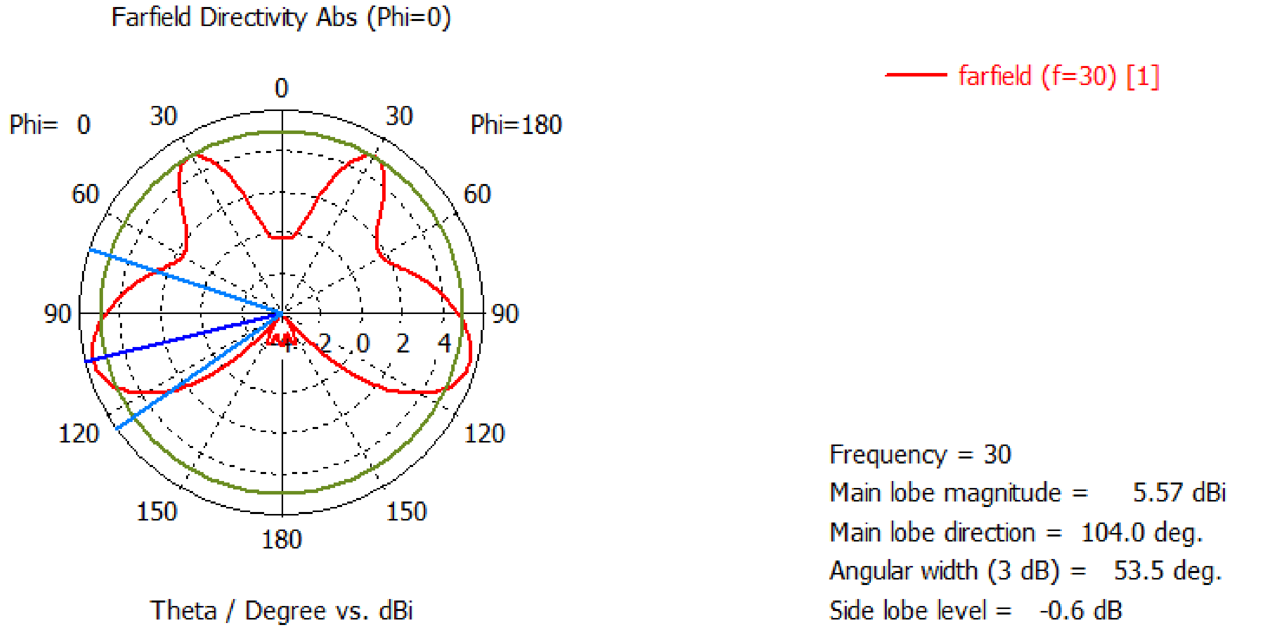


Figure 4.23: Radiation pattern for Phi Ø=0º in 30 GHz

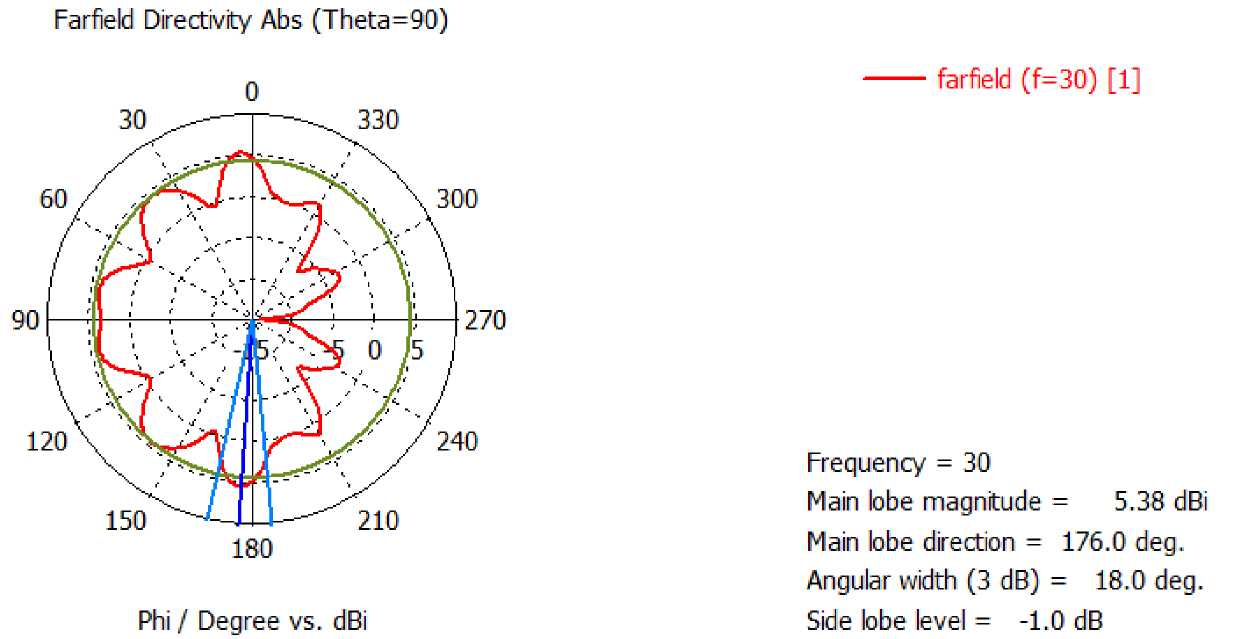
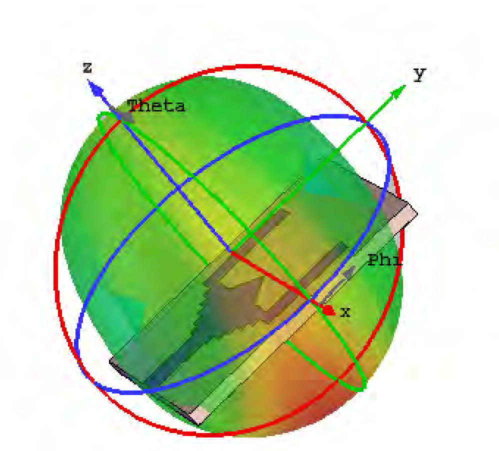
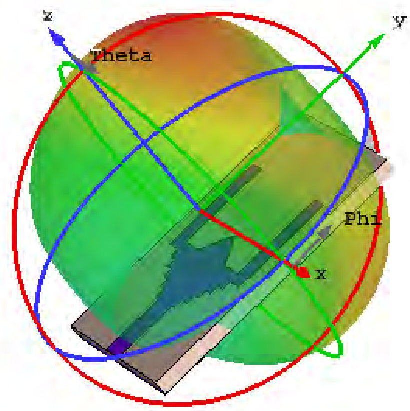


Figure 4.24: Radiation pattern for theta θ = 90º in 30 GHz

This radiation pattern is precise in figure 4.27 as in this bandwidth our antenna work almost omnidirectional.

3D view of Radiation Pattern:

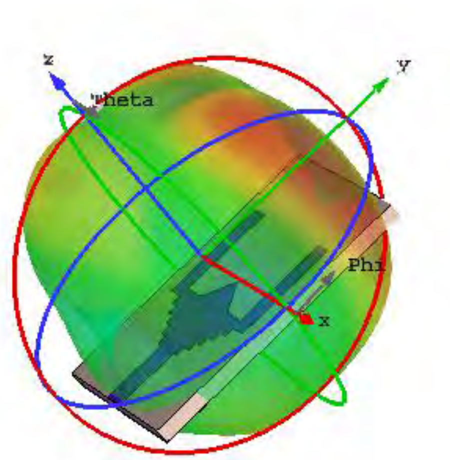


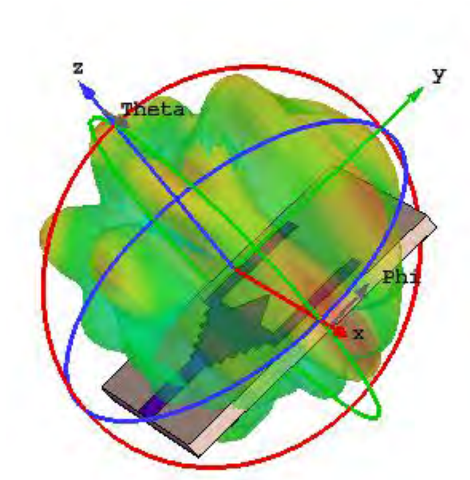


(a)

Radiation pattern at 1.9 GHz

(b)Radiation pattern at 5.9 GHz





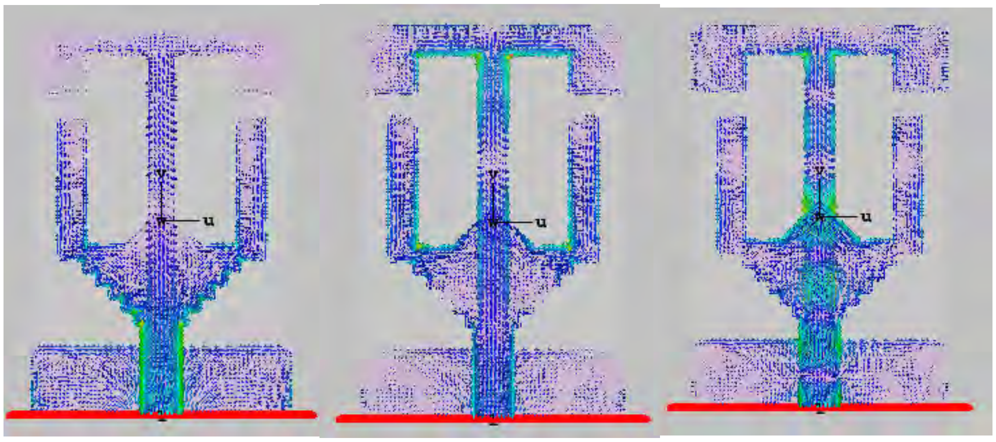
(c)Radiation pattern at 15 GHz
(d)Radiation pattern at 30 GHz frequency band

Figure 4.25: 3D view of Radiation Pattern at different frequency bands

At figure 4.25, constructed three dimensional view of radiation patterns are shown. Here we can see that the direction of radiated power of our proposed microstrip patch antenna for different frequency bands. The red and yellow part indicate the direction of radiated power. Thus we can understand the radiated power and its gain along with the corresponding planes.

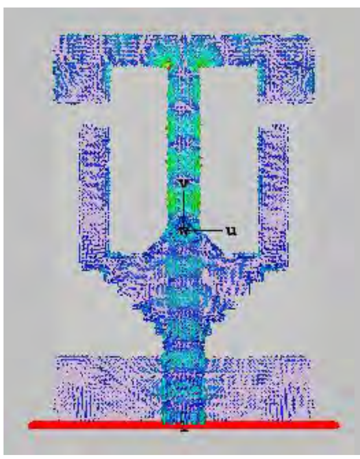
4.7 Current Flow

Current flow plays an important role for antenna design. In the following figure we can see the pictures of current flowing throughout the antenna. Deepest part (bluest part) shows where the current flow is high and lightest part indicates where it is low. If we change that part the return loss graph and far-field graph will also change.



(a) Current flow On 1.9GHZ (b) Current flow On 5.9GHZ (c) Current flow On 15.5GHZ

Figure 4.26: Current flow on different frequency range



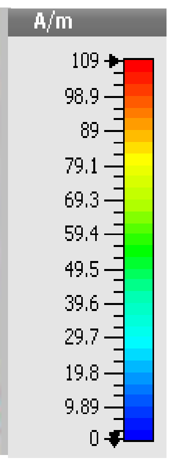


Figure4.27: current flow On 30 GHz

Figure 4.28: Current flow range

In figure 4.26 (a) we can notice that the current flow is more in the feed line and stair area. In feed line current flow range 49.5-59.4A/m. So this two area is the main for radiation in 1.9GHz. In figure 4.26 (b) we see current flow is more in feed line, ground (L1), front area (L8, L9). Current range is 50-59.4A/m and those area is main for radiation for 5.9GHz. In figure 4.26 (c) current flow is noticeably concentrated in cylinder area and feed line for this we get radiation in 15 GHz. In figure 4.27 we can notice that current flow is visible in ground (L1) and for this we get 30GHZ frequency.

CHAPTER FIVE

CONCLUSION

5.1 Conclusion

At last we can conclude that a multiband microstrip patch antenna for telecommunication and military radiolocation applications has been designed using a thin and optically transparent conductive film. The simulation results obtained by CST show good agreement with the measured results. The measured radiation patterns of the proposed multiband antenna are perfectly omnidirectional for PCS around 1.9 GHz and directional at around 5 GHz which can be used in WLAN application. Our proposed antenna has got directional result at 15 GHz at which there is a lot of defense use including military radio location.

The first section of this thesis showed the usage and potential future of the transparent device and research doing in the top companies. Then we addressed all the basics of the patch antenna which is much needed to go through design and simulation system. We mentioned the classification and discussed the parameters that indicates the efficiency of a patch antenna. In the next chapter we addressed the depth of Indium Tin oxide and its various deposition process. Although various studies claim that ITO is a viable material for the implementation of transparent antennas, it is seen in chapter 3 that this is true only for higher frequencies where skin depth is much smaller and it is important to understand the effects of ITO as thin film depositions. The properties of ITO can impact the deposition thickness, transparency and electrical conductivity and the result of the antenna parameters as well. These properties ultimately impact antenna efficiency. In the chapter 3, we went through the influence of the governing ideas of thin film ITO depositions.

5.2 Future Work

Although this thesis mainly discussed the design of transparent antennas, the application for such antennas is not limited and has a lot of other uses. These transparent microstrip patch antennas can be also used in other areas such as windshields of cars and even as lens or stealth use. As seen in this research, ITO is not good enough in antenna design at microwave frequencies of 100 MHz to 10GHz but can be used at frequencies above 10GHz, we have found some good usable frequency bands under 10GHz. Our proposed antenna gives some guidelines and requirements so that antenna engineers and scientists can push the boundaries and enable the use such materials. Huge investment of the big companies in developing the transparent electronics area shows us an obvious result that the future of transparent devices are extremely bright. Even few years back transparent antennas or devices were thought to be too cool to succeed in the long term as it eventually cries out to be built into highly futuristic scenario. But companies like Apple, Samsung and SONY are working on making there devices transparent and flexible. So this “too cool to succeed” term is coming to a reality in near future. Actually the appealing future and scope of these see through devices gave us the motivation to work on an antenna which can be set into a transparent mobile device. These improvement in the transparent device will undeniably have a great impact on human-machine interaction.

In our thesis work we used the most popular transparent highly conductive thin film named ITO as we have mentioned it before. It will be optically 80% transparent and have high optical transmittance in infrared regions. Moreover our proposed antenna will work on PCS, 3G and 4G frequency range. We have wish to make this same antenna working on 5G frequency range in future.

Apart from all these optimistic future, we want to further mention that our group want to do more researches on transparent antennas in the upcoming days. To make our proposed antennas even better structurally and simulation wise. Besides we want to work on fabricating antennas. So far with the satisfactory result we have got the inspiration to move forward but still have many room for development. We think we can improve our proposed antenna by increasing bandwidth and the usage in many other areas as well and bring the best out of our hard work.

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