# Base Station Antenna For 5G Networks With Beam-Switching Capabilities At 3.5 GHz


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Supervisor

Dr Muhammad Zeeshan Zahid


Submitted to the faculty of Department of Electrical Engineering, Military College of Signals, National University of Sciences and Technology, in partial fulfillment for the requirements of B.E Degree in Electrical Engineering

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# CERTIFICATE OF CORRECTIONS & APPROVAL

Certified that work contained in this thesis titled **"Base Station Antenna for 5G Networks with Beam-Switching Capabilities at 3.5 GHz"** carried out by **Capt Adnan Ali Liaqat, Capt Hamza Ali Babar, Capt Shahrukh Ahmed Janjua, Capt Shazil Sultan Khan Niazi** under the supervision of **Dr Muhammad Zeeshan Zahid** for partial fulfillment of Degree of Bachelors of Electrical Engineering, in Military College of Signals, National University of Sciences and Technology, Islamabad during the academic year 2020-2021 is correct and approved. The material that has been used from other sources, has been properly acknowledged / referred.

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# DECLARATION

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## Acknowledgements

We are thankful to our Creator Allah Subhana-Watala to have guided us throughout this work at every step and for every new thought which You setup in our mind to improve it. Indeed we could have done nothing without Your priceless help and guidance. Whosoever helped us throughout the course of our project, whether our parents or any other individual was Your will, so indeed none be worthy of praise but You.

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Finally, we express our sincerest gratitude to our faculty members and everyone who helped us in bringing this project to its successful completion.

# Dedication

*We dedicate this work to our* ***Parents,*** *to whom we are very thankful as they encouraged us and provided us all the necessary resources that made it possible for us to be able to accomplish this final year project work.*

*"We would also like to dedicate this work to our Army"*

&

*"To all the Electrical Engineers around the world who are playing their part in making this world a better place"*

# Abstract

A circular conformal array antenna at 3.5 GHz having switching module for beam-steering is presented. A power amplifier to increase the power of the output signal is also presented. The individual radiating elements have been designed on microstrip patch. Power divider has been routed in octagonal shape to give omnidirectional pattern radiation output to microstrip patches. Beam-switching and beam-steering capability has been achieved by placing an electronic switching network between the radiating elements and the power divider. The antenna, power divider and switching network have been entirely manufactured by using printed circuit board. Due to this a cost-effective and compact antenna design has been achieved which is suitable for use as high gain base-station antenna for 5G communication network as well as a smart antenna providing both directional and omni-directional applications.

**Key Words:** *Conformal array antenna, Beam-steering, Beam switching*

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# CHAPTER 1: INTRODUCTION

## 1.1 Background, Scope and Motivation

Antennas are main driving units of a wireless system. A device receiving and transmitting electromagnetic waves. Antenna has to be tuned to the same frequency band to which the wireless systems it is connected is operating in, otherwise reception shall be impaired. The presented antenna is a type of low-profile antenna which can be fixed on a surface. It contains geometrical sheet which can be circular, rectangular, and triangular on a patch of metal. There are fringing fields which are responsible for radiation mechanism through the edges which are radiating. Radiation causes it to present itself little larger than the original, electrically, than its actual dimensions on ground (physically), so if antenna needs to be resonant, size of micro-strip transmission line little less than half the wavelength at specific frequency is utilized. The patch antenna is normally made by putting a structured metal sheet on insulator substrate (dielectric), for example a circuit board which is digitally printed, with a running metal strip pasted to the other side of the substrate forming a base (ground) plane. The patch is workable at microwave frequencies, at which wavelengths are so less that the patches are conveniently small. Mostly workable in devices which are portable because they can be easily fabricated on printed circuit board. The numbers of patch antennas on the identical substrate are called microstrip antennas, can be made into huge phased array antennas & gain array antennas in which the beam is electronically steerable.

Any continuous shape can work for patch antennas, but there has to be no loss of physical connection. Patch antennas are physically very tough and can be shaped to take the curved skin of even a Car. Usually pasted on the outer surface of plane and spaceships or can be put into cell phones. Having a very high polarization diversity and multiple feed points can be served at the same time.

Receiving antenna in the system turns electromagnetic waves in the original form i.e. electrical signals in wire. Talking mathematically the properties to receive and transmit from antenna are done by Maxwell’s equations. First and simplest antenna used is dipole antenna, having a straight wire which has been fed from the center. If we want the wire to be an effective one that can receive or transmit electromagnetic waves, then the length has to be half of the wavelength at the frequency on which it is operating.

In our project we have selected microstrip patch antenna which is being mostly used in electrical appliances due to its small size and easy fabrication. The scope of our project involves the study and fabrication of 8 element patch antenna array along with Wilkinson power divider and PIN diode switching network. Power amplifier has been used to increase the output power to meet the needs of a base station.

# CHAPTER 2: PATCH ANTENNA

## 2.1 Radiation Pattern

The pattern of radiation of the antenna is an electromagnetic wave, at a distance, the intensity of these electric waves can be measured [1]. This remote point is located at a point when we consider a simple wave and is common in the antenna's direction. Pattern of radiation can be represented on any Polar or Cartesian polar links, as we can see in Figure below

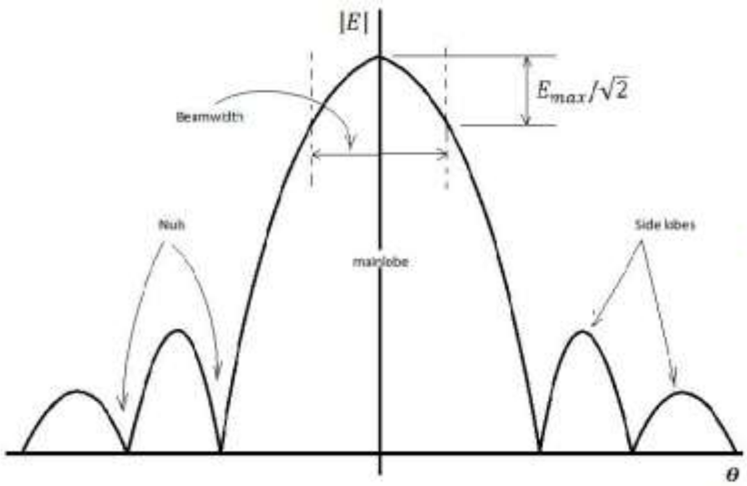



**Figure 2.1:** Cartesian and polar diagram of Radiation pattern

## 2.2 Microstrip Antennas

### 2.2.1 Introduction

Microstrip Patch Antenna is a design with only single layer consisting of 4 components (pool, base, and feed section). Patch antenna is taken as a single element antenna(resonant). Once we have the frequency available, input impedance and radiation pattern is corrected. A very small piece ($t << \lambda_0$ , where $\lambda_0$ is a free space space) that releases a piece of metal (or multiple strands) found on 1 side of a small stationary region, the earth plane is found at other end of substrate. A piece of metal is generally made of a slim layer of copper covered with an anti-corrosion metal, e.g. tin, gold. Several types of patches are structured as shown in Figure below and the mostly used are the circular and the rectangular shapes popular shapes. The thickness of the substrate layer is 0.01-0.05. Mainly has to provide suitable spaces and physical support in the ground plane and the clip. It is usually used in high-density materials — always loading a pool and reducing its size. The content of the substrate has to be less in incorrect loss having a lesser loss tangent than 0.005. For this, Arlon AD 410 can be used with a constant dielectric of 4.1 and a green loss of 0.003. Actually, the materials used are divided into 3, depending on the fixed dielectric.

a. It has εr grade 2.0-4.0 with materials containing reinforced Teflon with high fiberglass.
b. Having a related dielectric constant ranging 1.0-2.0. Material relating to this can be dielectric honeycomb, polystyrene foam or air.
c. Ranging 4 and 10. Contents may contain alumina or quartz.

Beauty of microstrip antennas in smaller size and simple, compatible with planetary and non-planetary environments. Requires small space when installed. These are easy and affordable to produce applying the latest circuit printing technology. But necessary to mention, like any other thing patch antennas does have problems too. The most important of which are that microstrip antennas have:

a. Less efficiency
b. Low bandwidth less than 5%
c. Low RF power because of little partition between the ground plane and radio frequency (unsuitable for high power applications).

### 2.2.2 Forms of Patch Antennas

There can be huge number of microstrip patch antenna cases; structured to match particular features. Most common types are shown in figure below, in millimeter waves, the most known types being rectangular, square, and circular ones.

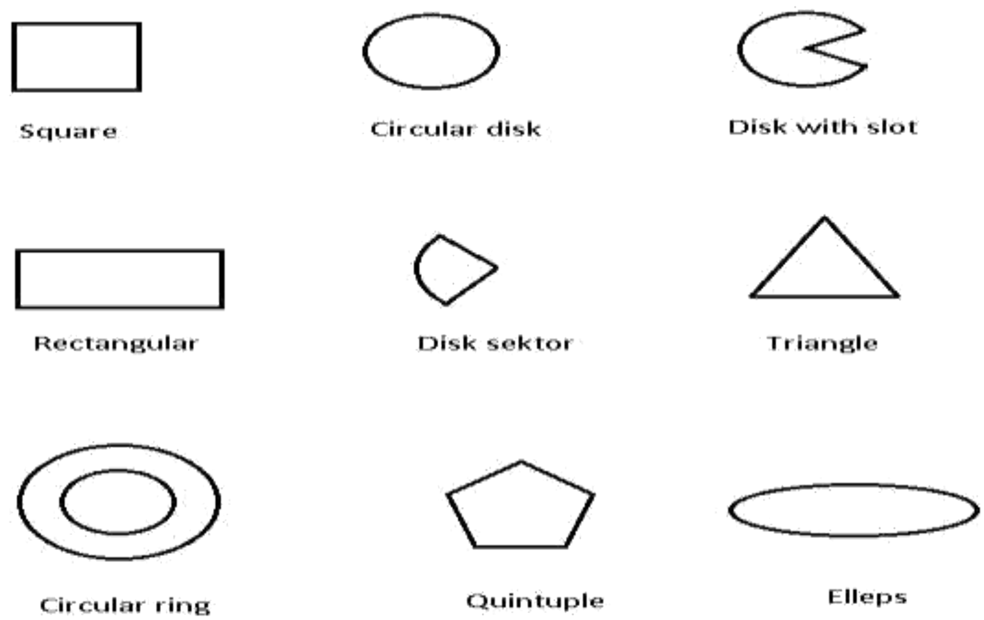



**Figure 2.2:** The most common shapes of patch antennas

Choosing a substrate holds significance, The environmental performance factors like temperature and humidity must be kept in view. The size of the substrate does have a significant impact on frequency(resonant) and BW. Microstrip antenna's Bandwidth will increase with the size of the substrate but only in some limits, if not, the antenna will cease ringing.

### 2.2.3 Serving Methods

Multiple methods of feeding an antenna (microstrip) exist. The popularly used ways are:

a. Aperture Coupling

b. Coaxial Analysis (coplanar feed).

c. Vicinity Connection

d. Microstrip Line

As antenna emanates from a side of the substrate, it is therefore easier to suckle it from the other end (plane of the earth). Important factor to consider is the high-power transmission.

### 2.2.4 Microstrip Line Feed.

Frequently used as it is easy to structure and analyzed. Figure below shows a microstrip line fed patch from the side angle.

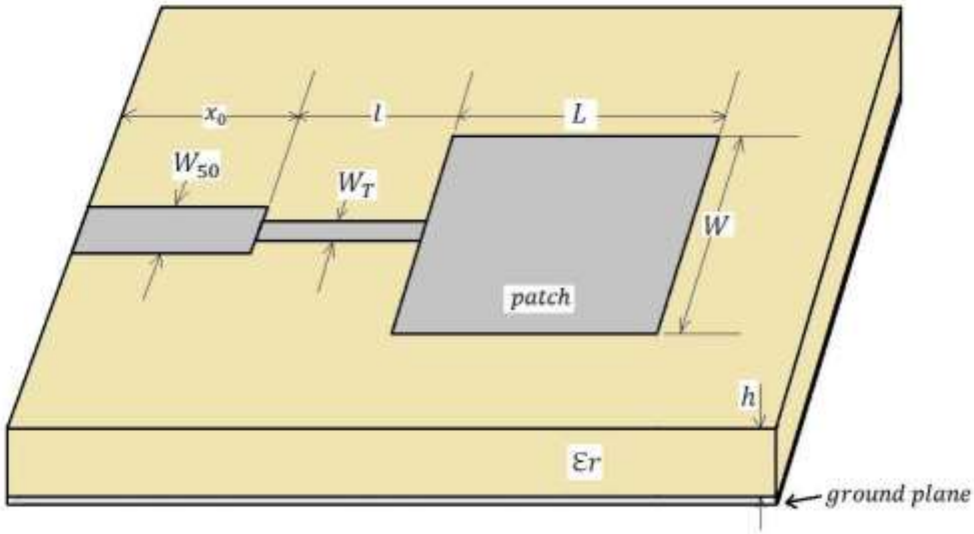



**Figure 2.3:** Rectangular microstrip patch antenna

### 2.2.5 Coaxial Feed (Coplanar Feed)

The combination of power in a field antenna for inquiry is easy to fabricate and also very economical. If the maker fixes the feed point to 50Ω, then you need to use a coaxial cable of 50Ω with a co-connector (N coaxial).

It is attached to the reverse side of antenna (ground plane side) and the central coaxial connector has to be transferred to the substrate and soldered to the clip, as shown in Figure below.

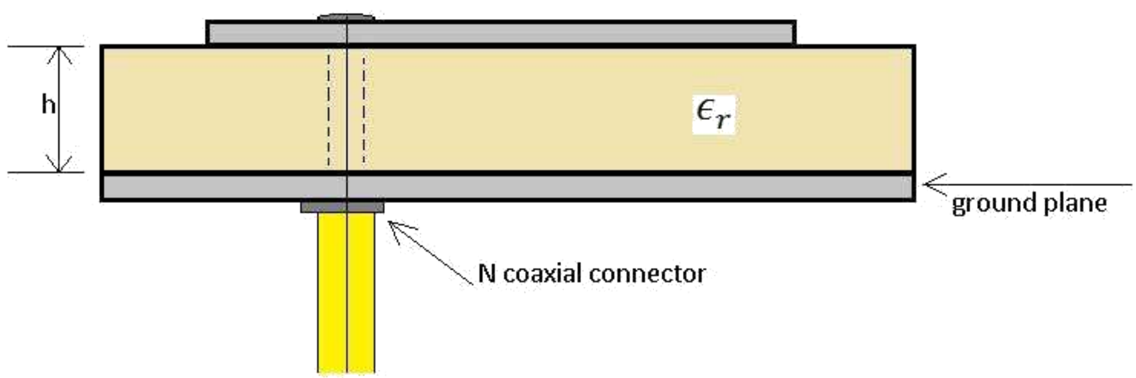



**Figure 2.4:** Coaxial Feed Antenna

### 2.2.6 Proximity Coupling

Proximity integration uses two substrates [2]. The unit will be on top, the bottom plane and the microstrip cable and lie in the 2 sections as can be seen in the figure below. This is also called as "electromagnetically coupled microstrip feed". Goal of the process is to work joining a clip & feed line.

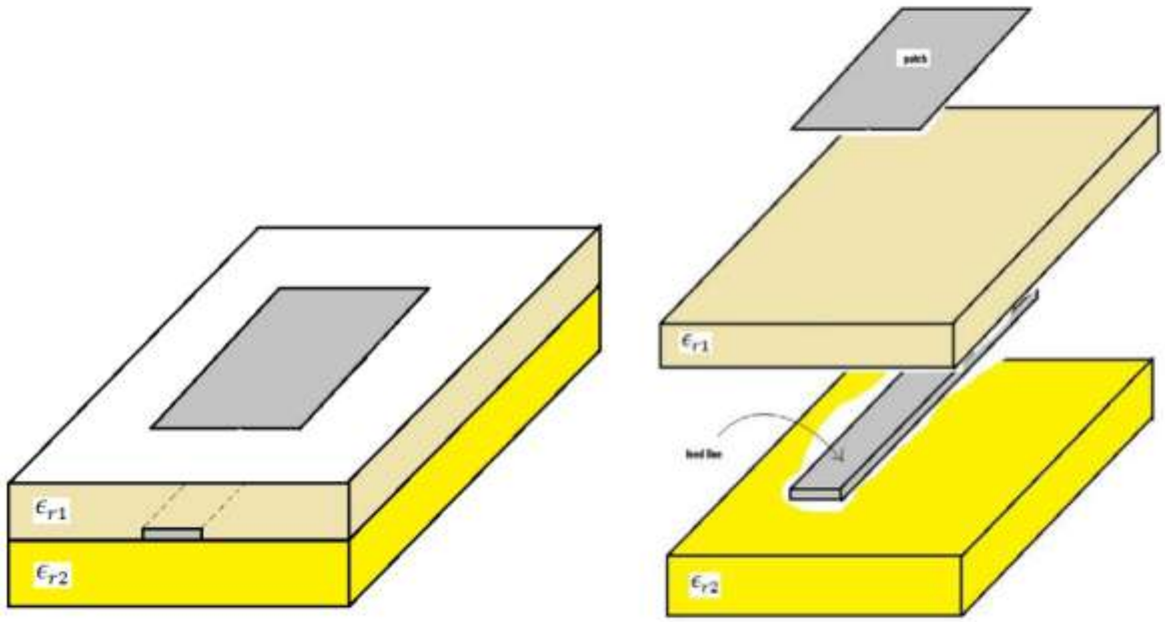



**Figure 2.5:** Proximity coupling feed method

### 2.2.7 Coupling by Aperture

Figure below demonstrates the layers of the microstrip patch antenna exploitation. The bottom plane with an aperture in an exceedingly form of a rectangular or circular and partitions the 2 substrates: the higher substrate is with the patch thereon, and also the bottom substrate with the microstrip feed line under that. This type provides broader information measure. One more feature this type is that the shielding impact of the bottom plane is reduces the divergent of this feeding strip line. Polarization purity is improved by using this very attribute [3].

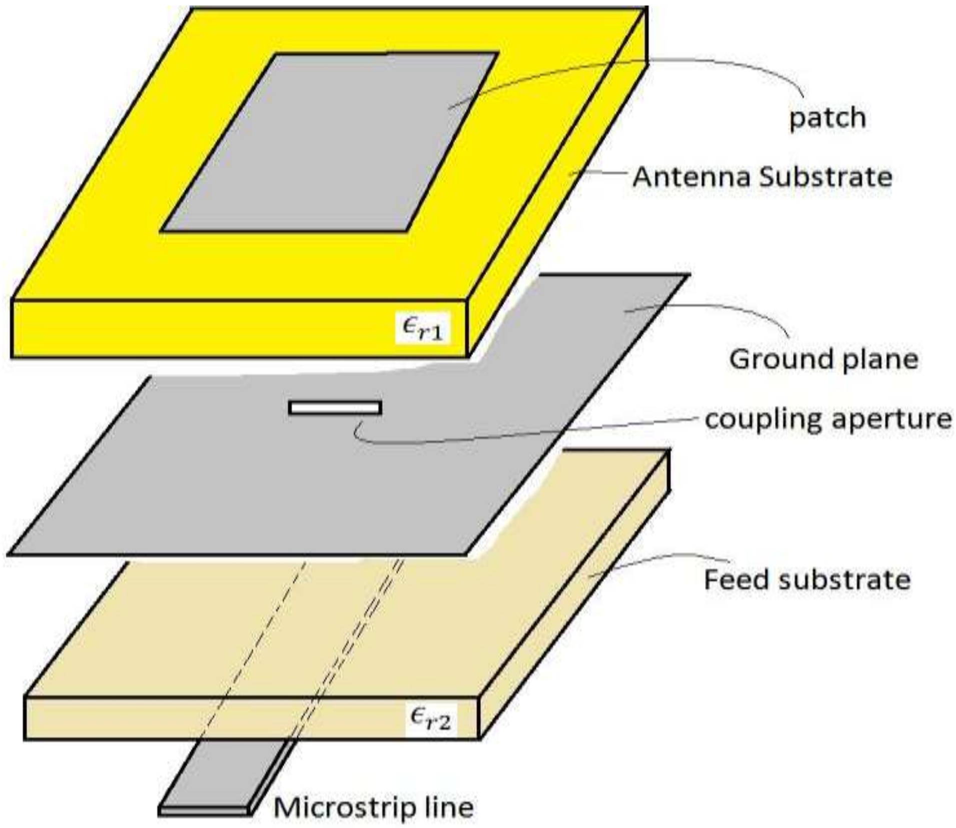



**Figure 2.6:** Aperture coupling feed method

## 2.3 Analysis Methods

Several ways of microstrip antenna study; foremost are conductor (in that we tend to understand that the patch may be a conductor or region of a line of transmission). The second technique is the mode of cavity (in this we tend to say that the patch may be a material cavity which is loaded). Conductor technique is that the stress-free method of learning the microstrip patch.

### 2.3.1 Transmission Line Model

This is the convenient method to see microstrip antenna. The transmission line structure shows microstrip patch antenna by 2 openings, parted by a less-impedance transmission line of extent L. Resultant what is obtained are not the most precise equated to other ways but can serve well to structure the antenna.

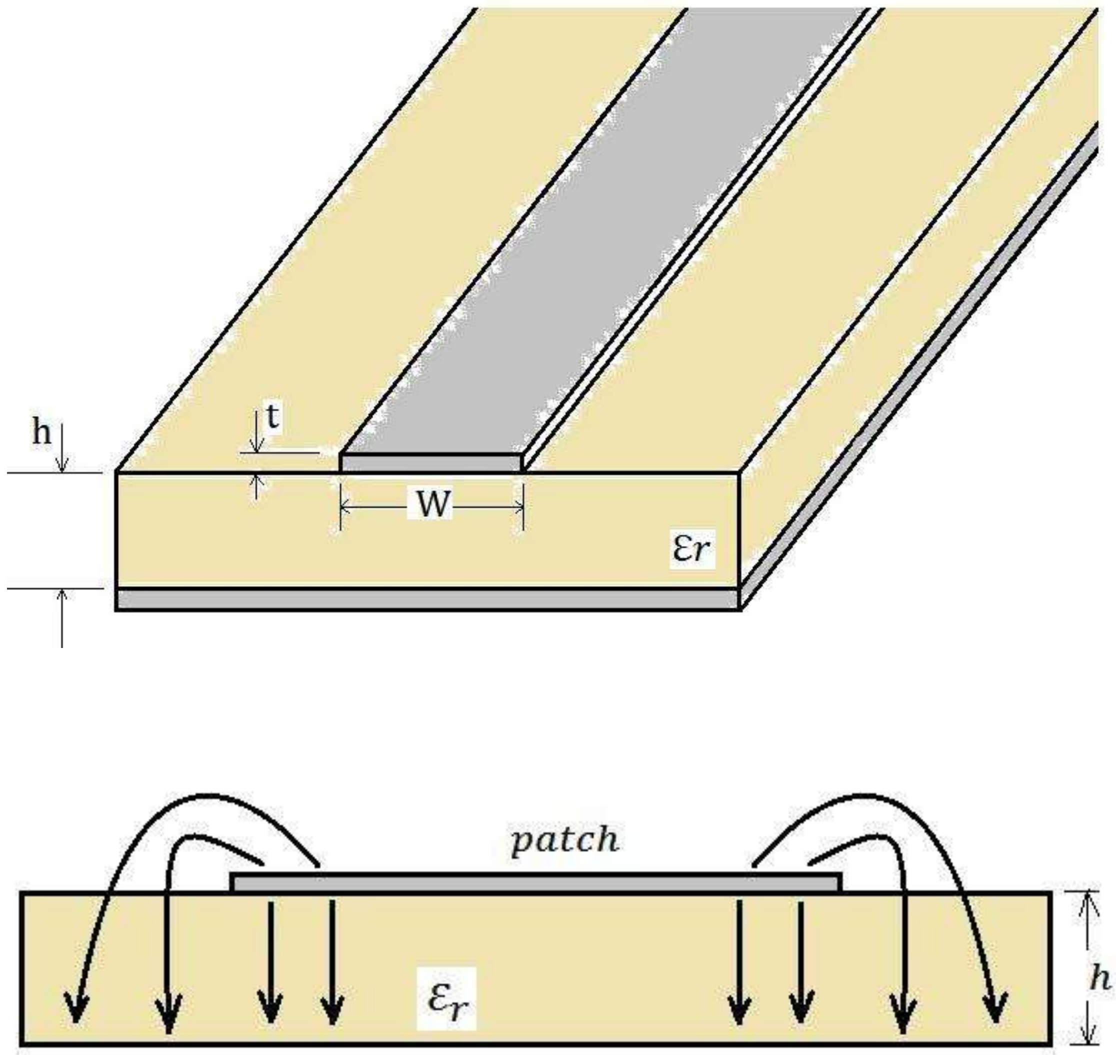



**Figure 2.7:** Electric field lines

### 2.3.2 The Cavity Model

In examining the micro strip antennas depend on the trust that the area amid the micro strip patch and ground plane may be a resonance cavity bordered by top limit and floor of electrical conductors side walls which are magnetic on sting of the conductor as can be seen in figures following.

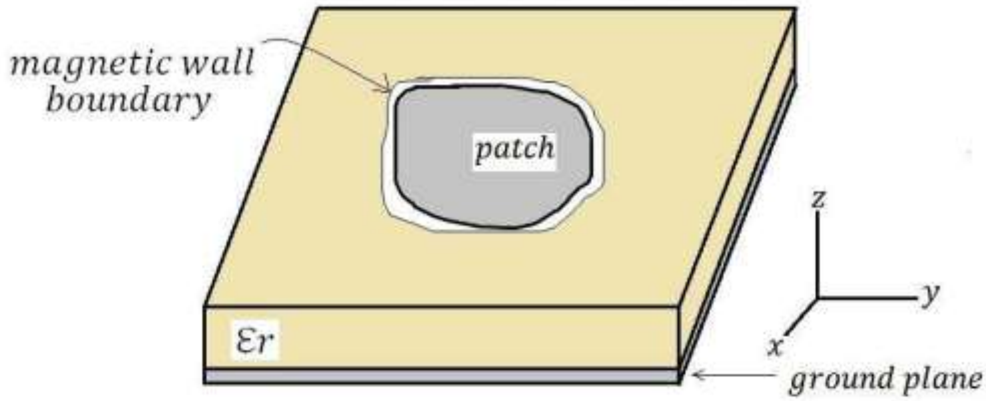



**Figure 2.8:** Magnetic wall model of a microstrip patch antenna

The assumption higher than relies on the observation of [2]:

a. There are solely 3 field elements within the region boxed-in as for the cavity: E part in the z-axis and 2 elements of on the x and y axis.

b. As a result of h (height of the substrate) is extremely tinny (h<<λ), field within the inner area don't vary with z-coordinates for all frequencies.

c. The electrical current within the microstrip patch has no part traditional to the sting of the patch at any purpose.

When the micro strip antenna is linked to a microwave supply, the charge supply are working to recognize on the higher and also the lesser planes of antenna. 2 mechanism control the charge distribution: repulsive & enticing. Power is among the alternative charges on the covering and on the lowermost plane, it makes a current density inside the material at all-time little of the covering.

The force is among sort charges inclines to thrust the fees from lower of the patch round the fringe of the patch to the top of it. Case regarding micro strip antennas tells that W>>h the enticing mechanism controls & at charges attentiveness can enclose matter below the patch also the current flow around the verge can be abandoned as a consequence of it cuts as the measurable relation height to dimension becomes lower. This will allow the 4-sided walls to be sculptured as better magnetic conducting shells that preferably will not interrupt the magnetic flux and in return the electrical field circulation underneath the patch. Clever estimate to the cavity model takes United States of America to touch upon the facet walls as best magnetic conducting walls.

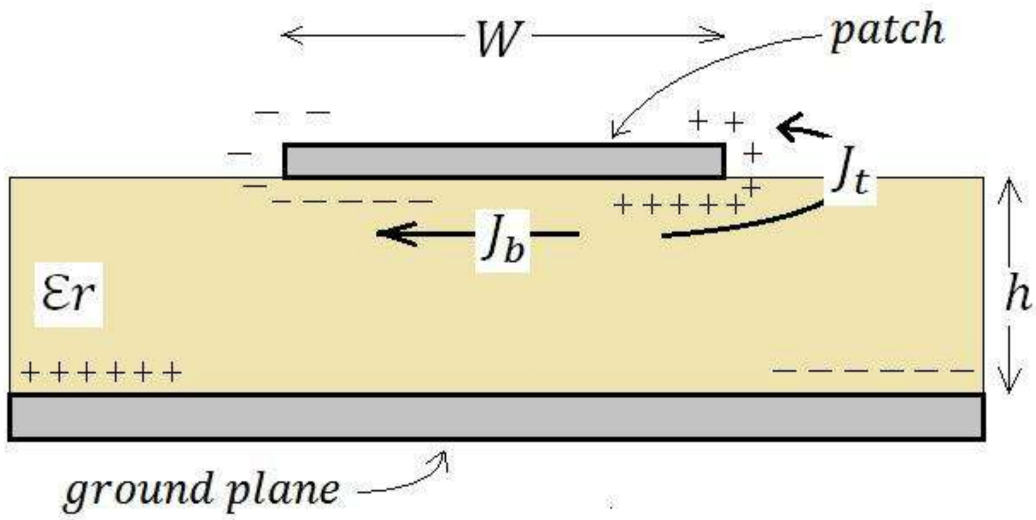



**Figure 2.9:** Charge distribution and current density on a microstrip antenna

## 2.4 Antenna Parameters

### 2.4.1 Pattern of Radiation

A precise graphical picture of the emission assets of the protuberance as a role of planetary coordinates.

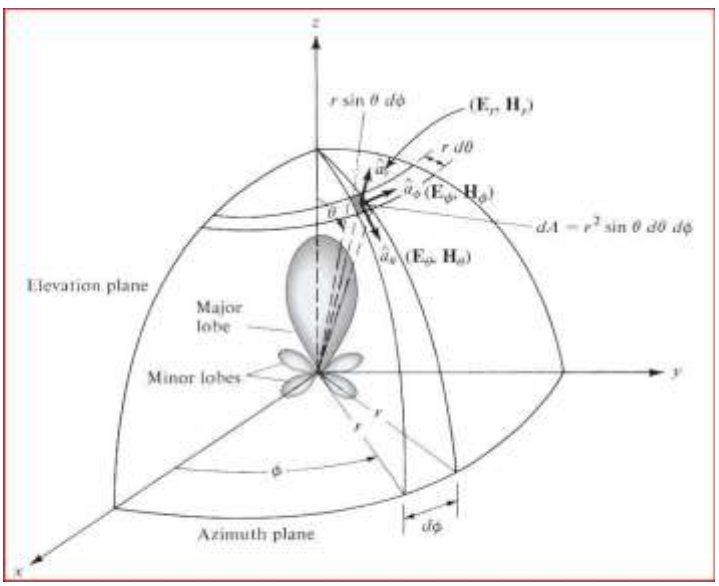



**Figure 2.10:** Coordinate system for antenna analysis

### 2.4.2 Quality and Efficiency Factors

In the case of microstrip patch antenna, potency may outlined because the power emitted by micro strip part separated from ability established by the feedback to the part. Things those have an effect on the potency of this antenna and create it more or less workable. The loss of conductor, the loss of matter, the power mirrored (Voltage stationary wave magnitude relation VSWR), cross-polarized loss, power degenerate in any hundreds within part.

### 2.4.3 Gain and Directivity

It is the quality to associate antenna to point power in a very specific way. The outline of the directionality consistent with IEEE normal 145-1983: "Directivity is that the measurable relation of the emission strength in a very given way from the antenna to the emission strength be an average in all ways". We should know that it is capable the overall power emitted by the antenna separated by four.

### 2.4.3 Matching of Impedance

Maximum power transfer theorem say that for the relocation of supreme power from a basis with immovable inner impedance to the load, the impedance of the load must be the equal of the source [4].

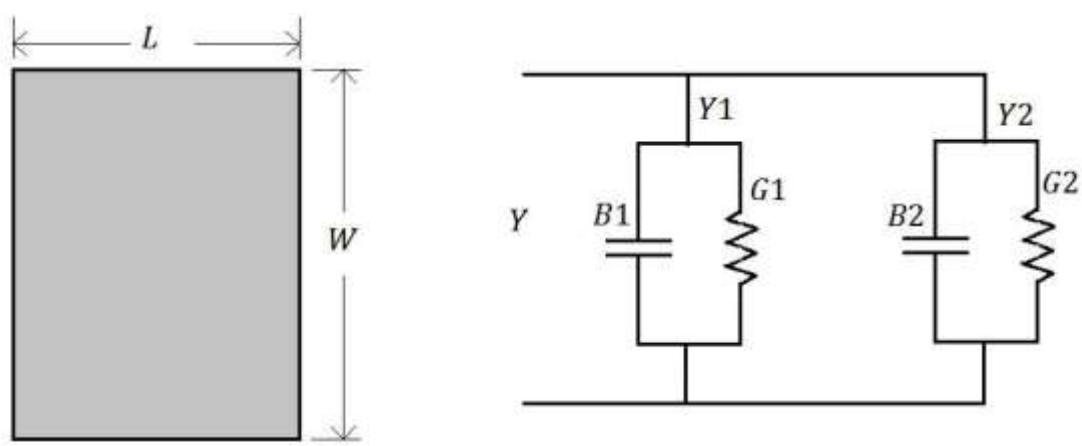



**Figure 2.11:** Rectangular patch and its transmission model equivalent

### 2.4.4 Return Loss

Return loss could be a live in comparative footings of the ability of signal mirrored through separation during conductor and glass fiber. Separation is often produced by a pair amongst closure or load linked to the path and also the representative resistance of the path. it's typically articulated as a magnitude relation in decibels (dB).

It is said that each wave magnitude relation reflection constant (Γ) and (SWR) . Growing return loss resembles to inferior SWR. If we see in an explicit perspective 'Return Loss' could be name. The standard perform of a conductor is to carry power from a supply to a load with negligible loss. If a conductor is properly coordinated to a capacity, the mirrored power is zero, no power is lost because of reflection, and 'Return Loss' is infinite. If the road is terminated in a parallel circuit, the mirrored power is sufficient to the instance power; all of the incident power is lost in the logic that none of it is transferred to a load, and RL is unity. As a result, the numerical ideals of RL tend to be in the reverse direction of what is expected of a 'loss.'

#### 2.4.5 Polarization

The polarization of wave emitted by the antenna is the associate antenna's polarization. A reception antenna must be inside the similar polarization since the transferring antenna else it'll not ring. Polarization might be a characteristic of the magnetism wave, describing the level and path of the electrical arena vector, with different arguments "the positioning of the electrical field for a given location in space". an up-front passage cable has 1 polarization if fixed upright, and totally dissimilar polarization once fixed flat.

Polarization is categorized by linear, spherical, and oblique. When the polarization is linear the protuberance emits radiations in the base of broadcast, just 1 plane, antenna is steeply linear polarized if electrical arena is vertical to the earth's base, and flat linear diverged once electrical field is equivalent to the planet's base.

In terms of emission, a circular polarization antenna emits radiations in all planes (vertical, horizontal, and between them).  In order to complete one whole sequence in one quantity of wave the emission plane revolves in a circle.

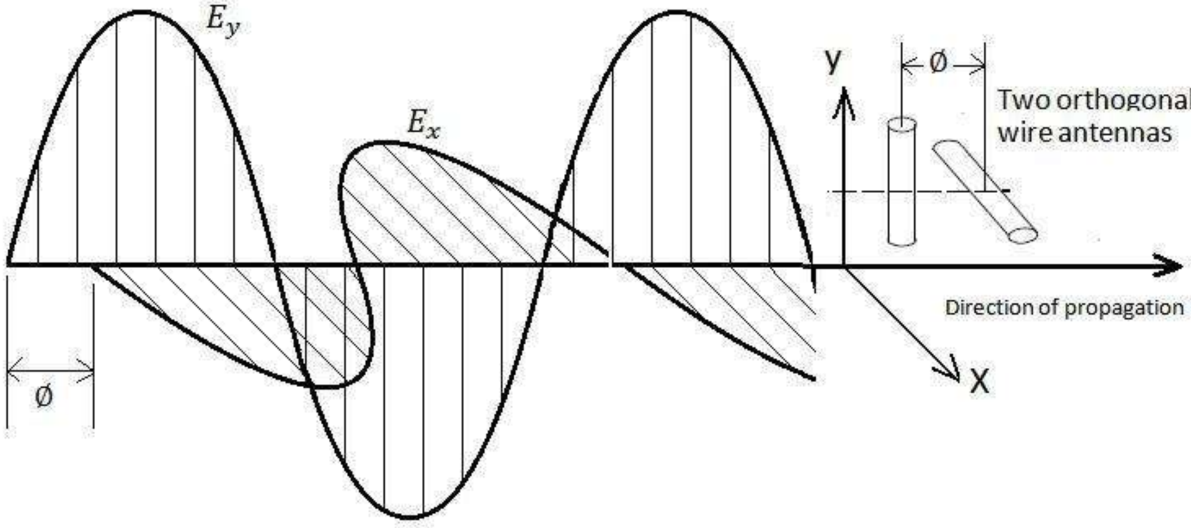



**Figure 2.12:** Polarization of electromagnetic wave

## 2.5 Antenna Array

### 2.5.1 Introduction

Microstrip antennas can put to task in arrays also as lone elements. With the use of array in communication systems one can improve the working of antenna e.g. directivity scanning the beam of this system, or by gain increasing and also other features that are not expected to reach with single element.

Feeding of microstrip array antenna is done through corporate-feed network figure below or series-feed network figure below on the left.

The figure below demonstrates the use of impedance transformer lines to match the 100Ω patches to a 50Ω transmission line [5].

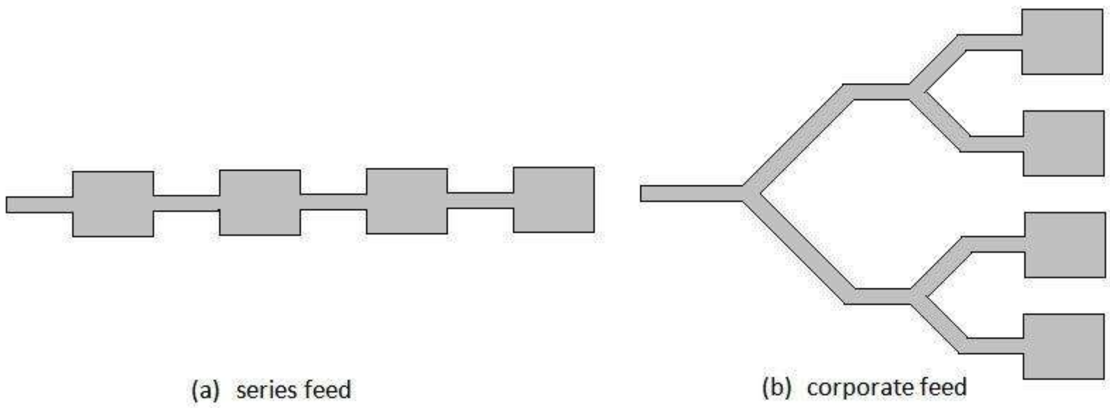



**Figure 2.13:** Feed arrangement for microstrip patch array

Array antenna could be a pack of numerous linked antennas which performs as 1 antenna, on the way to communicate or accept radio waves. Discrete antennas (called elements) area unit characteristically linked toward 1 receiver or transmitter through feedlines. Radio waves emitted through each separate antenna mixture, accumulation along (interfering usefully) to increase the capability emitted inside wanted directions and stopping (interfering harmfully) to cut back the capability emitted in different directions. Same way, once worked for receiving, the separate oftenness currents from the individual antennas mix within the accepter by the proper part relationship for increasing signals accepted by particular directions and abandon signals by unsolicited directions. Added superior array antennas can have numerous receiver or transmitter modules, each linked to a distinct antenna part or bunch of components [6].

Antenna array remain capable to perform upper gain (directivity), that's a thinner beam of radio waves, than might be achieved by 1 part. Normally, the more the quantity of discrete antenna apparatuses being used, the more the gain and so thinner the beam. Roughly antenna arrays (such as military phased array radars) area unit containing many discrete antennas. Arrays are usually familiarly achieve high gains, to surrender path diversity (also known as MIMO) that can rise communication workings, to render interference from particular directions, to navigate the motioning electronically to drive in many directions, and for radio direction finding (RDF) [6].

Term antenna array usually proposes an striving array comprising of many indistinguishable determined components all linked to transmitter or receiver. A dependent array comprises of 1 driven substance linked to the feedline, & other part which doesn't seem to be, known as dependent components. it's actually the other identification for a Yagi-Uda antenna [7].

## 2.6 Design of Patch Antenna Used

In the project omni-directional properties of the antenna have been shown by circular conformal antenna design [8]. Our project requires an omni-directional system with beam-steering. We have designed a directional patch array antenna at 3.5 GHz frequency. After designing a single patch and attaining the required results, we have replicated our patch eight times. These 8 directional patch antennas working at 3.5 GHz of frequency are then arranged in an octagonal geometry and the power is supplied to them using 1x8 Wilkinson Power Divider with a switching network to support the beam-steering capabilities.

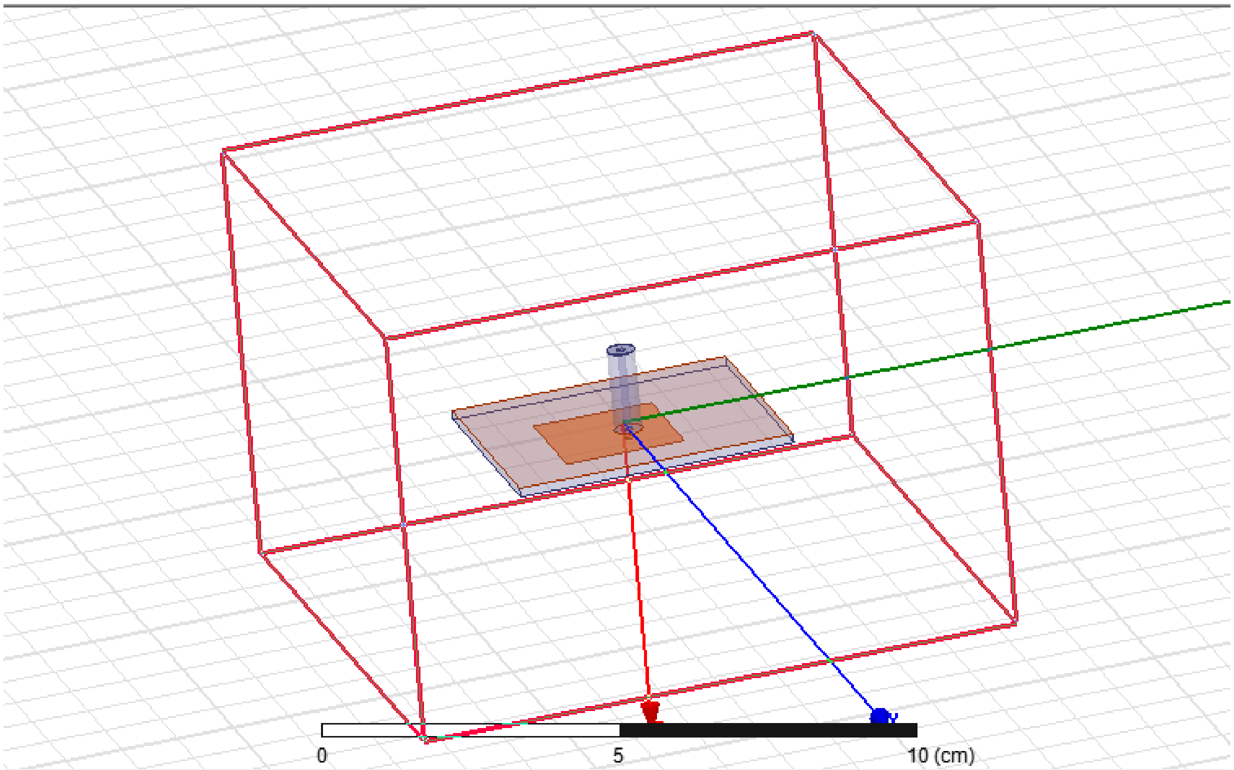
Our designed patch is a coax-fed patch antenna with FR4 as substrate. FR4 has a relative permittivity of 4.4 and a thickness of 1.6mm is used. The patch used in our design has a length of 19.5mm and a width of 21.1mm. Double sided PCB is used with its base as ground and patch designed on the upper side. The antenna is probe fed using SMA connector.

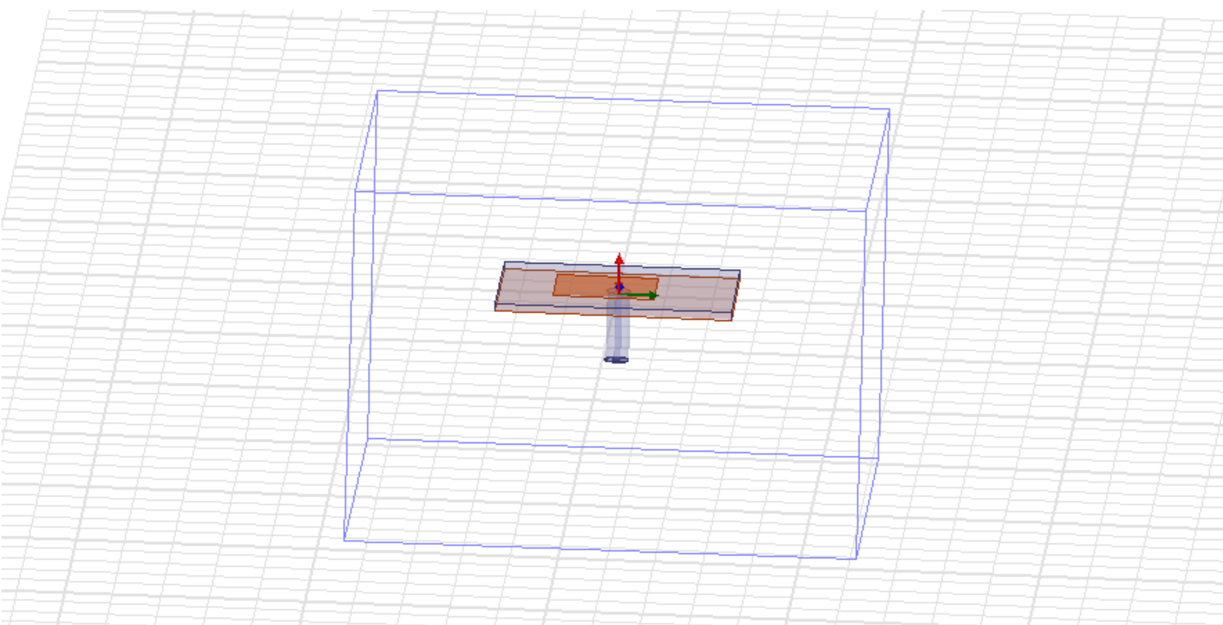
Other measurements of our designed antenna are given below:

**Table 2-1:** Measurements of designed antenna

| | X-dimension | Y-dimension | Z-dimension | Radius | Material |
|---|---|---|---|---|---|
| Substrate | 49mm | 40mm | 1.6mm | - | FR4 |
| Ground | 49mm | 40mm | - | - | Copper |
| Patch | 21.1mm | 19.5mm | - | - | Copper |
| Coaxial Pin | - | - | 14.3mm | 0.71mm | Pec |
| Feed Pin | - | - | 1.6mm | 0.71mm | Pec |
| Coaxial Coating | - | - | 14.3mm | 2.43mm | Teflon |

In this portion the results achieved for the designed antenna will be presented.


0
5
10 (cm)



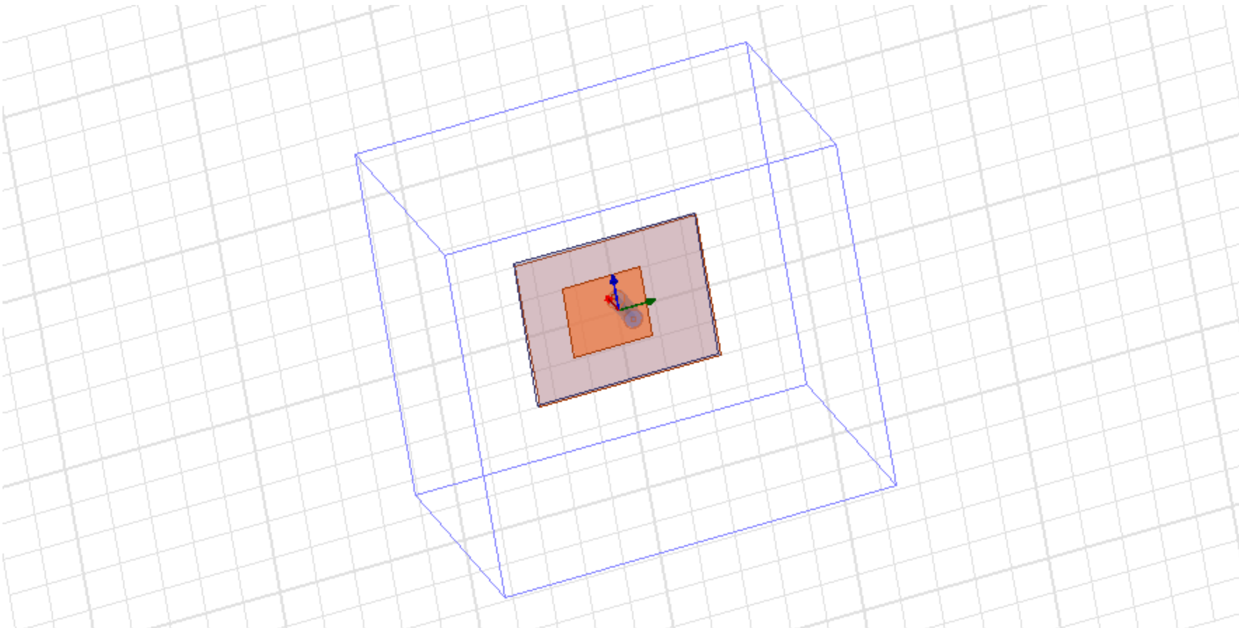


**Figure 2.14:** Antenna schematic in HFSS

The above design shows a patch antenna (in orange) fed by a coaxial pin with FR4 as substrate and surrounded by an airbox of vacuum.

### 2.6.1 Simulated Results

Results produced by our designed patch antenna are as given below:

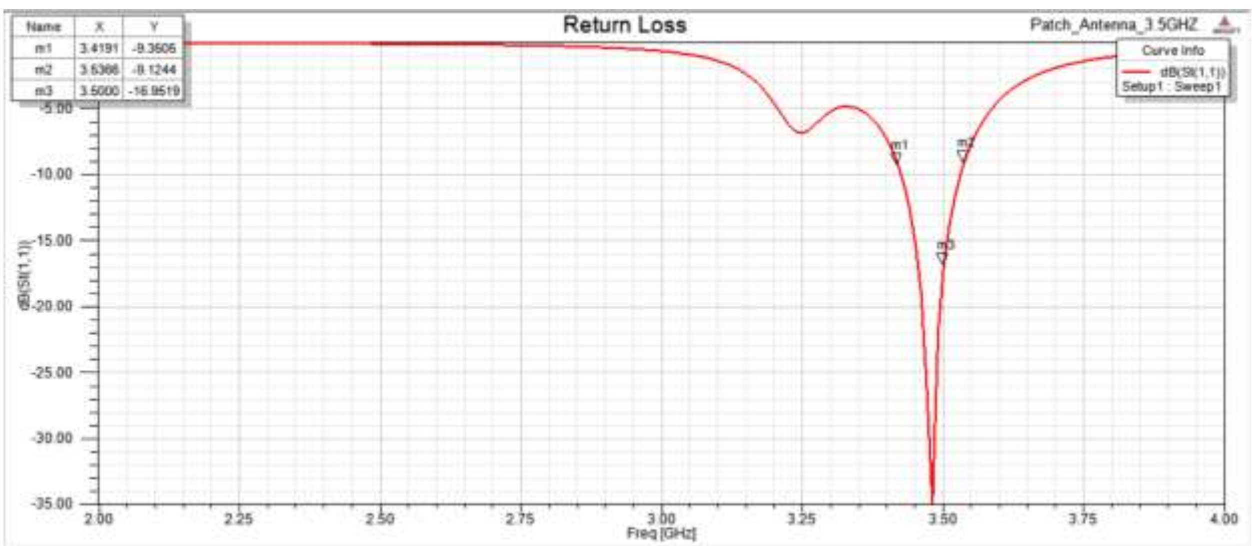



**Figure 2.15:** Plot for return loss of designed antenna

This S(1,1) curve shows a return loss of -16.9519 dB at 3.5GHz. This shows that our design has a return loss lower than -10 dB, so it’s a functional design.

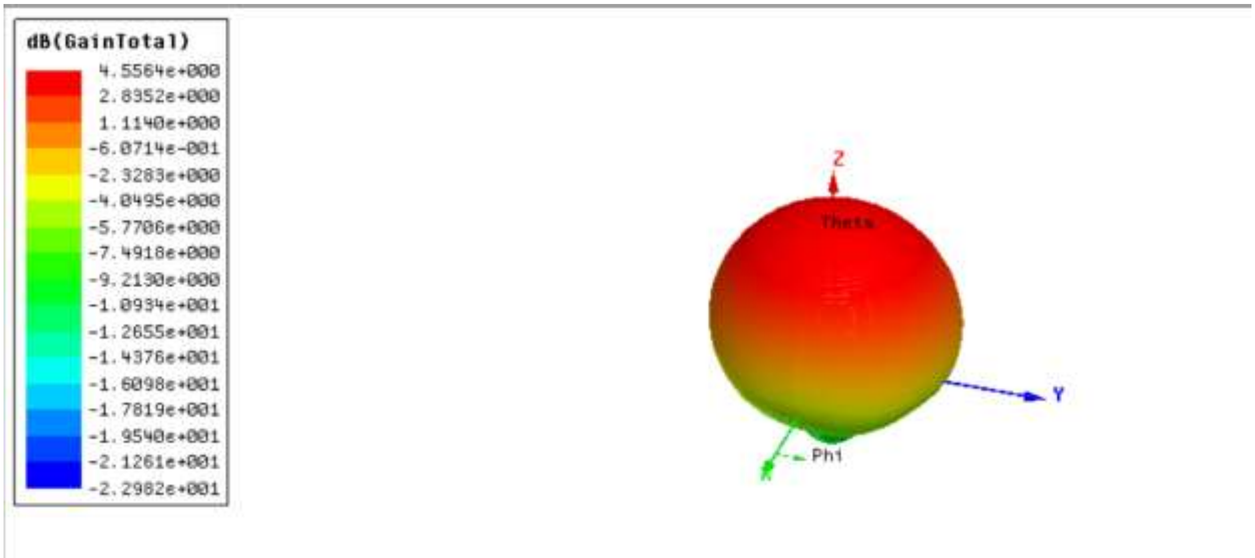



**Figure 2.16:** 3D Polar plot of designed antenna

The 3D polar plot of our patch designed patch shows a directional gain along z-axis with a positive gain of 4.5564 dB.

### 2.6.2 Measured Results

The original fabricated patch antenna is given below.

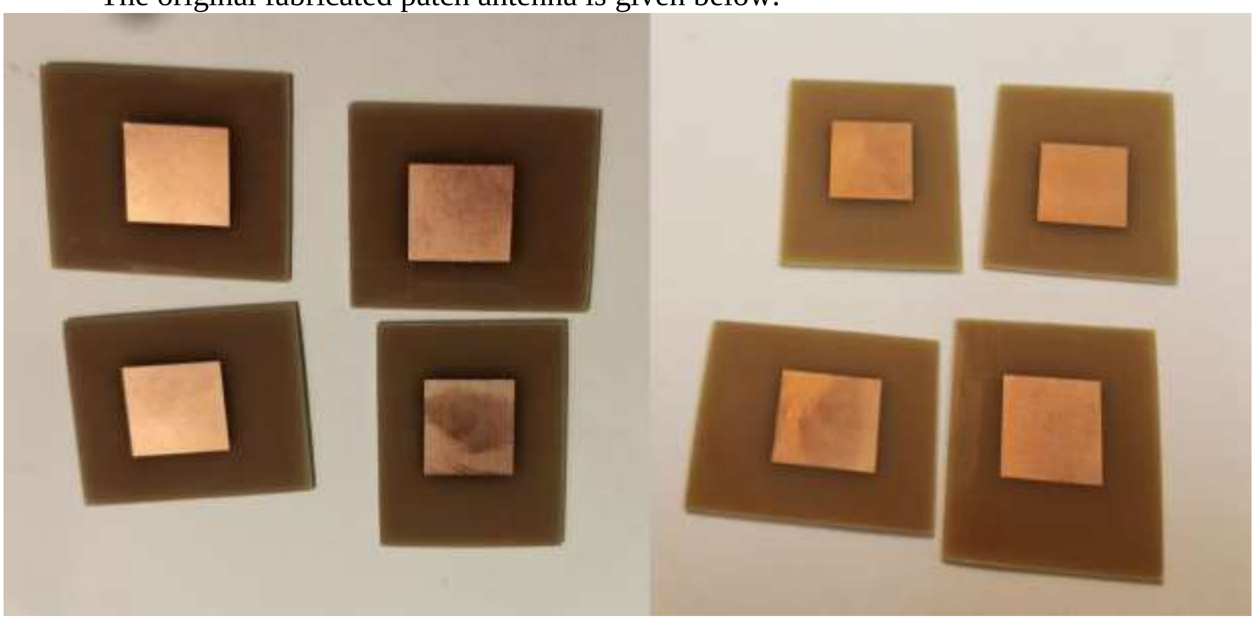


**Figure 2.17:** Fabricated microstrip patches

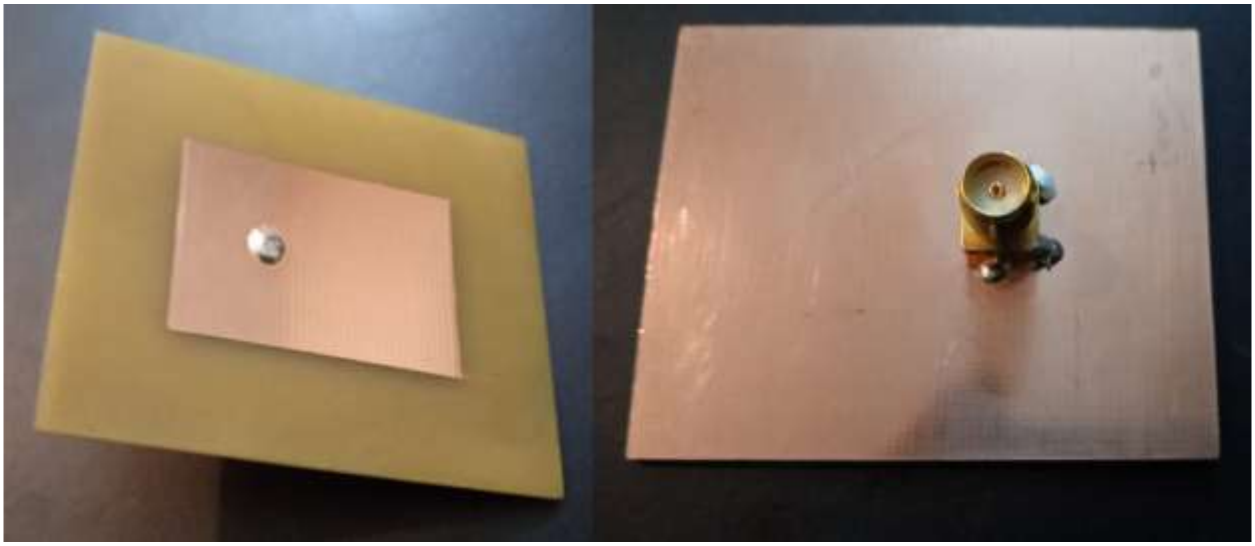


**Figure 2.17:** Fabricated patch after connecting SMA connector

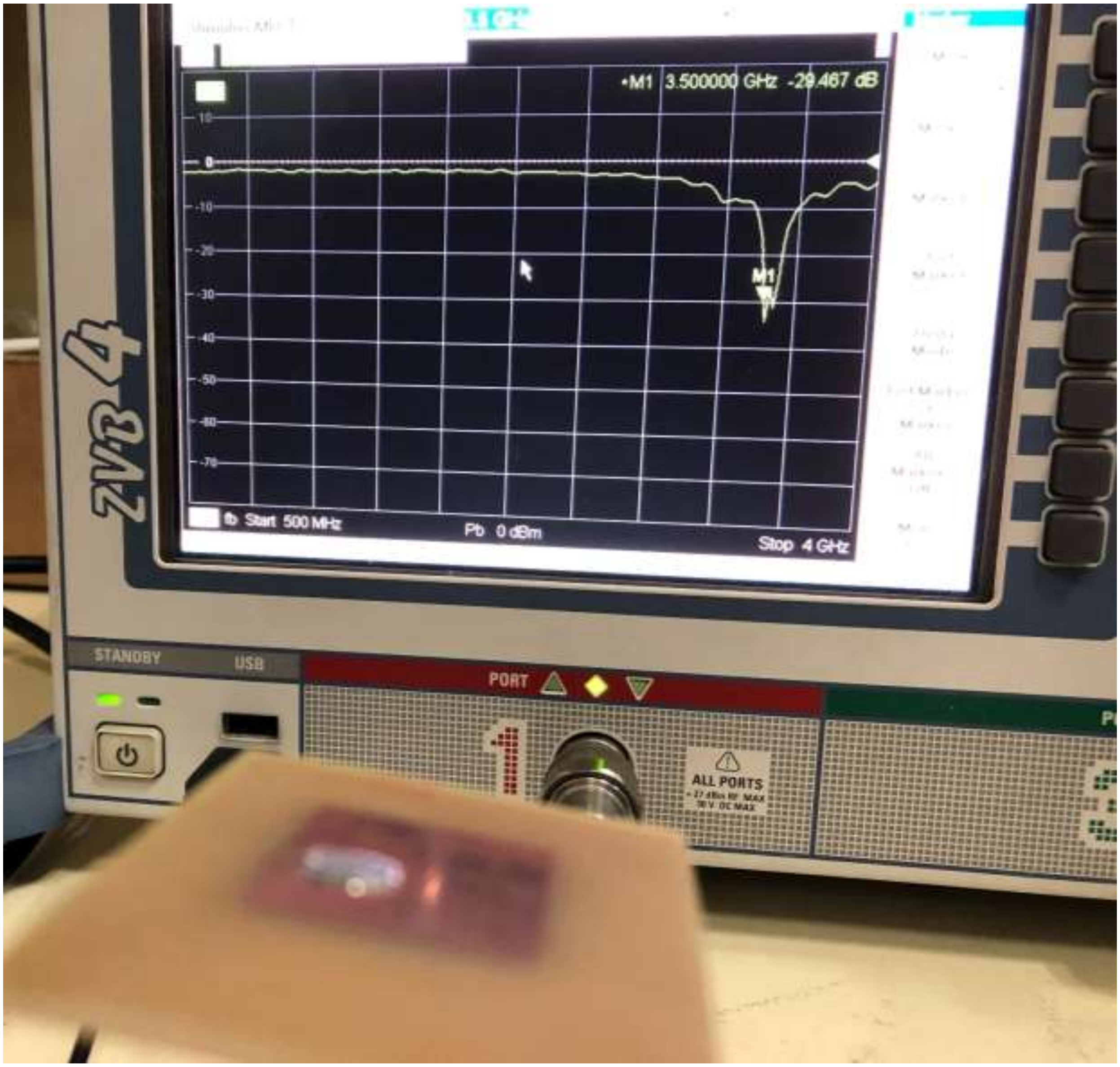



**Figure 2.18:** S(1.1) parameter of antenna as measured on Vector Network Analyser

From the above result it can be seen that the fabricated patch antenna has a very good return loss of -29.467 at 3.5 GHz.

# CHAPTER 3: WILKINSON POWER DIVIDER

## 3.1 Introduction

A power divider is a component that equally divides the power of an input signal among multiple output signals. Lossless T-junction dividers have the drawback of being matchless at all ports and having no isolation between output ports. Although if every port of the lossless resistive divider can be matched, isolation is still not attained. We do know, however, that a network with lossy three ports that are isolated and matched between outputs can be built. When the output ports are matched, the Wilkinson power divider has the benefit of seeming lossless, which means, output ports only dissipate the reflected power. Although any power division mechanism can be used to produce the Wilkinson PD, we'll start with the equal-split (3 dB) instance [9]. This divider is frequently manufactured in the shape of a micro strip line or strip line shape, as shown in Figure 2.1a; the TL circuit is shown below in Figure 2.1b.

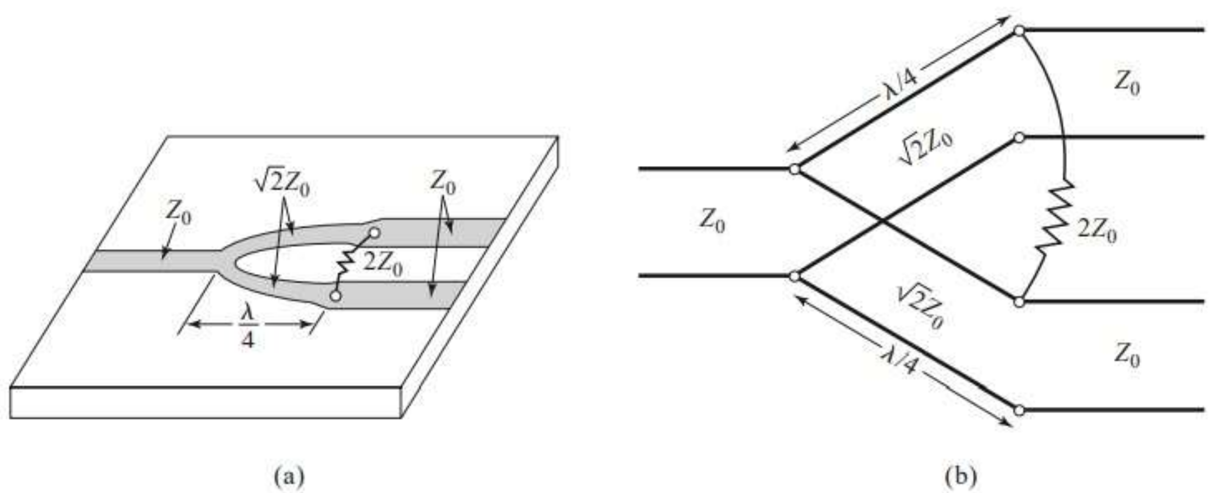



**Figure 3.1:** Wilkinson Power divider in micro strip line shape with an equal split(Left), Equivalent transmission line circuit (Right)

## 3.2 The Circuit

Ernest J. Wilkinson created the Wilkinson Power Divider in 1960.

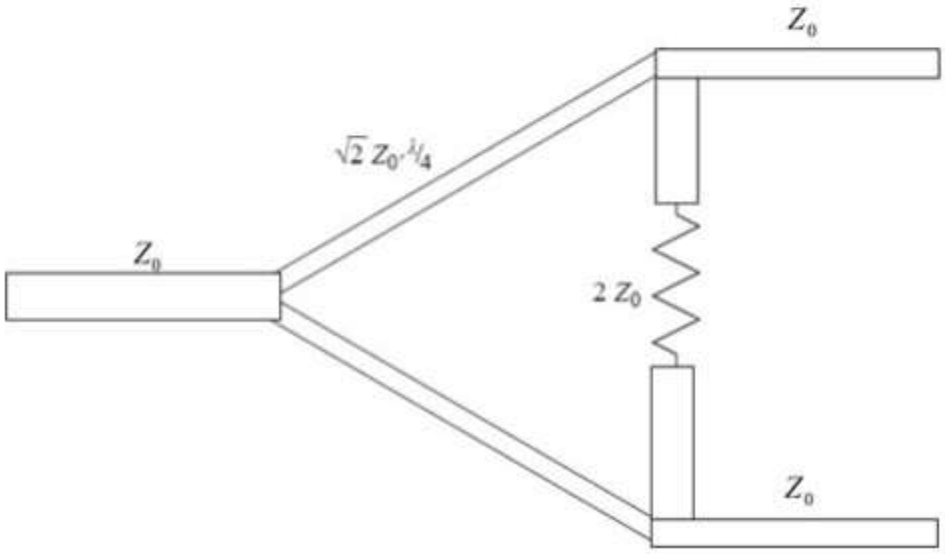



**Figure 3.2:** Wilkinson Power Divider.

Wilkinson Power Divider is designed to distribute input power evenly and without loss between two output ports. It can also be used as a power combiner. Wilkinson power divider's ports are all matched, and the two isolated and reciprocal output terminals ensure that a signal passed from one port to another in either direction yields the identical result.

It is impossible to match and reciprocate three port networks without incurring a loss. The Wilkinson Power Divider provides the answer by placing a resistor between the two outputs that absorbs any energy that is lost due to a mismatch. When used as a power combiner, the resistor aids in the isolation of the two outputs.

### 3.2.1 S-Parameters

Equation below depicts the S-parameter matrix of an ideal Wilkinson Power Divider

$$[S] = \frac{-j}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

The s-parameter matrix reveals the following:

a. Ports are matched ($S_{11}$, $S_{22}$ and $S_{33}$ equals 0)

b. Isolated ports are 2 and 3 ($S_{23}$ and $S_{32}$ equals 0)

c. Port 1 power is split evenly across ports 2 and 3 ($S_{12}$, $S_{13}$,$S_{21}$ and $S_{31}$ equals -3dB with a 90 degree phase shift)

d. Circuit is reciprocal ($S_{mn}$ equals $S_{nm}$)

### 3.2.2 Improving the Bandwidth

Wilkinson Power Divider's main shortcoming is its limited bandwidth, which can be enhanced by addition of a quarter-wavelength section in front of the power combiner. The impedance modification is completed in two phases to improve bandwidth.

Another technique to enhance bandwidth is to divide the two quarter wavelength sections into several pieces, each having a resistor between them. To improve the bandwidth even more, we can use three or more sections instead of one, but this will make the circuit more difficult, with more loss and chip area size.

### 3.2.3 Lumped Components

The size of the quarter-wavelength segments can grow extremely enormous at low frequencies. The most popular method of reducing circuit size is to replace transmission lines with their lumped component counterparts.

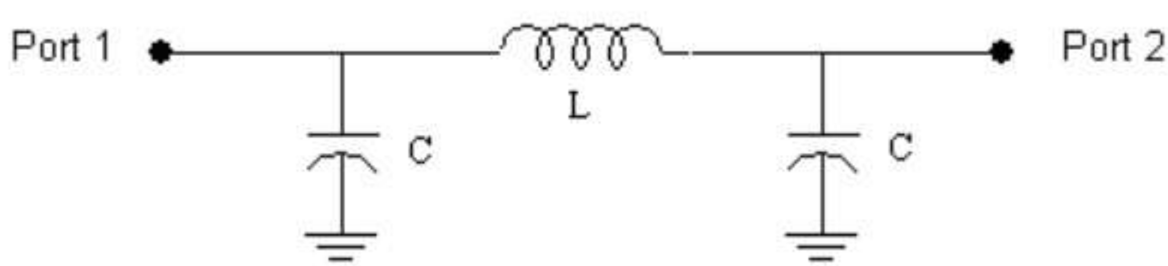



**Figure 3.3:** Lumped components equivalent to distributed transmission line

Using two shunt capacitors and an inductor in series, as shown in Figure 1.2, is one technique to equalize the ideal transmission line with lumped components. Using the following logic, the component values may be simply calculated:

We set the resonant frequency of a LC-circuit i.e. $\frac{1}{\sqrt{LC}}$ ; equaling to the center frequency that we designed the circuit for. We need another equation because we only have one equation but two unknowns. This can be accomplished by matching the impedance of the lumped equivalent to that of the dispersed transmission line. The lumped circuit's impedance is given by $\sqrt{\frac{L}{C}}$ , and when we set this equal to $\sqrt{2}Z_0$, which is known as the transmission line's characteristic impedance, we get the following two formulas:

$$\sqrt{\frac{L}{C}} = \sqrt{2}Z_0$$

$$\frac{1}{\sqrt{LC}} = \omega_0$$

This is further solved to give:

$$C = \frac{1}{\sqrt{2}\omega_0 Z_0}$$

$$L = \frac{\sqrt{2}Z_0}{\omega_0}$$

Formula 1: The calculations above are used to calculate the values of the capacitor and inductor in Wilkinson Power Divider lumped components.

Figure 3.4 shows the lumped components Wilkinson Power Divider, as well as the regular Wilkinson circuit.

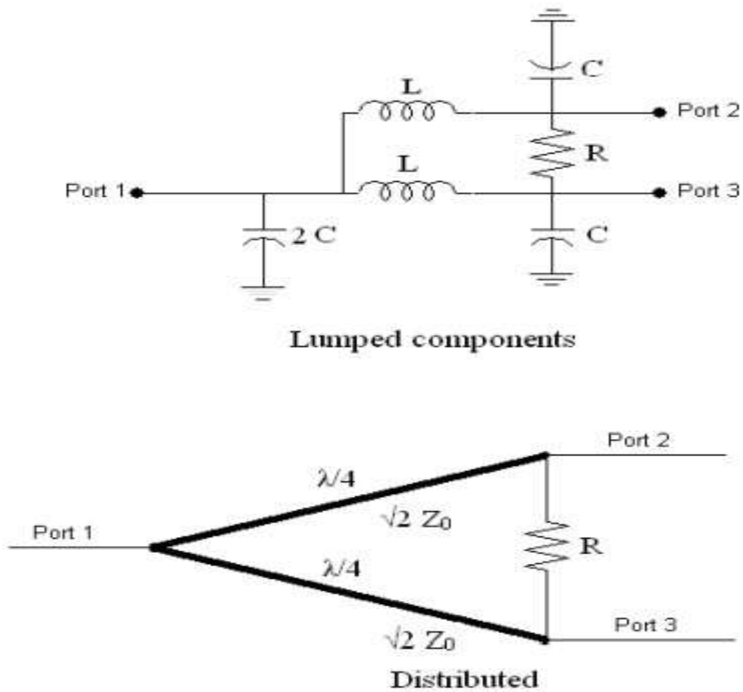



**Figure 3.4:** Wilkinson Power Divider, Lumped and distributed realizations

An Agilent ADS s-parameter simulation is run on both realisations to investigate the dissimilarity between the quarter wavelength transmission line and the lumped components equivalent depicted in Figure 1.3. Figure 1.4 shows the resulting $S_{11}$ and $S_{21}$ values for both realisations in different Smith charts. We must have $S_{22}$ = $S_{11}$ and $S_{12}$ = $S_{21}$ because of symmetry [10].

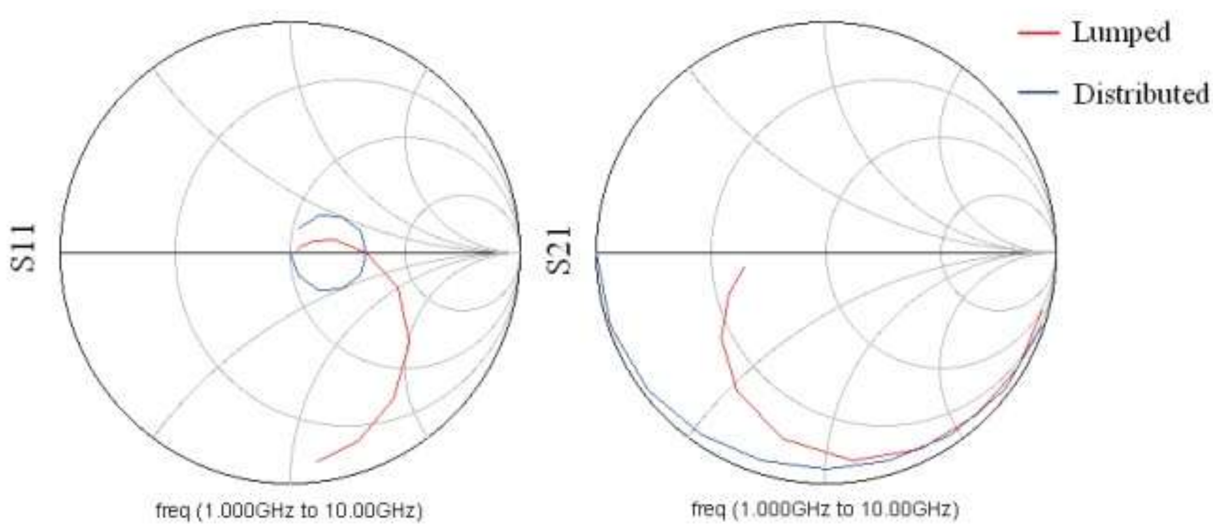



**Figure 3.5:** Agilent ADS simulations of $\boldsymbol{S_{11}}$ and $\boldsymbol{S_{22}}$ for ideal transmission line and lumped components equivalent

The left graph distinctly shows that the two topologies are only equal at 5 GHz, which is the design frequency. The $S_{11}$ value is purely real in both topologies and equals 2. The lumped components react inductively below and capacitively above this frequency, but the dispersed line reacts in the opposite direction. The input mismatch for the lumped components realisation will be greater than for the transmission line at frequencies above the design frequency [11].

The left graph reveals that the value of the two realization of $S_{21}$ is also not alike. We can observe that at 10 GHz, where the transmission line is a half wavelength, the signal is delivered lossless and with a 180 phase shift on the transmission line. At this frequency, the $S_{21}$ value of the lumped components realisation differs significantly from this value [12].

## 3.3 N-Way Wilkinson Power Divider And Unequal Power Division

Wilkinson Power Dividers has a type which can be fabricated which has power splits that are dissimilar as well [13]. Figure 2.6 shows a micro strip line version.

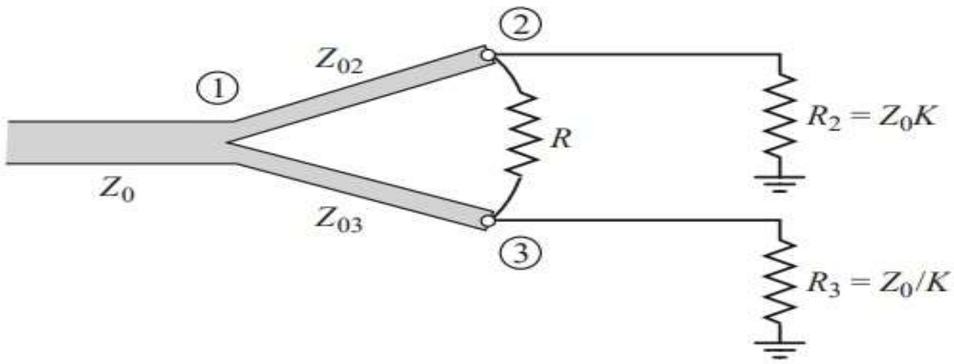



**Figure 3.6:** W.P.D with unequal power division in microstrip form.

The following design equation applies if the power ratio between ports 2 and 3 is K2 = P3/P2:

$$Z_{03} = Z_0 \,.\, \sqrt{\frac{1+K^2}{K^3}}$$

$$Z_{02} = K^2 Z_{03} = Z_0 \,.\, \sqrt{K.(1+K^2)}$$

$$R = .\, Z_0 \,.\, (K. + \frac{1}{K})$$

For K =1, the foregoing outcomes are reduced to the equal-split scenario. As opposed to the impedance$Z_0$, the output lines are also matched to the impedances $R_2$ = $Z_0$K and $R_3$ = $\frac{Z_0}{K}$ ; matching transformers can be used to alter these output impedances [9].

As demonstrated in Figure 1.6, the Wilkinson divider can also be extrapolated to a combiner or N-way divider. All ports of this circuit can be matched, and all ports can be isolated. The reality that the crossovers for the resistors is required by the divider for N $\geq$ 3 is a disadvantage, as it makes manufacturing hard in planar form. For greater bandwidth, the Wilkinson divider could be built with stepped multiple sections [14].

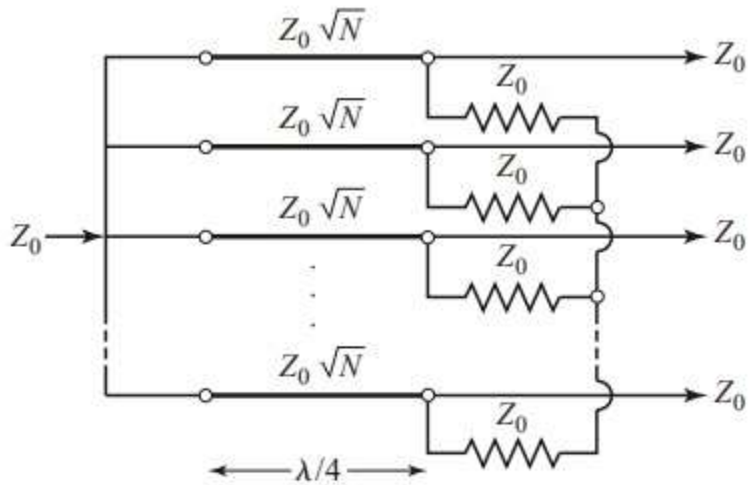



**Figure 3.7:** Wilkinson power divider with N-way equal split

## 3.4 Designed Wilkinson Power Divider

The design requirements of the project are such that 8 array elements of patch antenna have to be connected to a single output of the power amplifier. To achieve this 1 x 8 Wilkinson power divider has been designed. Simulation part of the power divider has been done on Advanced Design System software. Firstly, single power divider was designed and simulated. After getting accurate results from 1 x 2 power divider it was further extended to 1 x 8 power divider. The substrate used in simulation is FR4 as the original fabrication was also to be done on the same.

### 3.4.1 Results

Schematic and results of single power divider are given below.

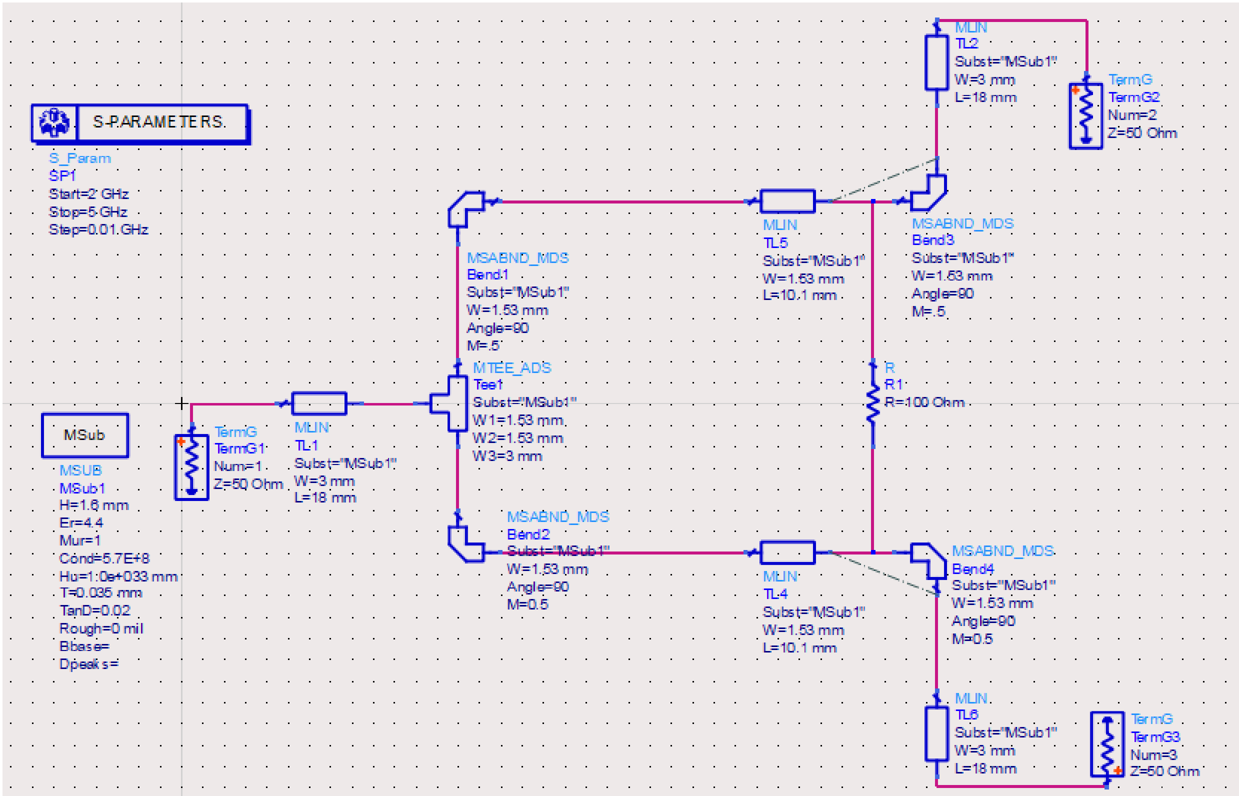



**Figure 3.8:** Schematic of single Wilkinson Power Divider

Results achieved after the simulation of the power divider are given below.

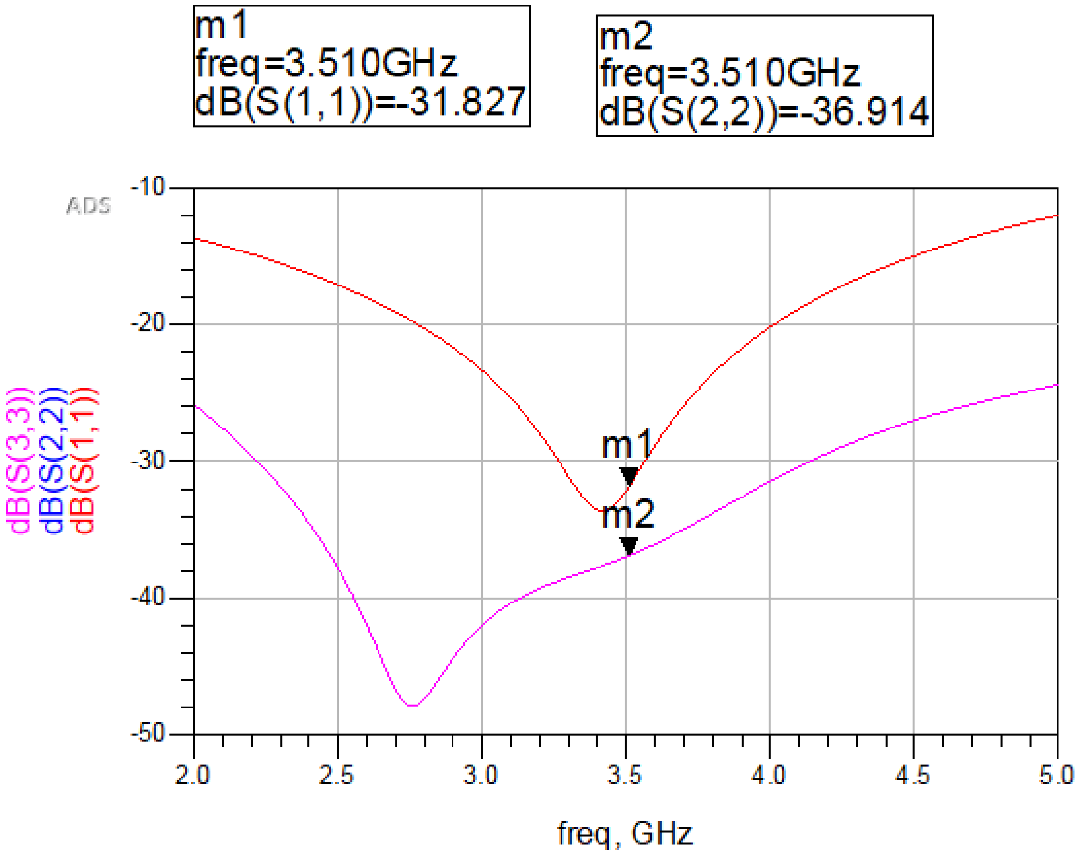



**Figure 3.9:** S(1,1), S(2,2) and S(3,3) of single power divider

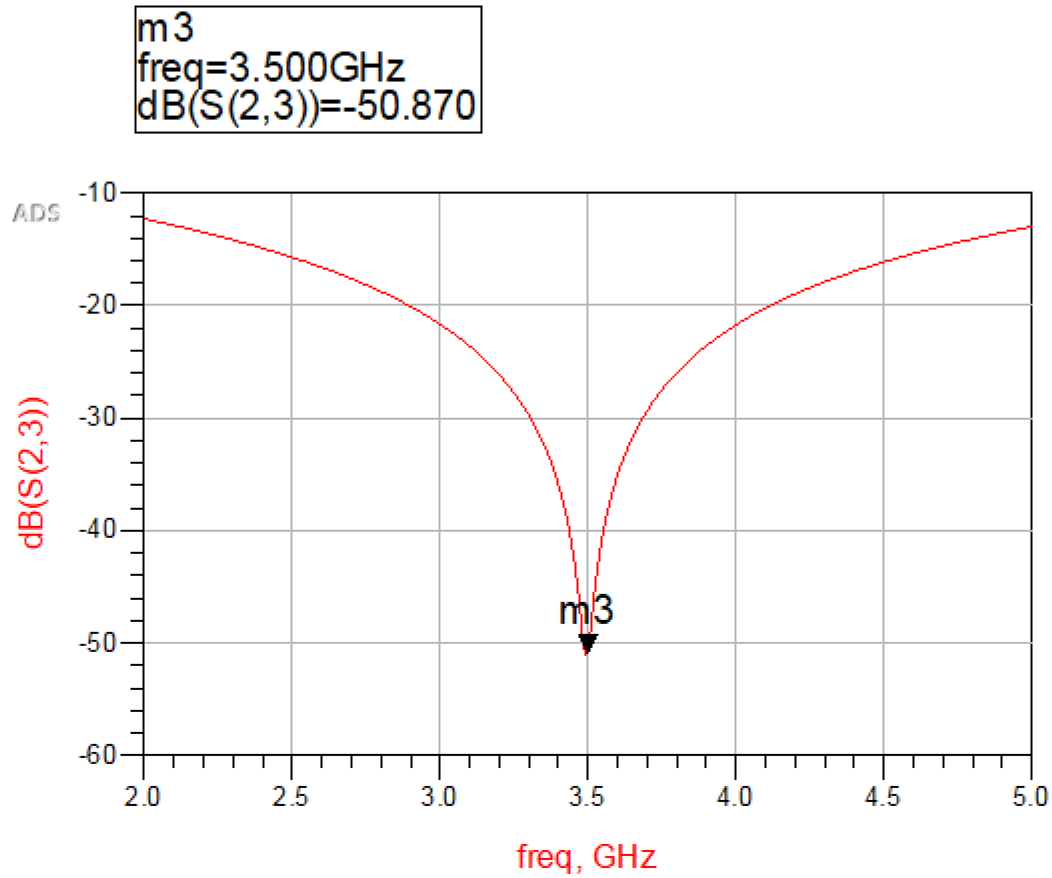



**Figure 3.10:** S(2,3) of single power divider

From the above results it can be seen that return loss at all ports is below -30 dB which indicates that the ports are matched. Coupling between ports 2 and 3 is -50.87 dB at 3.5 GHz which is well below -30 dB. This indicates that the output ports are isolated. After getting desired results from the simulation of single power divider its layout was generated in keysight Advanced Design System. The layout is as given below.

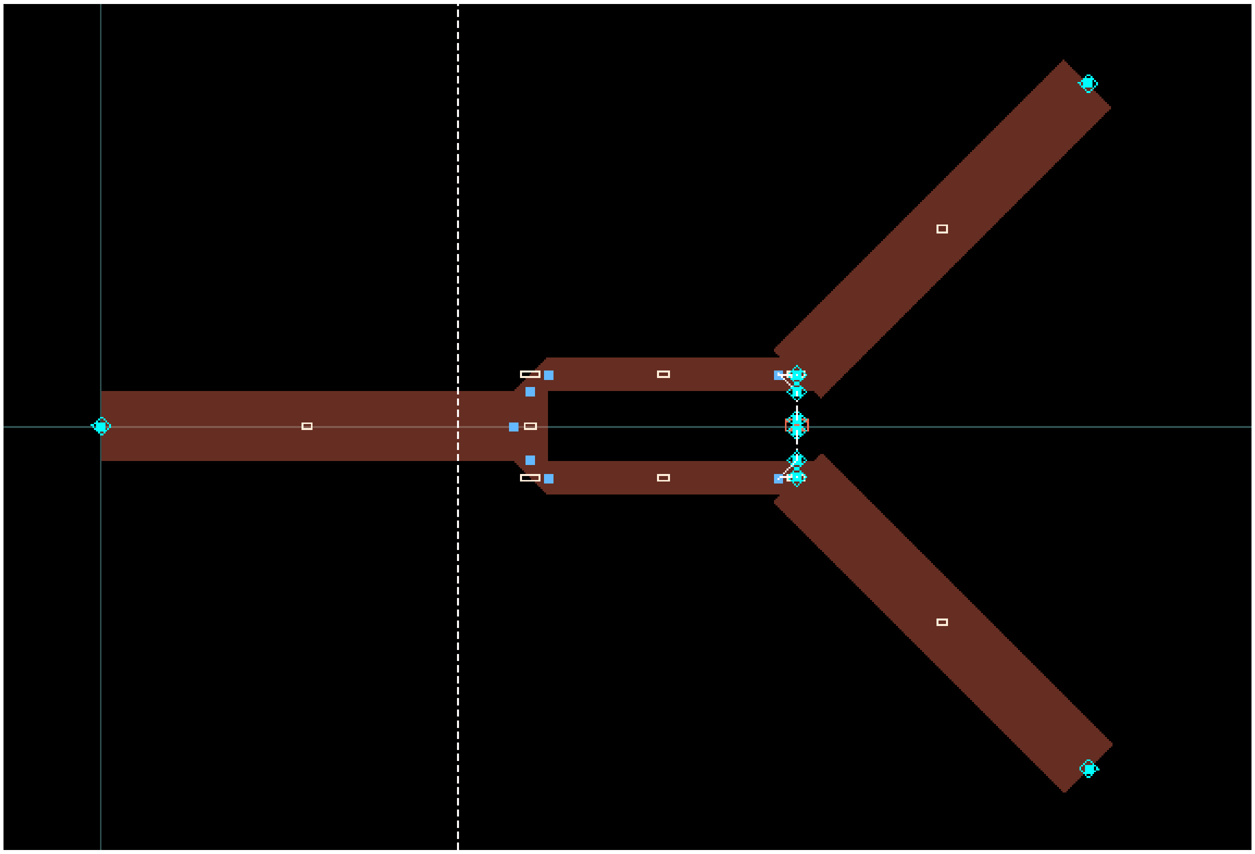


**Figure 3.11:** Layout of single power divider

After designing of layout gerber file was created and power divider design was fabricated. Fabricated single Wilkinson Power Divider is given below.

**Figure 3.12:** Fabricated single Wilkinson Power Divider

After getting the Power Divider fabricated its results were measured on VNA. Measured results are given below.

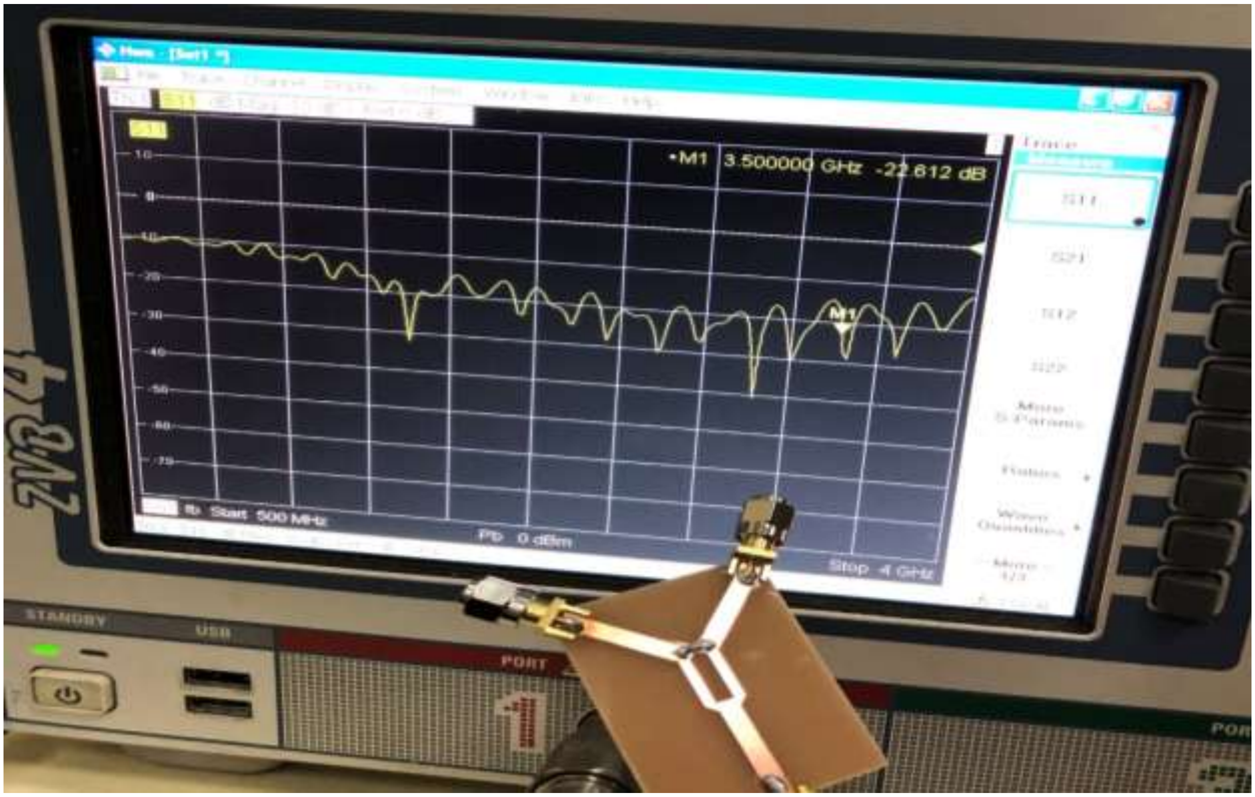



**Figure 3.13:** S11 plot of single Wilkinson Power Divider

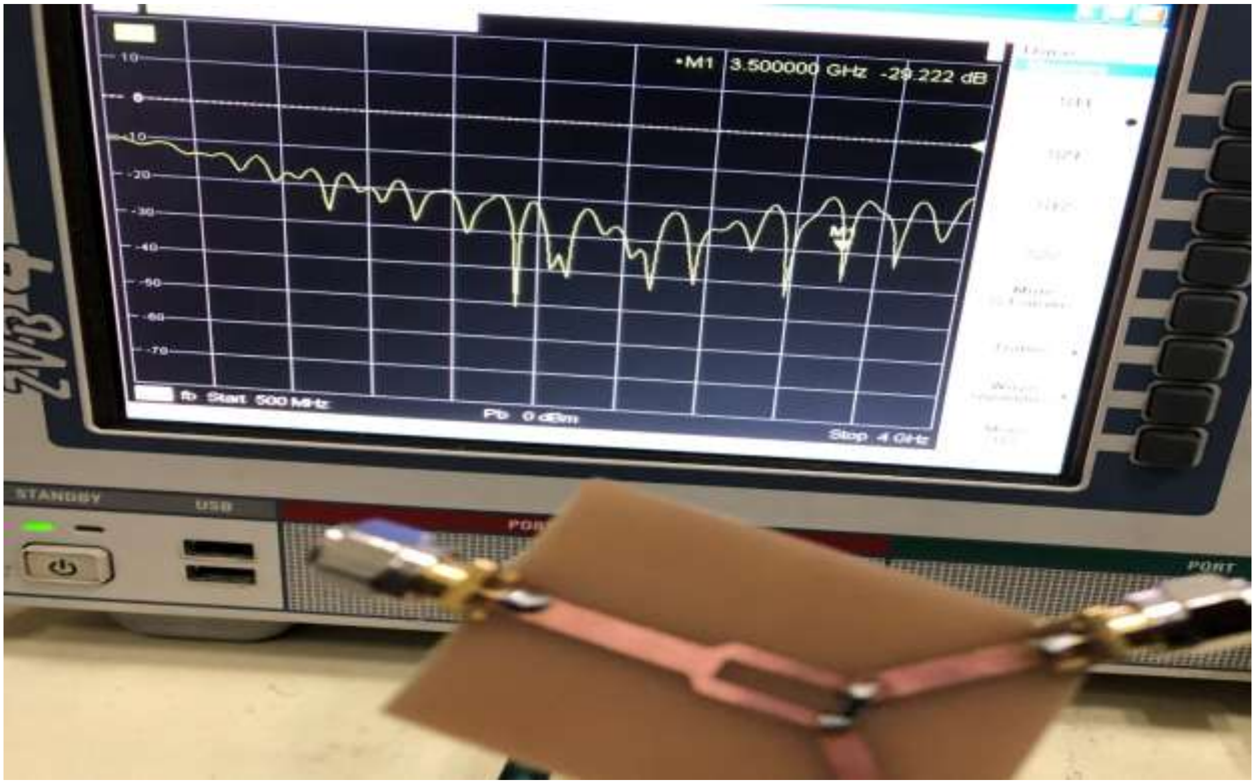



**Figure 3.14:** S22 plot of single Wilkinson Power Divider

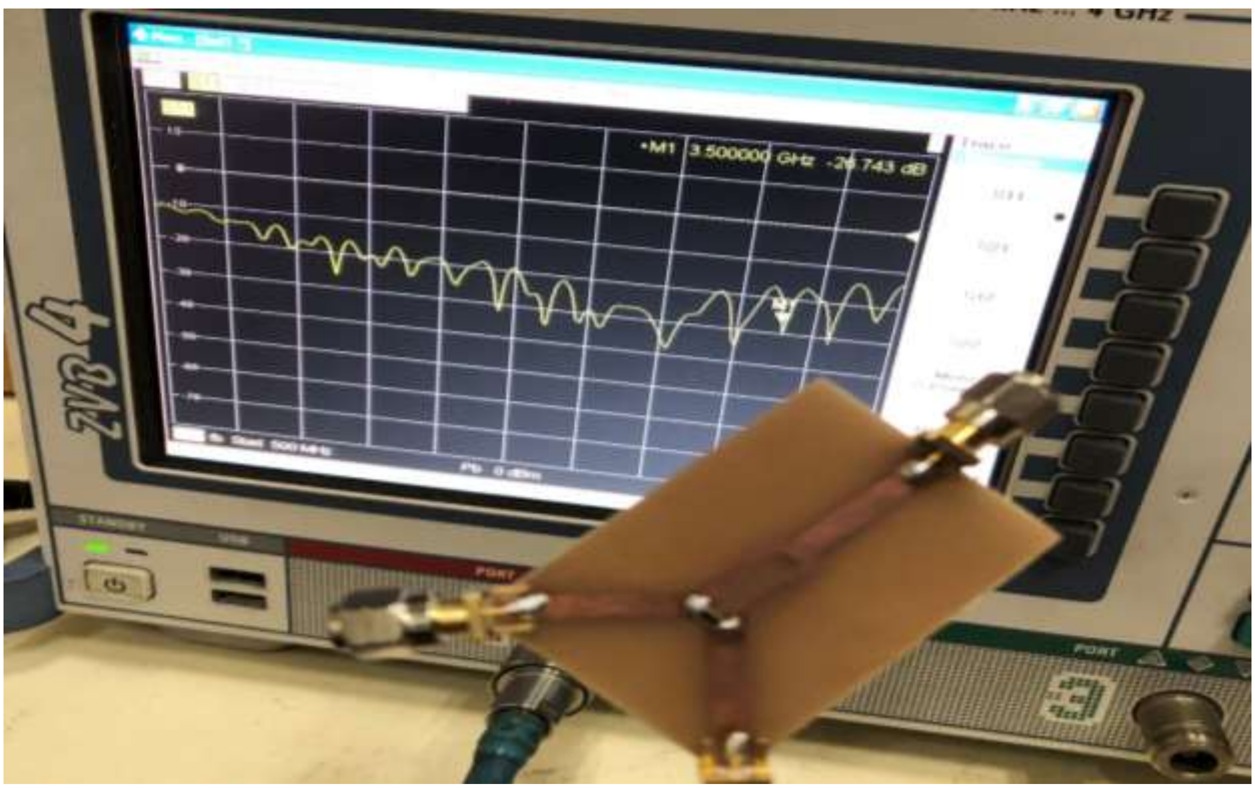



**Figure 3.15:** S33 plot of single Wilkinson Power Divider

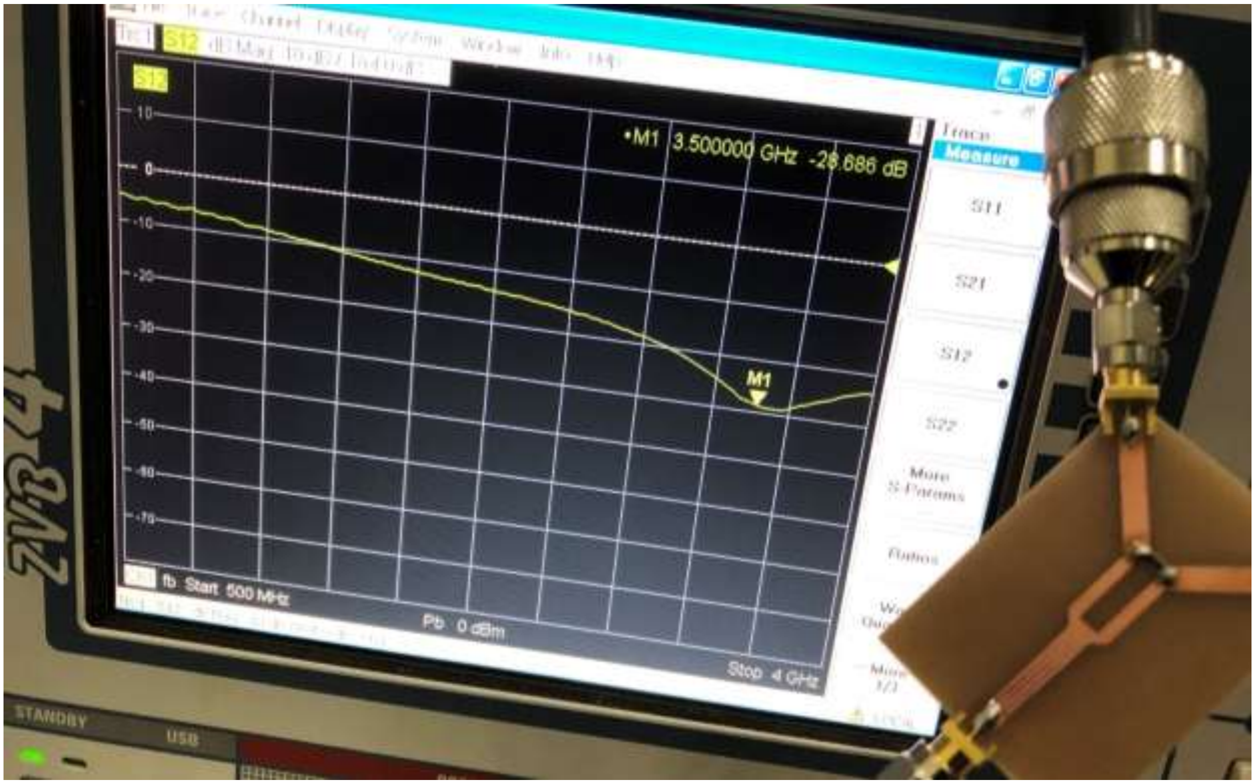



**Figure 3.16:** S23 plot of single Wilkinson Power Divider

Schematic of single power divider was further extended to 1 x 8 Wilkinson power divider. This was done because the actual design requirement was being fulfilled with the 8 outputs of the power divider. Schematic design of 1 x 8 Wilkinson power divider in keysight Advanced Design System is given below.

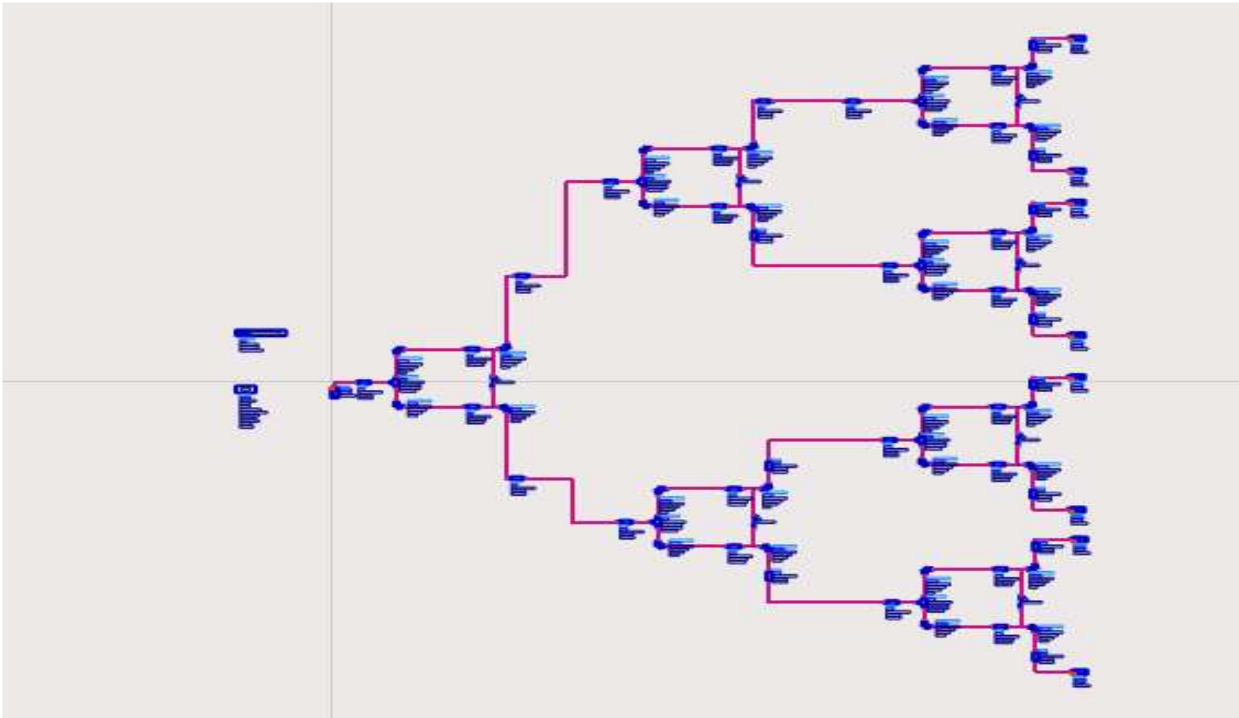


**Figure 3.17:** Schematic of 1 x 8 Wilkinson Power divider

Simulations of the design were run in order to check the different parameters. Ports matching, isolation and insertion loss were checked for 1 x 8 Wilkinson power divider. Results of the simulation are given below.

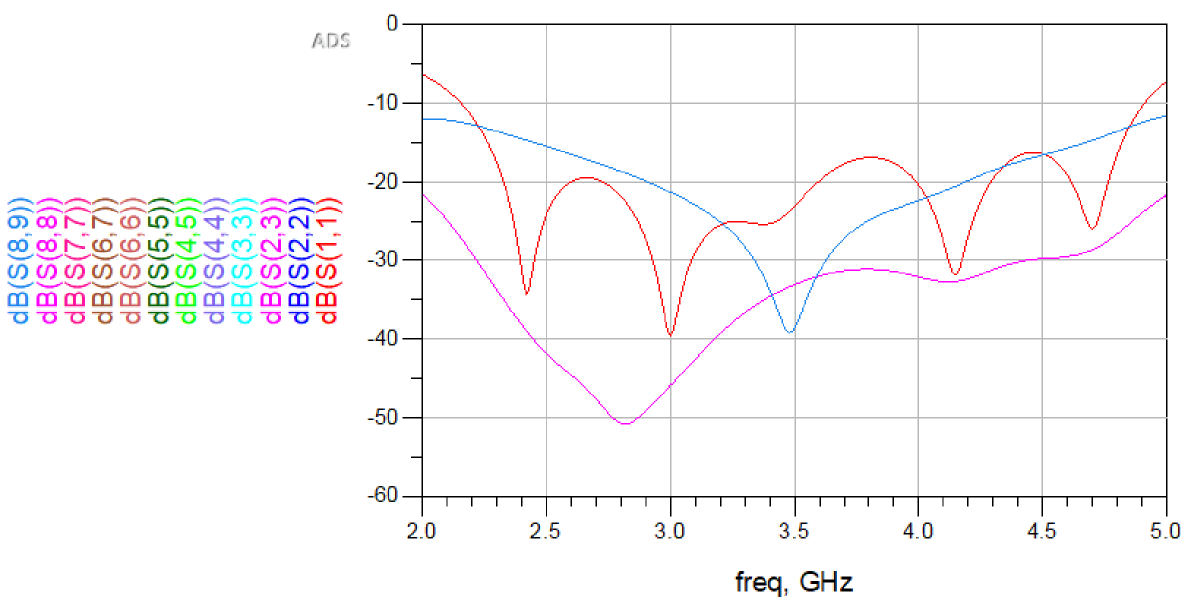



**Figure 3.18:** Return loss plot of 1 x 8 Wilkinson power divider

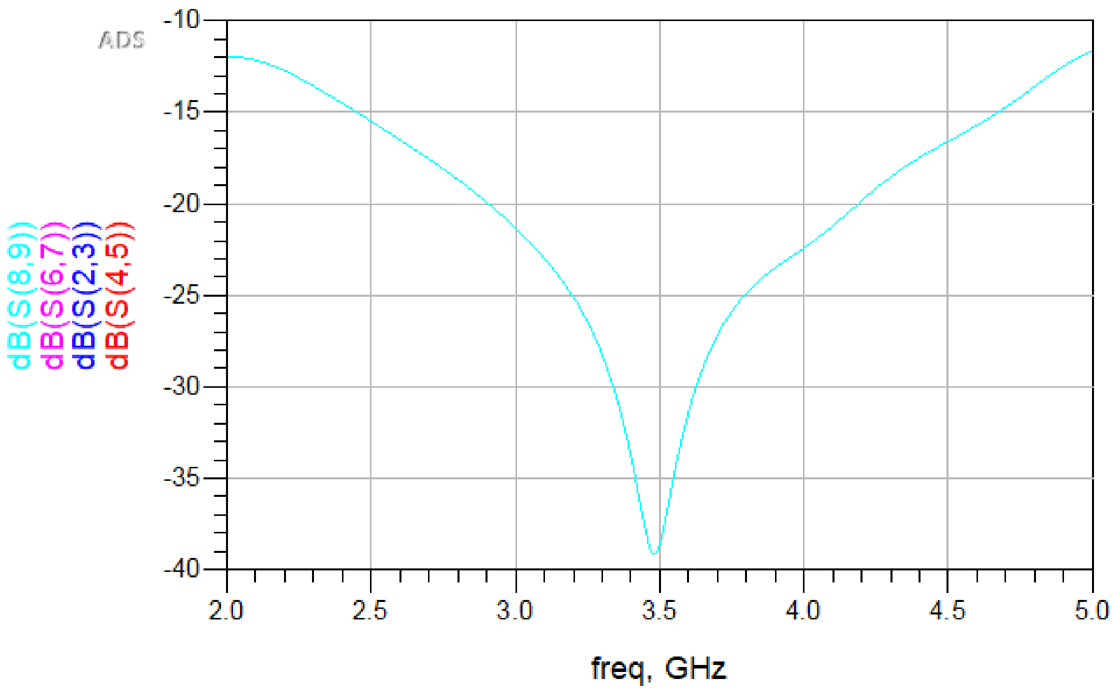



**Figure 3.19:** Port isolation plot of 1 x 8 Wilkinson power divider

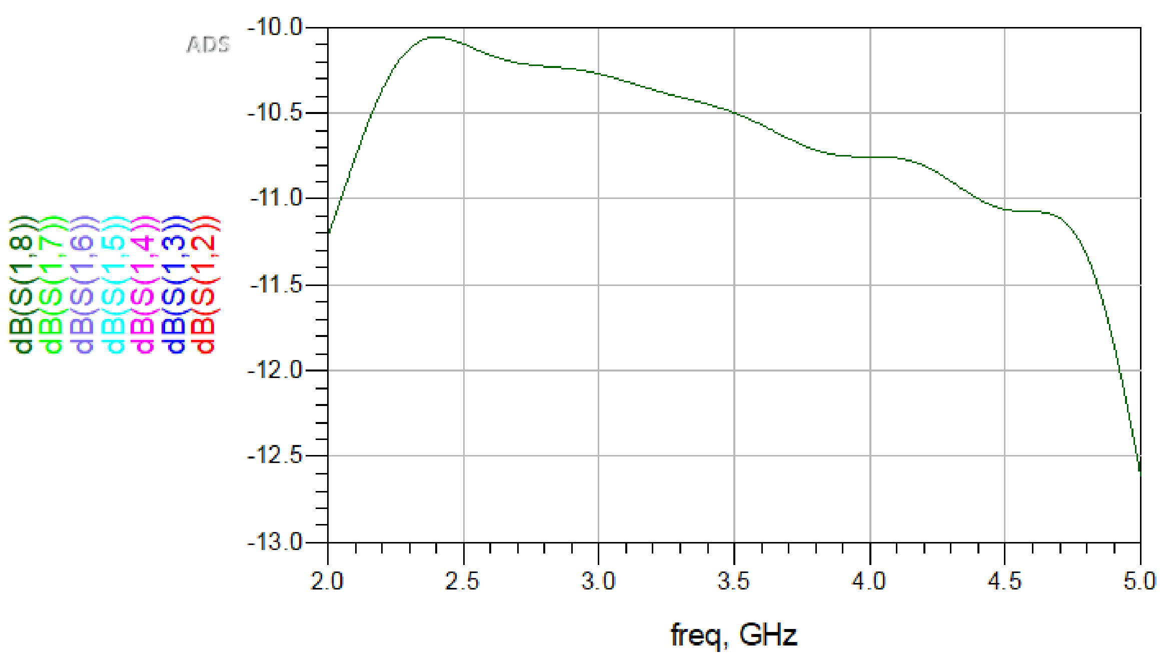



**Figure 3.20:** Plot for insertion loss of 1 x 8 Wilkinson power divider

From the return loss plot result it can be seen that all the ports are matched because return loss is well below -10 dB. Coupling between ports is well below -30 dB so output ports are isolated. Although the insertion loss is not ideal but this is due to the losses of the substrate. The layout of 1 x 8 Wilkinson power divider along with switching network is given below.

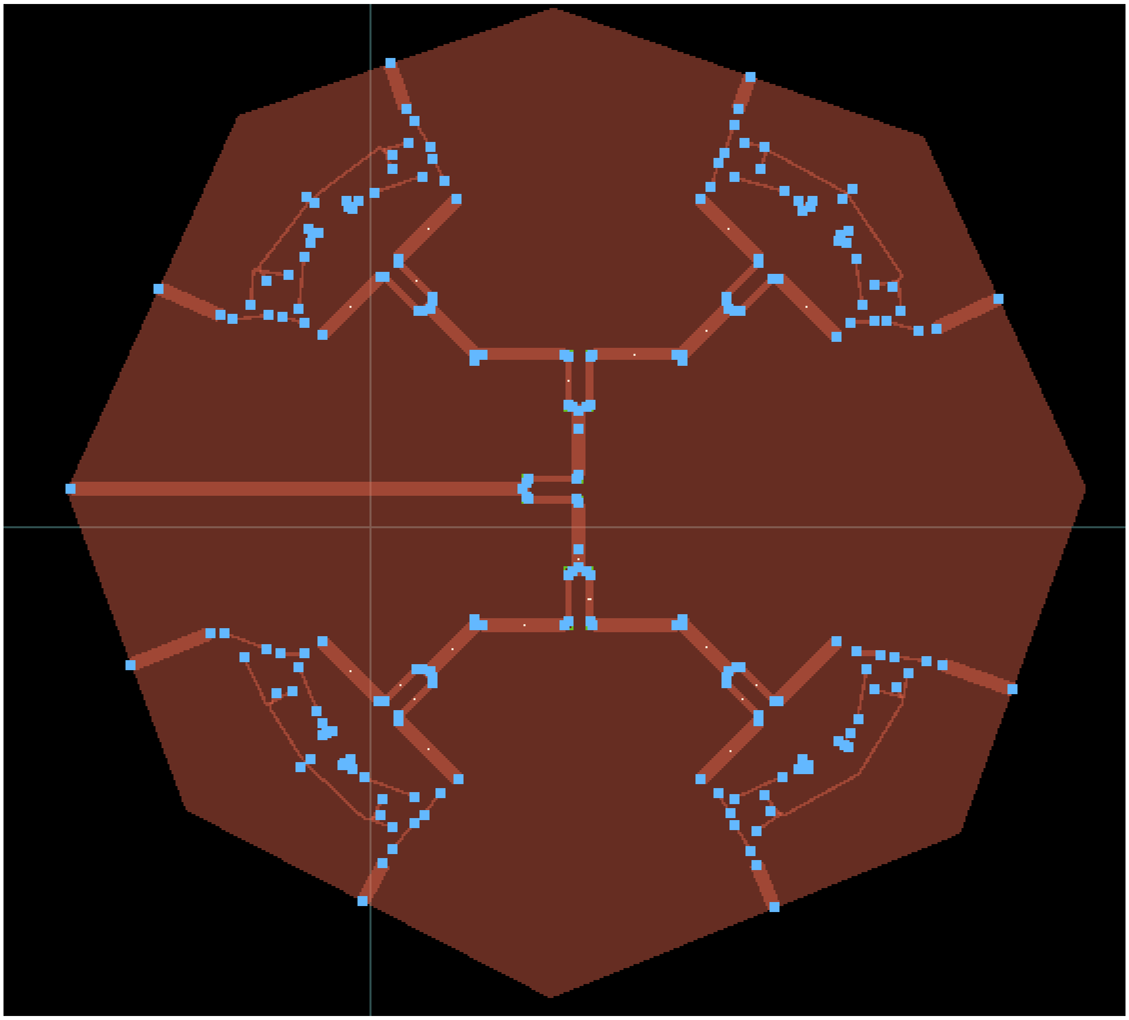


**Figure 3.21:** Layout of 1 x 8 Wilkinson power divider

The original fabricated Wilkinson power divider along with switching network is given below.

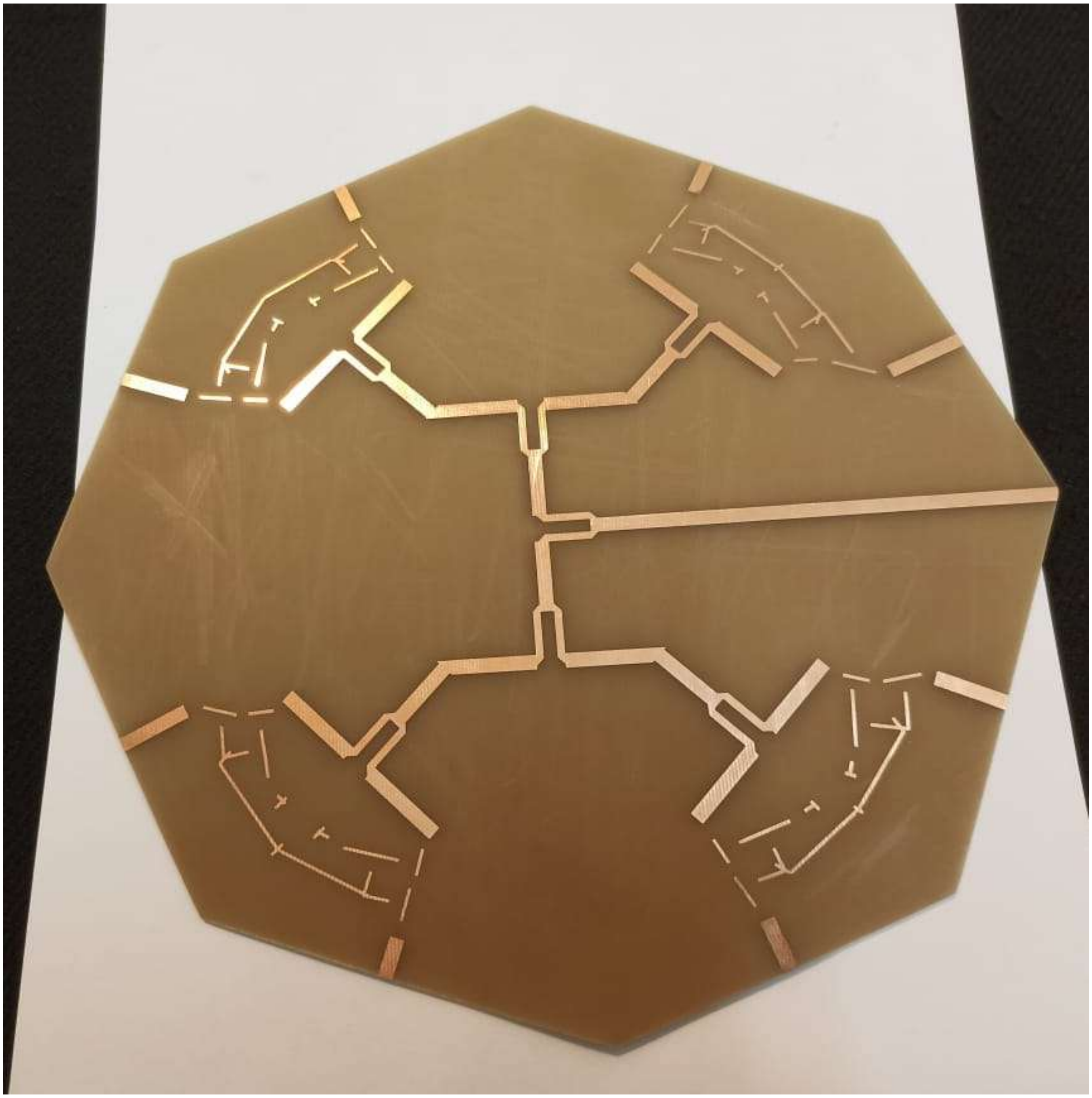


**Figure 3.22:** Fabricated 1 x 8 Wilkinson Power divider along with switching network

# CHAPTER 4: POWER AMPLIFIER

## 4.1 Introduction

To improve the radiated power level, Power Amplifiers will be employed in the last phases of radio or radar transmitting mechanism. For mobile voice or data communications systems, typical output powers are in the range of 100–500 mW, while for fixed radios or radar systems, output powers are in the limit of 1–100W. Efficiency, gain, intermodulation distortion, and thermal effects are all important factors to consider when designing Radio Frequency and microwave power amplifiers. At UHF frequencies, single transistors can supply output powers of 10–100 W, whereas devices operating at higher frequencies are typically limited to less than 10 W. If greater output powers are necessary, several power-integrating strategies can be utilised in concurrence with numerous transistors [15].

## 4.2 Definitions and General Principles

The power amplifier’s design necessitates the consideration of numerous characteristics that characterize the circuit's operation. These parameters serve as figures of merit, allowing for a comparison of the power amplifiers' performance to the state of the art. The o/p power, linearity, gain, efficiency, stability, and bandwidth are the most important parameters.

### 4.2.1 Output Power

A power amplifier's primary function is to enhance the power level of the applied i/p power without changing the substance of the supplied signal, as the name implies. At the operation frequency, the active actual power delivered into the antenna load is described as the output power of a power amplifier. The electrical energy is subsequently dissipated in the antenna as a radiated electromagnetic wave. In figure. 2.1, the o/p and i/p power lines of an amplifier are shown, here $E_S$ can be taken as an RF source producing a signal at frequency $f_0$.

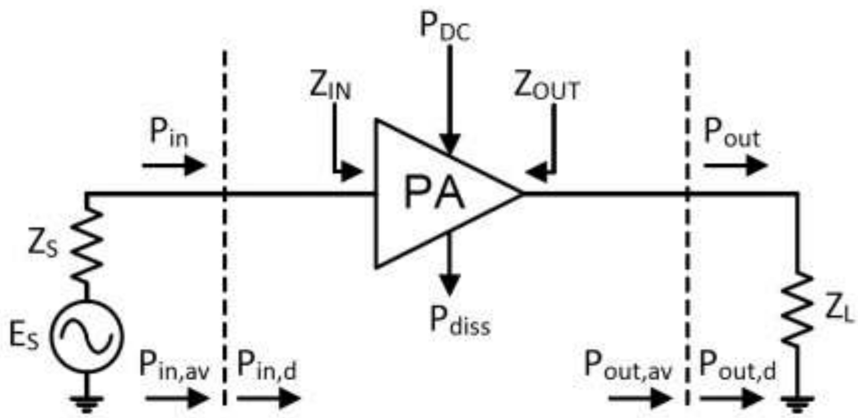



**Figure 4.1:** Characteristic parameters of a Power Amplifier

Where

| | |
|---|---|
| $P_{in}$ | I/p power of the power amplifier |
| $P_{out}$ | O/P power of the PA |
| $P_{in,av}$ | Power available from the source-supply |
| $P_{in,d}$ | Power provided to the amplifier |
| $P_{out,av}$ | Power available from the amplifier |
| $P_{out,d}$ | Power provided to the load |
| $P_{DC}$ | DC Power to amplifier |
| $P_{diss}$ | Dissipated power by the amplifier |
| $Z_{out}$ | Output impedance of the power amplifier |
| $Z_{in}$ | Input impedance of the power amplifier |
| $Z_{L}$ | Load impedance of the power amplifier |
| $Z_{S}$ | Source impedance of the generator |

### 4.2.2 Gain

The 2-port network amplifier power gain is determined as the ratio of o/p power to i/p power. While the signal flows past the power amplifier from the generator to the load, there are several reflections owing to mismatching issues. This phenomena results in distinct gain definitions and has power gain penalties:

Transducer Gain $$G_T = \frac{P_{out,d}}{P_{in,av}}$$

Available Gain $G_A = \frac{P_{out,av}}{P_{in,av}}$

Operating Gain $G_P = \frac{P_{out,d}}{P_{in,d}}$

Because of matching flaws, the available power differs from the delivered power. Assuming that the match is flawless:

$$P_{in,av} = P_{in,d}$$

$$P_{out,av} = P_{out,d}$$

Because it is simply quantifiable and takes into consideration output and input mismatches, the transducer gain is the most commonly utilized in the manufacturing of RF PA. As a result, the abbreviated word ‘gain’ refers to the deliberated meaning of the "transducer gain." The stability and matching network losses in the small signal domain are investigated using the other gain definitions.

### 4.2.3 Efficiency

The quantity of the direct current power source which is transformed into the RF signal is measured by the PA efficiency. A power amplifier's efficiency should be high as feasible in order for it to devour as little power as possible. As previously said, efficiency has an impact on key features of communication systems such as power supply weight, operating duration, and cooling system size. The two most common definitions of efficiency are as follows:

The Drain Efficiency ($\eta_d$ or DE) is the output power to the consumed power ratio:

$$\eta_d = \text{DE} = \frac{P_{out}}{P_{DC}}$$

And the PAE stands for Power Added Efficiency which is described as the ratio of the addl power supplied by the power amplifier commonly rendered as the difference between the o/p power and the i/p power) to the power consumed ($P_{DC}$):

$$\text{PAE} = \frac{P_{out} - P_{in}}{P_{DC}}$$

It may be demonstrated using the transducer gain expression that:

$$\text{PAE} = \eta_d(1 - \frac{1}{G_T})$$

When a result, as the transducer gain rises, the PAE tends to reach its maximum limit, which is the drain efficiency. Because it considers the input power, the PAE expression is far more popular than the $\eta_d$.

### 4.2.4 Linearity

The capacity of a power amplifier to increase an i/p signal having little distortion is referred to as linearity. A trade-off between efficiency and efficacy is imposed by this metric.

As shown in Fig 3.2, the initial stage in building an amplifier is by applying a sinusoidal signal to the i/p while executing a power sweep ($P_{in}$). The output power of a gain factor G is proportional to the input power in linear operation:

$$P_{out}[\text{dBm}] = G\ [\text{dB}] \times P_{in}[\text{dBm}]$$

When gain G starts to diminish, non-linear operation happens. One of the most important hallmark to characterize the linearity of a power amplifier is the compression point of 1 dB (CP1) [15]. The output power level at which a power amplifier's transfer characteristic deviates from the ideal linear transfer characteristic by 1 dB is known as the CP1. The more linear the power amplifier is, the greater the 1 dB i/p compression point (.ICP1.).

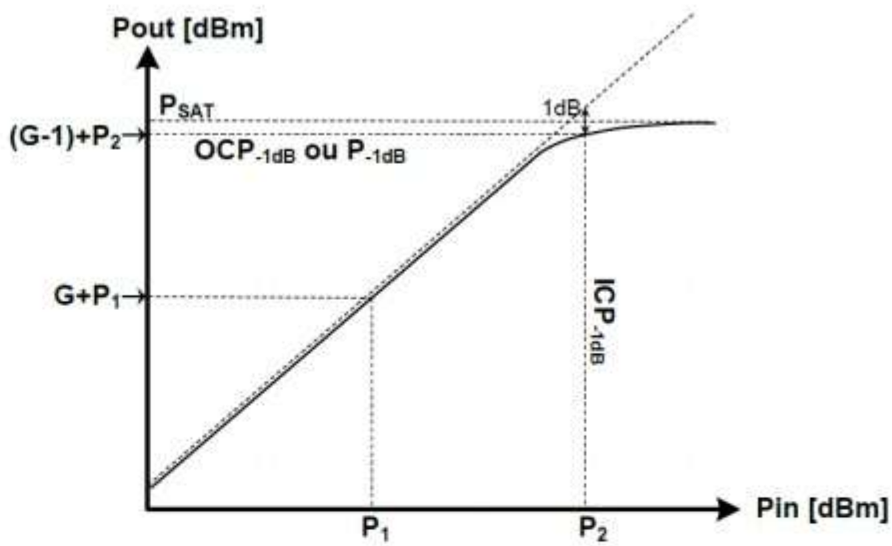



**Figure 4.2:** A sine signal's output power as a function of its input power **[16]**

In view of gain (Figure 3.3), the CP1 is the power amplifier, defined as the level of the power at which the gain reduces by 1 dB compared to the linear region gain. AM/AM gain conversion is another name for these amplitude non-linearities. A second non-linearity feature of the amp is shown by showing the phase of the o/p signal as a function of the i/p power:

Conversion of AM/PM amplitude-phase. The nonlinearities distort the signal, affecting the Adjacent Channel Leakage Ratio (ACLR) and the EVM (Error Vector Magnitude), which are important metrics in complex modulation signals.

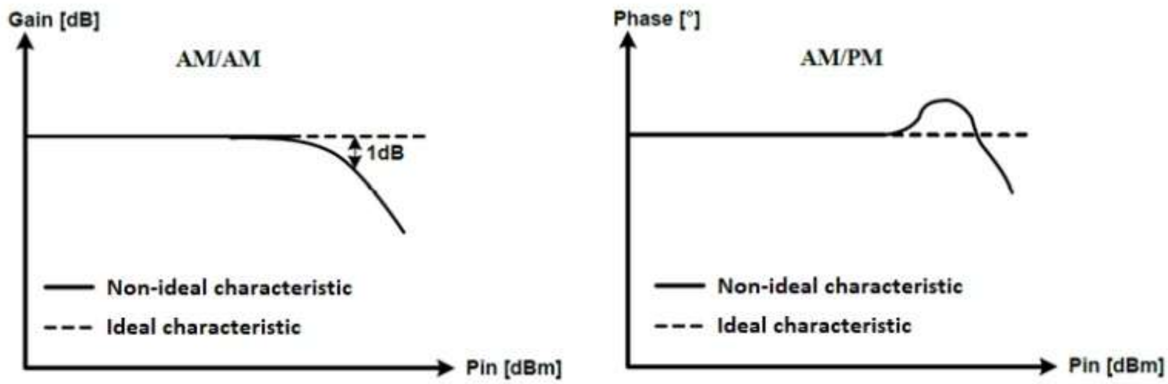



**Figure 4.3:** AM/AM and AM/PM conversions

## 4.3 Power Amplifier Architectures

### 4.3.1 Power Amplifier Structures

There have been several power amplifier architectures published in the literature. Single-ended, differential, and balanced are the three types that can be found.

**Single-ended structure:** The majority of power amplifiers are built as a series of single-ended stages. This decision is based on two factors: the antenna is usually single-ended, and such RF circuits are considerably simpler to assess than different circuits. The performance and stability of this construction, on the other hand, are dependent on the ground return path, which should be perfected.

**Differential structure:** Baluns (BALanced to UNbalanced) are used to divide and combine two channels that are 180 degrees out of phase. Such baluns to be applied as integrated transformers at millimetre frequencies, operating as a conversion mode and impedance matching circuit. The advantage of this structure is that it is less sensitive to the ground return path.

**Balanced structure:** The i/p signal is supplied via a quadrature coupler, evenly distributed, infused into the inputs of two parallel amplifiers in this configuration. A quadrature coupler then combines the amplified signals at each amplifier's output. All the three structures are shown in fig 3.4 below

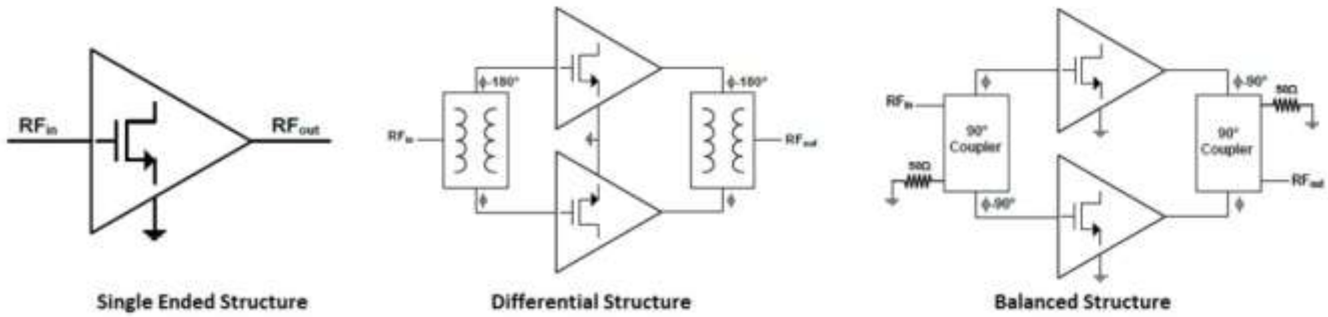



**Figure 4.4:** Power amplifier structures.

### 4.3.2 Power Amplifier Topologies

The common source and cascade topologies are the two most prevalent power amplifier topologies.

**Common source Topology:** This architecture contains fewer components and takes up less space. The power gain, stability, and output impedance of a common source transistor are all low. The $C_{GD}$ capacitance works as a feedback loop, bringing about gain and isolation to deteriorate. Capacitance $C_{DS}$ grows as the transistor size decreases, lowering the output impedance. In order to reduce parasitic capacitances, special attention must be made to the routing. This structure, on the other hand, provides for excellent efficiency and linearity.

**Cascode Topology:** Higher supply voltage levels $V_{DD}$ can be achieved by stacking transistors, allowing for higher output power levels. The cascode structure outperforms the common source structure in terms of gain and stability. Furthermore, the cascode structure provides improved isolation. On the other hand, parasitics, particularly those connected to the link between the two transistors, are significantly more sensitive in this circuit.

Common source and Cascode Topologies are shown in fig 3.5 below

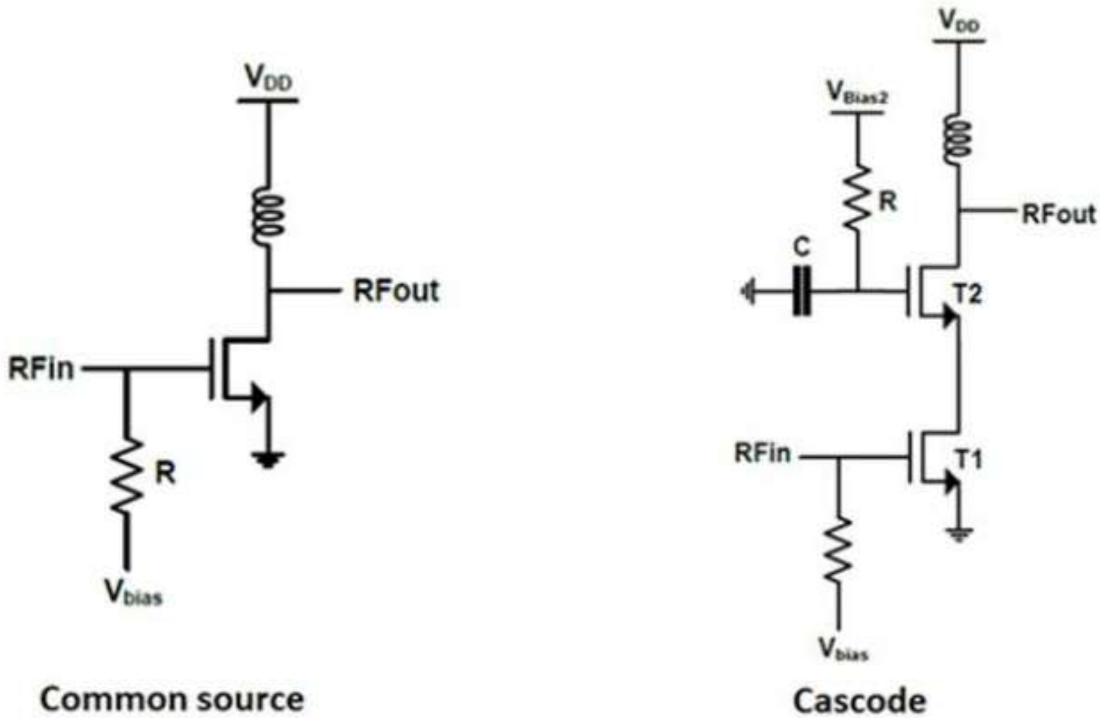



**Figure 4.5:** Power amplifier topologies

## 4.4 Characteristics of Power Amplifiers and Amplifier Classes

The correlation between the i/p signal and the o/p signal determines the operating classes of power amplifiers. The biasing given to the transistor, as well as the matching circuits processing the signals' harmonics, distinguishes these operating classes. Because the power amplifier consumes the majority of the Direct current power in every hand-held wireless device, efficiency is crucial. One indication of efficiency of an amplifier is the ratio of output RF power and power input (DC):

$$\eta = \frac{P_{out}}{P_{in}}$$

Sometimes the above equation is mentioned as drain efficiency. A disadvantage of this approach is that it ignores the RF power delivered at the amplifier's input. Due to the modest gains of most power amplifiers, the efficiency tends to overestimate the real efficiency. The power added efficiency, which is output to input power ratio, is a measure of how efficient a system is. This is a computation that comprises the effect of i/p power. It is given as

$$\eta_{PAE} = \text{PAE} = \frac{P_{out} - P_{in}}{P_{DC}} = (1. - \frac{1}{G})\frac{P_{out}}{P_{DC}} = (1. - \frac{1}{G})\,\eta$$

Where gain of amplifier is given by G. In range of 800–900 MHz (cellular range), silicon bipolar junction transistor amplifiers which improve the power efficiencies up to 80 percent, but it diminishes rapidly with rise in frequency. PA are frequently constructed for optimum efficiency, even if this results in a gain that is less than the maximum attainable.

The compressed gain $G_1$ is another significant parameter for power amplifiers. It refers to the amplifier's gain at the compression point of 1dB. Thus, if $G_0$ is rendered as the small-signal (linear) power gain, we have

$$G_1(.\text{dB}) = G_0(\text{dB}). -. 1.$$

Nonlinearities can create intermodulation distortion and erroneous frequencies. In wireless transmitters, it can cause a major problem, especially in multicarrier systems, where spurious signals might arise in neighboring channels. Non-constant envelope modulations, like amplitude shift keying and higher order quadrature amplitude modulation schemes, require linearity as well.

Inherently linear circuits, Class A amplifiers have a transistor that is biased in such a manner that it covers the whole input signal cycle range. Theoretical highest Class A amplifiers' efficiency is approximately fifty percent as a result of this. Class A circuits are used in most low-signal and low-noise amplifiers. In a class B amplifier, on the other hand, the transistor is biased to control for only half of the input signal cycle. In a class B push-pull amplifier, amplification over complete cycle is usually attained by two complementary transistors [15].

Theoretical efficiency of class B amplifier is 78 percent. A resonant circuit in the output stage of Class-C amplifiers to recover the fundamental when the transistor is approaching cutoff for more than half of the i/p signal cycle. Class C amplifiers have near-100 percent efficiency, but they can only be utilised with constant envelope modulation. In Class D, E, F, and S, a transistor is used as switch to pump a highly resonant tank circuit which can attain extremely high efficiency. Because of the requirement for products with low distortion, Class A, AB or B PA is used for UHF or above frequency transmitters.

### 4.4.1 Design of Class A Amplifiers

The utilization of large-signal characteristics in the manufacturing of class-A amplifiers will be discussed in this section. Because class-A amp are essentially linear, so sometimes there is a possiblility to build them with modest signal scattering parameters, but larger signal parameters usually yield superior results. The first stage, like with design of small-signal amplifier, is to ensure that the device is stable. Small-signal scattering parameters can be utilised since instabilities arise at low signal levels. Highly intensed power oscillations can quickly destroy active devices and accompanying circuitry, therefore stability is crucial for PA.

The transistor should be chosen based on range of the frequency and power o/p, with a capacity of power of at least 20% greater than that required by the design. At frequencies up to a few GHz, silicon bipolar transistors provide better power outputs than GaAs FETs and are generally less expensive; GaN HBTs are becoming increasingly popular for high-power applications at RF and low microwave frequencies. Any amplifier with a power output more than a few tenths of a watt requires a reliable thermal contact between the packaging of transistor and the heat sink. O/p matching networks are built for attaining max output power, whereas input matching networks are designed for maximum power transfer (conjugate matching). The best source and load reflection coefficients are not the same as those found using small-signal scattering parameters. Low-loss matching elements are critical for high efficiency, especially at the o/p stage, where electric currents are greatest. Chip transistors which are internally matched are occasionally available and have the benefit of decreasing parasitic package reactance, enhancing bandwidth and efficiency. Figure 3.6 shows an image of a GaN power amplifier chip.

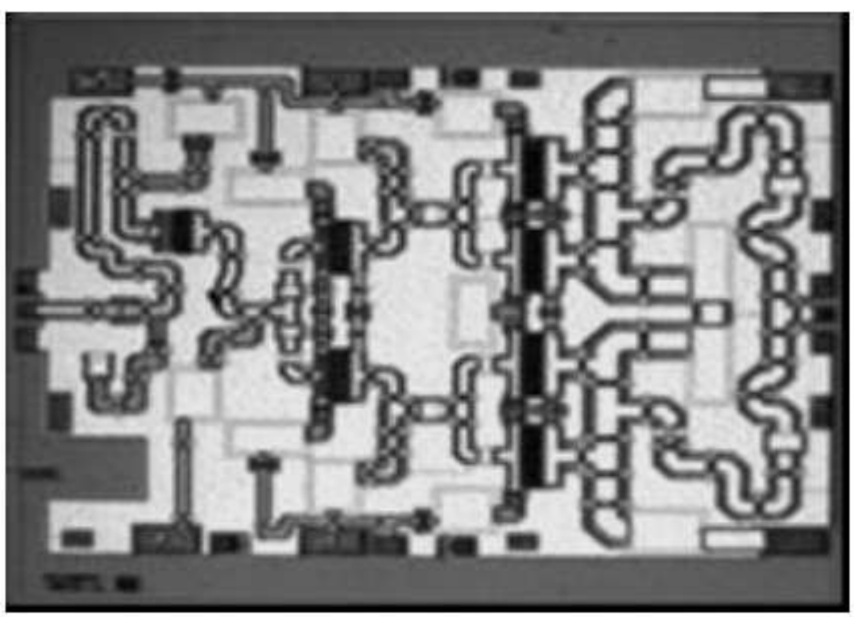


**Figure 4.6:** A three-stage Ku-band GaN MMIC amplifier is seen in this photo

## 4.5 Power Amplifiers in Transmitters

In a transmitter, the Power Amplifier is the important component. In reality, a transmitter's main purpose is to send out a signal with sufficient power, a narrow frequency range, and a clean enough spectrum to avoid interfering with other radio systems. The power amplifier is usually the transmitter's final stage before the antenna. As a result, the power amplifier's performance is critical for the transmitter. Gain, power o/p, .bandwidth, Power efficiency, linearity, i/p and o/p impedance matching, and heat dissipation are all common design requirements for power amplifiers, as detailed in section 3.1.

Furthermore, the most power consuming component in a transceiver is rendered as power amplifier. A 4G smartphone has the breakdown of power consumption at the max transmission power of 23 dBm which is shown in Fig. 3.7, where the power amplifier consumes 44 percent more than the other components. This consumption of power issue is a serious concern in communication systems since it has an impact on essential variables such as cost of battery, power supplies weight, prices of electrical power, phone operational timings, and space taken by cooling system, all these factors have a substantial environmental impact.

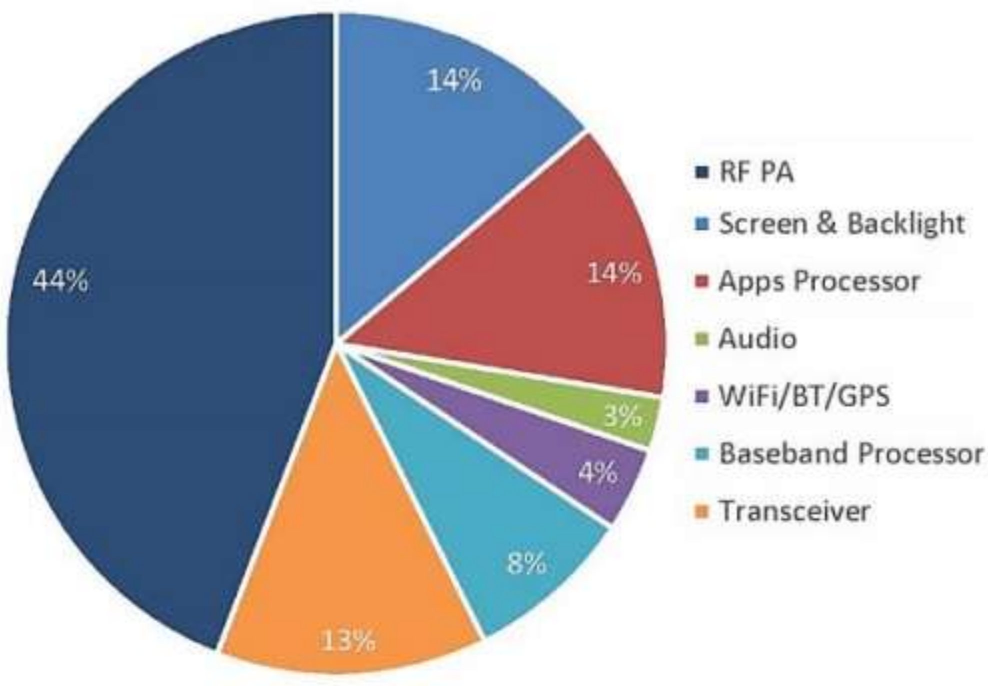



**Figure 4.7:** Power consumption breakdown of a 4G smartphone

## 4.6 Designed Power Amplifier

The proposed antenna is to be used as a base station antenna. Therefore, there is a requirement of a power amplifier which increase the output power to a desired level. In order to fulfill this requirement a power amplifier has been designed in Keysight Advanced Design System which uses Avago's AT-41435 Low Noise Silicon Bipolar Transistor. It is a NPN bipolar transistor, and its greatest advantage is its excellent performance at higher frequencies. Matching of the transistor at 3.5 GHz was done by tuning with the help of manipulation in the length of microstrip lines.

### 3.6.1 Results

The schematic and results of the power amplifier as designed in Keysight Advanced Design System are given below.

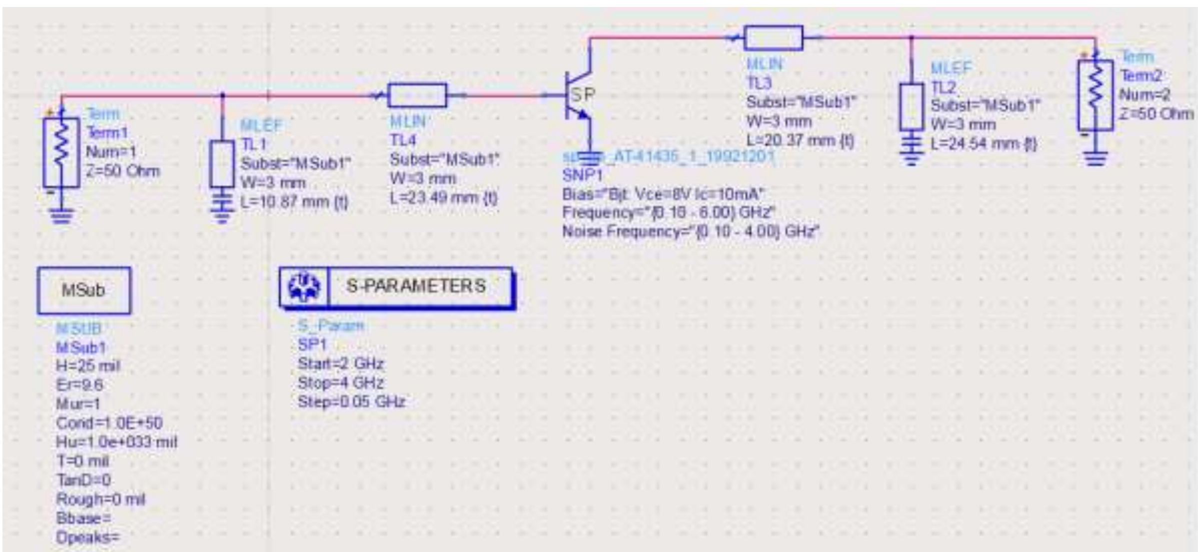



**Figure 4.8:** Schematic of Power Amplifier in Keysight Advanced Design System

After the design of power amplifier simulation were run in order to measure the gain, return loss and noise figure. Results of the simulations are given below.

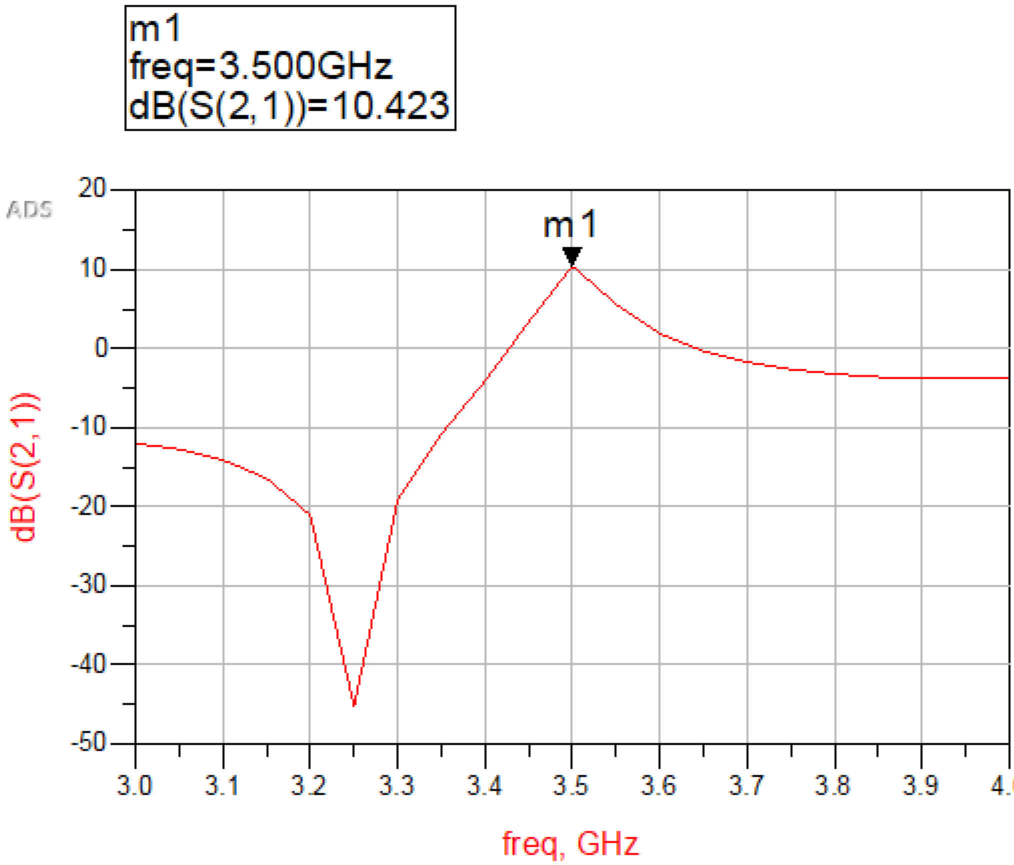



**Figure 4.9:** Gain plot of power amplifier

From the above figure it can be seen that the power amplifier circuit is giving a gain of more 10 dB at 3.5 GHz which is according to the rated gain capacity of the At-41435 Silicon Bipolar Transistor.

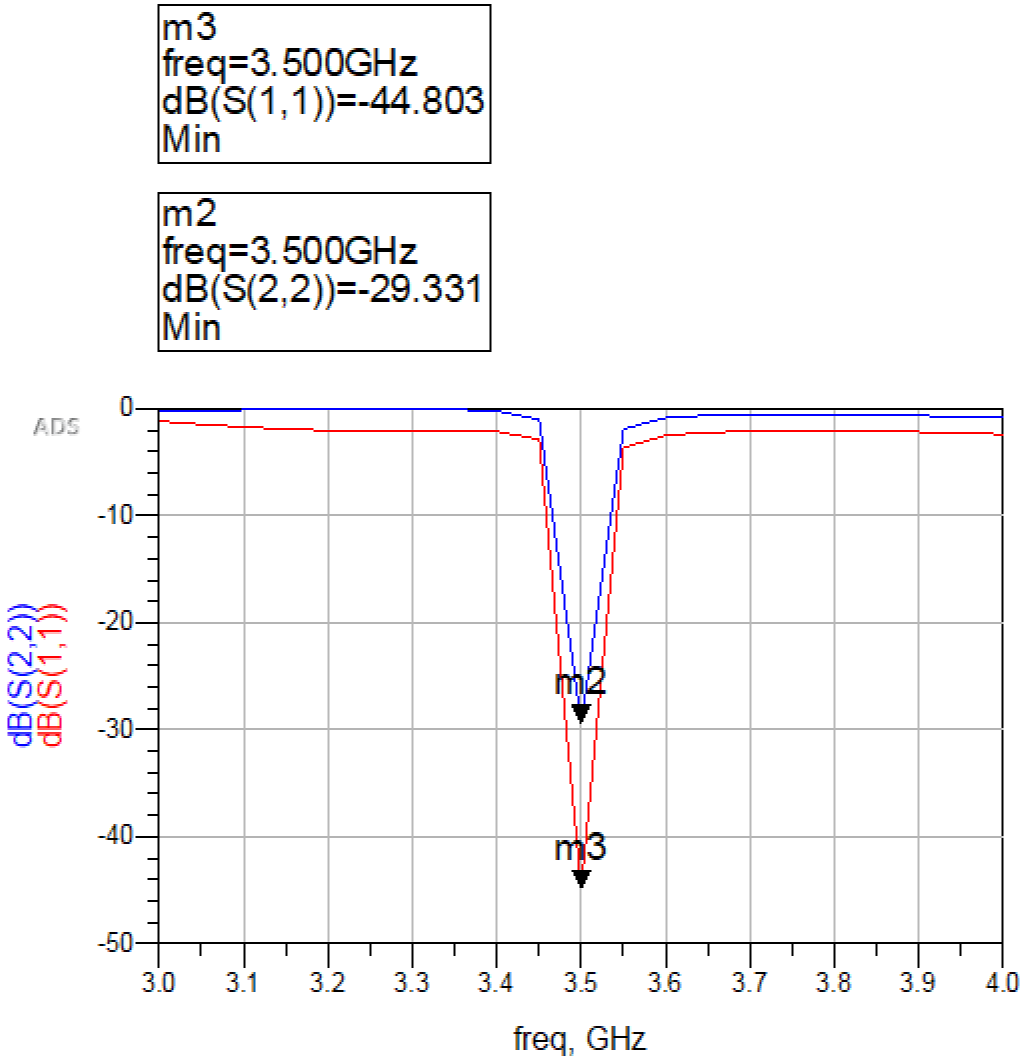



**Figure 4.10:** Return loss plot of power amplifier

From the above figure it can be seen that the return loss at both the ports is well below -20 dB which shows that both the ports are matched.

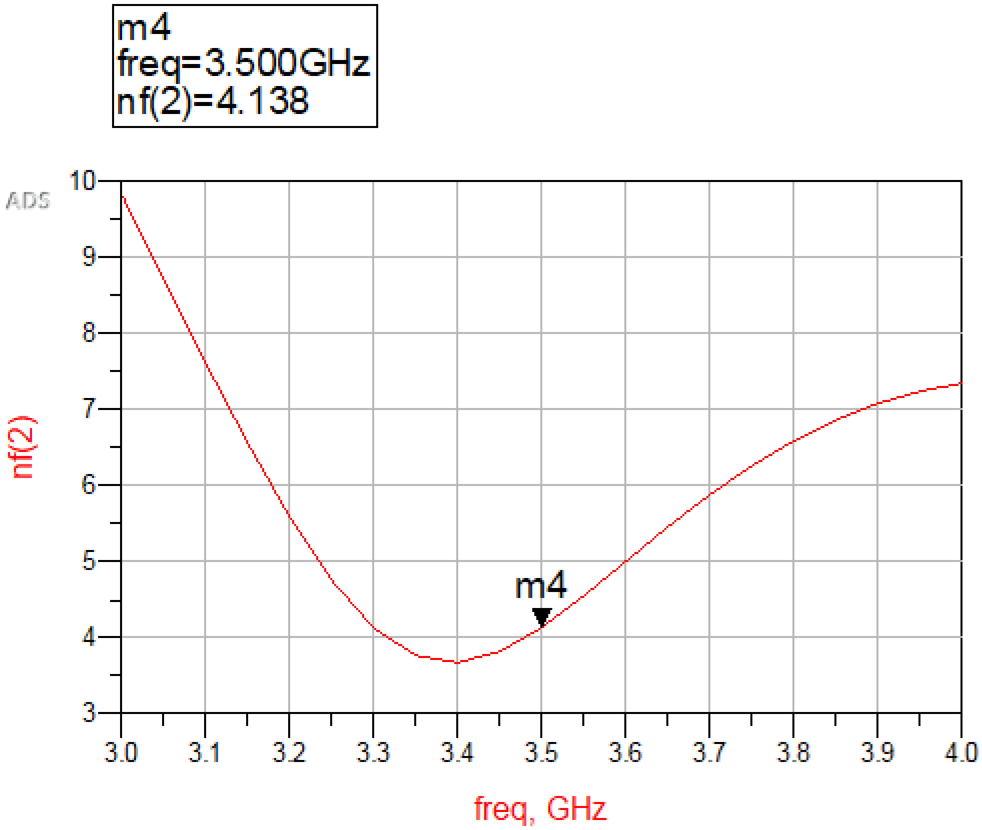



**Figure 4.11:** Noise figure plot of power amplifier

From the above figure it can be seen that the power amplifier has a noise figure of 4.138 at 3.5 GHz which is well within the optimum range. From the hardware part of this project power amplifier was used was commercial off the shelf. Amplifier TQP3M9009 LNA module was ordered via Ali Express. The rated gain capacity of this amplifier at 3.5 GHz is 18.9 dB with a noise figure of 2.1 dB. The operational frequency range of this amplifier is 50 MHz – 4000 MHz. Pic of LNA module used is given below.


**Figure 4.12:** TQP3M9009 LNA module used

# CHAPTER 5: SWITCHING NETWORK

## 5.1 Introduction

An extensive diode that has an undoped intrinsic semi-conducting area between the type-n and p is called a pin diode such that the regions of type- n and type- p, that can frequently be used for ohmic contacts, are highly doped. The extensive intrinsic area that makes the pin diode suitable for fast switches, high-emf power electronics applications, photosensor, and debilitation actually results in it being a mediocre rectifier. It is also in contrast to an ordinary p-n diode [17].

## 5.2 Why To Use PIN Diode As Switches?

Due to the speed, size, and cost concerns, it is moderately difficult for mechanical devices to change or switch RF power in movable applications. However, relative to non-mechanical devices, pin diodes provide us with some distinctive outro. It is important that their characteristics are clearly understood or else they may be a little troublesome to style within a circuit.

The following data will display some realistic examples of pin diode to indicate the technological advancements as well as different ways to frame with pin diode. It will further describe the challenges of R.F switching and the fundamentals of operating pin diode like pin configuration or work principle.

### 5.2.1 The RF Switching Challenge

RF signal paths must be modified in a variety of applications to route and connect with various antennas, amplifiers, and filters. Along the introduction of MIMO, multiband wireless devices (SG), and other advanced technologies, the demand for more change with higher performance is only increasing, mainly for mobile and motorized devices [18].

Since these alterations should operate in the Gc area or better, they are very complex from their design, underlying technology, board layout, to matching their power to applying primacies. All of the above-mentioned machineries provide us with adjustments in basic presentation parameters like bandwidth, insertion loss, isolation, etc. (Table 5-1)

**Table 5-1:** Parameters of Solid State and Electromechanical Switches

| | Solid state switches | | | Electromechanical switches |
|---|---|---|---|---|
| | **Pin diode** | **FET** | **Hybrid** | |
| **Frequency range** | from MHz | from DC | from kHz | from DC |
| **Intersection loss** | Medium (Roll off at low frequencies) | High (Roll off at high frequencies) | High (Roll off at high frequencies) | Low |
| **Isolation** | Good at high frequencies | Good at low frequencies | Good at high frequencies | Good across broad frequency range |
| **Repeatability** | Excellent | Excellent | Excellent | Good |
| **Switching speed** | Fast | Average | Average | Slow |
| **Power handling** | Low | Low | Low | High |
| **Operating life** | High | High | High | Medium |
| **Power consumption** | High | Low | Moderate | Current interrupt feature reduces current consumption |
| **Sensitive to** | RF power overstress, temperature | RF power overstress, temperature | RF power overstress, temperature | Vibration |
| **Agilent switch examples** | P9400/2/4 85331/2 | U9397, U9400 | | L series, 8710x/20x |

As shown in Table 4-2, for the three categories of solid-state switches, demonstrative maximum and minimum levels, cover a good set of overlapping ranges. The growing interest in utilizing electronic transistor buttons due to their IC flair and simplicity, along with the massive claim for RF alterations in smartphones, routers, and other various solicitations. Resultantly, retailers square measure cathartic several new electronic transistor electronics that have improved stipulations, causing the relative shift in the characteristics and statistics in the tables.

**Table 5-2:** Comparison of PIN diode, FET and Hybrid Switches

| | PIN diode switches | FET switches | Hybrid switches |
|---|---|---|---|
| **Lower frequency limit*** | 100 MHz | DC | 300 kHz |
| **Upper frequency limit*** | >50 GHz | >20 GHz | >20 GHz |
| **typically built upon the provisions of the performance* | | | |

## 5.3 Basics of PIN Diode

At radio and microwave frequencies, a PIN diode operates as current-controlled electrical device. It, like the standard PIN diode, permits electricity to flow in a single route when forward biased but not in the opposite direction when reverse biased. This, practically, could be a plain yet significant slab of various circuits ranging from DC TO RF.

The PIN diode has an "intrinsic" sheet squeezed in between its P and N sheets, unlike the PN diode. Despite the fact that the method physics are complicated, the end product is a manageable switch action with a twist. When the pin diode is forward biased, RF energy can flow through it, but when it is reverse biased, the RF energy is blocked. This is frequently the basis for employing the pin diode in a variety of RF switch technologies [18].

The electrical model of the PIN diode sounds similar to a serial electrical device associated with a forward biased electrical device. Once reverse biased, it is as if you're connecting a serial electrical device to a parallel electrical condenser and electrical device (figure 4.1). The PIN diode model determines the precise value of the reflexive components in these replicas.

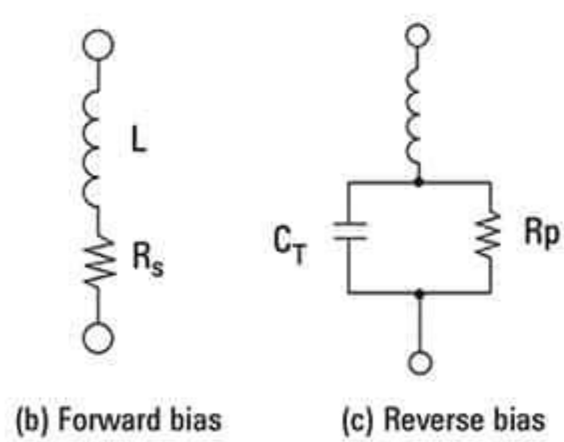



**Figure 5.1:** The PIN diode's forward and reverse models

In PIN diode models Rs, when forward biased, is the diode's (low) resistance, L is the parasitic inductance (largely a function of the package), CT is the package's diode junction capacitance plus parasitic capacitance, and RP, when reverse biased., is the diode's (high) resistance. PIN diodes have excellent dimensionality and are good to use for extremely high incidence and high-power submissions. Their disadvantage is the large amount of DC power they have for biasing (the advanced the DC command used, the lower the attachment loss). Furthermore, their separate presentation conditions square measure challenging to see, and they necessitate meticulously intended maintenance electronic equipment.

## 5.4 Reason for PIN Diodes Challenging Nature

It appears to be a modest construction, which asks the plain question: why is the PIN diode so challenging to use? The logic is straightforward. PIN diode is a dual-terminal expedient, and the management dock required for biasing and thus the dock for the RF motion square measure corporeal purpose are inextricably linked. Hence, the design should permit them to "merge" at the diode while remaining separated from the rest of the electronic equipment. Consequently, engineers have combined feelings about utilizing PIN diodes because they aren't the best control alternative to use, but they are able to do stuff that various other alternatives can't.

A diode by itself is not a whole and useful button because it is only the central switch component. At the very least, an RF switch supported PIN diode requires a DC block condenser to avoid the DC bias current from getting the RF production, as well as an RF clog to produce a lane for the DC bias current to come so that the RF indicator is not blocked.

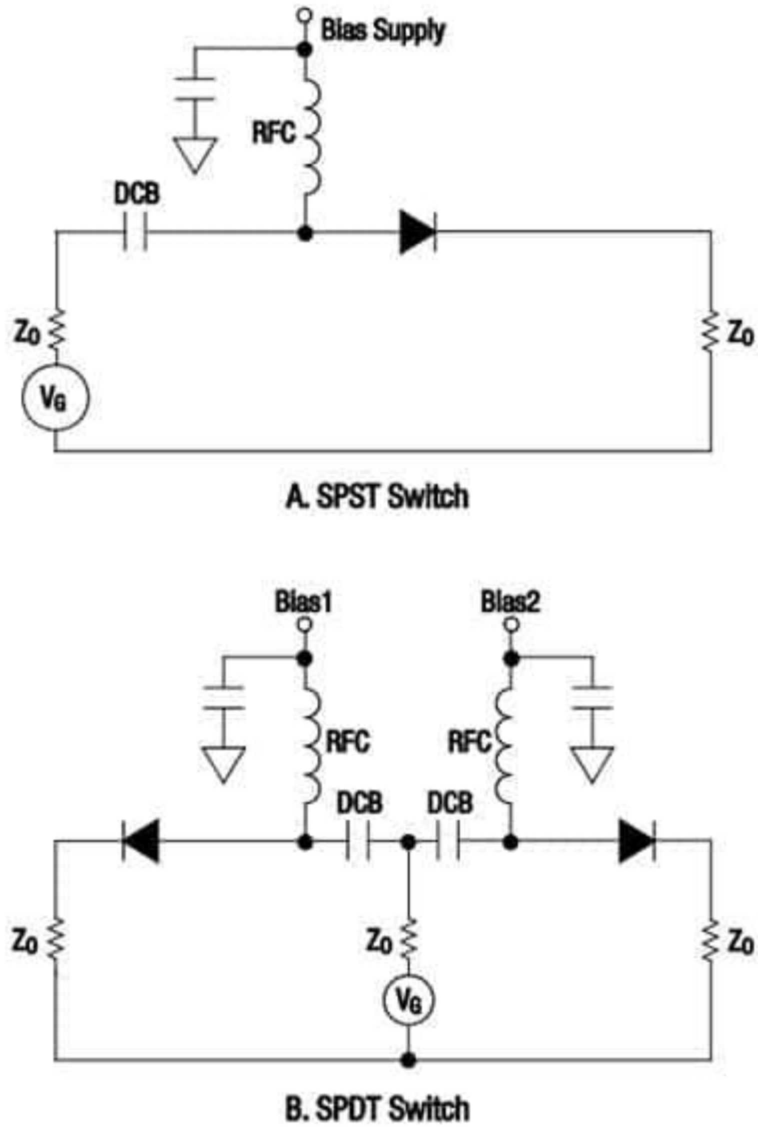



**Figure 5.2:** Series PIN diodes for a plain SPST control and an SPDT control, where VG is the RF originator power

The basic SPST and SPDT functions can be replaced by shunt-diode switches (Figure 5). Great isolation is provided by the shunt method, it can handle excessive RF control than a diode in a sequence topology because the diode is also heat inked at one conductor. Some strategies swell a one-fourth-wave electrode between the diode and its interloping electrical condense to generate lumped-series inductance for a low-pass strainer. This allows the button to calculate the required incidence.

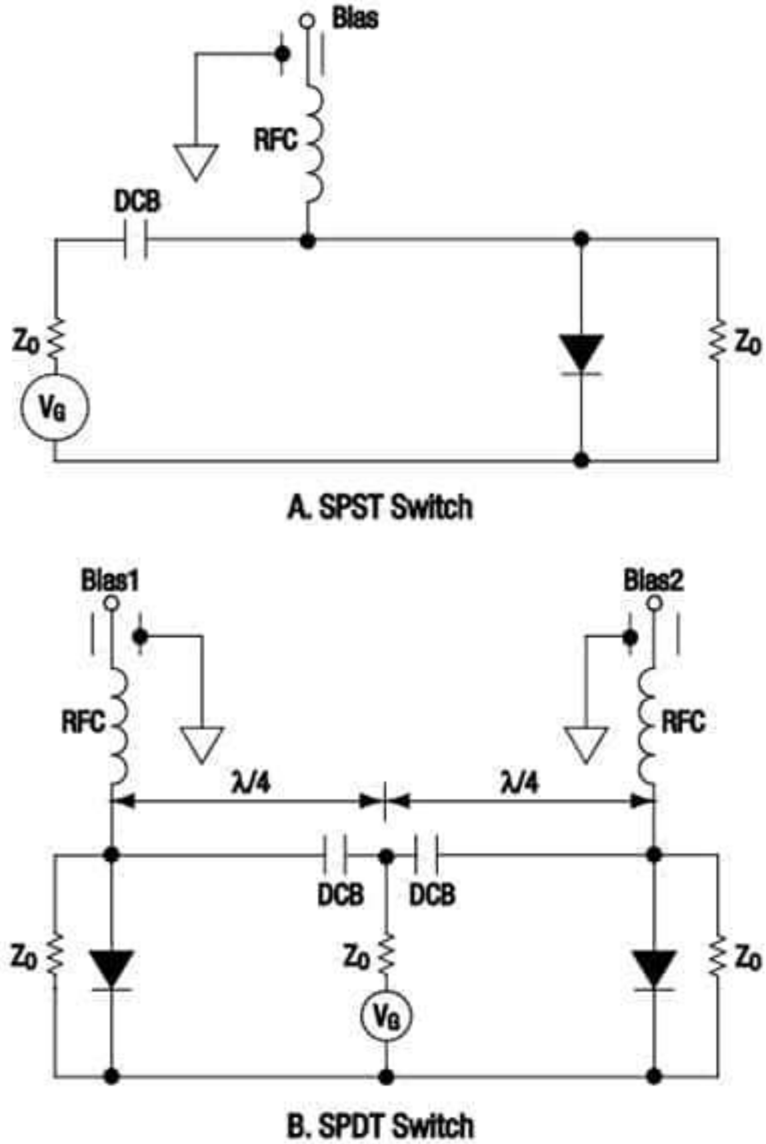



**Figure 5.3:** Shunt mode PIN diodes for two switches, the plain SPST and an SPDT control

A noteworthy feature is the insertion of one-fourth-wavelength diffusion lines to arrange a low-pass filter. It is difficult to achieve higher than forty decibel isolation using a single PIN diode in either a shunt or series topology, mainly at the advanced functioning incidences. These constraints can be eliminated in part by utilizing compound switches, which are made up of a combination of series and shunt diodes. PIN diodes are available in extension (series-shunt) or TEE (shunt-series) topologies (Figure 4.6). In a very complex button, the loss attachment state occurs when the sequence diode is onward bias and the shunt diode is at either zero or at reverse bias. The situation is exactly the opposite in the remote area. It should be noted that the bias electronic equipment required by a composite button is far more advanced as compared to the former which is required by simple series or shunt switches [18].

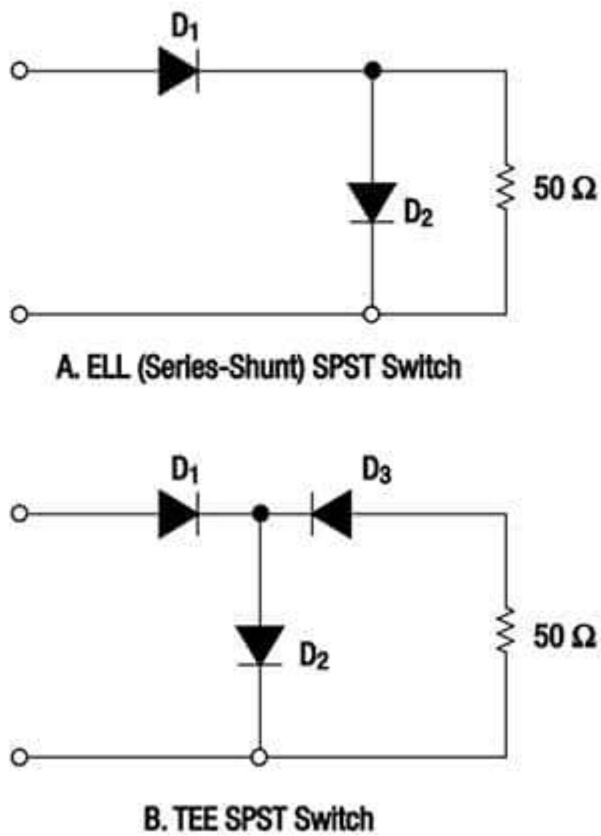



**Figure 5.4:** ELL and TEE alignments SPST Switch

An additional, further sophisticated method of improving remote presentation employs a resounding arrangement to form a nicely modified switch. In this case, the two chains two shunt diodes are set apart a wavelength, yielding a three-dB increase in isolation over a sole diode button.

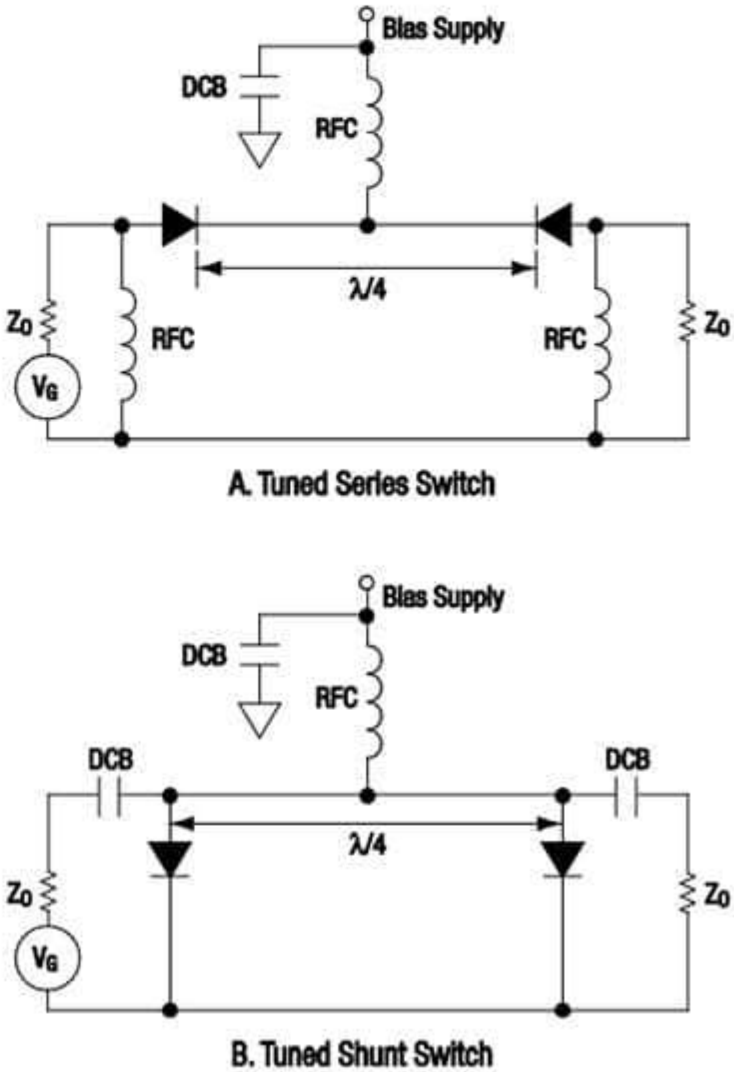



**Figure 5.5:** Tuned Series Switch and Tuned Shunt Switch

## 5.5 PIN Diode Biasing

The bias voltage of DC which is required to manage the mode of PIN diode could be a diode function as well as the RF amplitude, temperature variation, and other aspects. As any racket or ripple can interfere with the diode's operation, hence, we must decouple this bias voltage from the RF signal and stable.

A PIN diode requires a high bias-control emf, when used in compelling applications, in order to reduce the cross-regulating outcomes of the RF signal's electromotive force swing. A one hundred W RF motion, for example, has a maximum voltage of two hundred V in an average 50/50 structure. The management’s potential force ought to be far superior than it is and should prepare for extra main room to prevent the RF signal's emf from touching the diode's confrontation and causing alteration.

## 5.6 Demonstrating the Switch

Several market models and equations characterize the stagnant and vigorous presentation of PIN diodes. These models apprehend the characteristics along with the changes found in them as a result of high temperature, power, incidence, and added aspects. This knowledge, and thus the related replicas, enables a truly reasonable first-pass imitation to be performed. Deviations in features such as inaccessibility, linearity, alteration, inclusion loss, and command intake versus incidence and voltage are frequently resolute with rational precision.

These given models, however, only depict a portion of the division. Like all RF styles, Interconnection, PC board effects, etc. will distort the replica. In order to ensure a more precise read of the performance of the PIN diode switch, designers should consider integrating these into their replication model.

## 5.7 Wide diversity of PIN diode to Counterpart Design Priorities

PIN diodes area unit provided by several contractors of RF parts. For example, M/A-COM's MA4AGBLP912 is associate degree AlGaAs PIN diode with simply four four “on” resistance, low capacitance, and a particularly quick five nsec switch speed (Figure 8). It is exhausted to forty gig cycle per second during a shunt formation, along with an associate degree operational preference of +10 mA for the minimum-loss condition, and zero V for the sequestration state, employing an easy +5 V TTL gate driver [18].

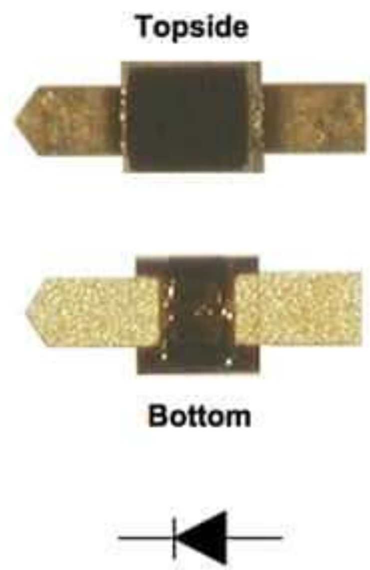



**Figure 5.6:** The MA4AGBLP912 PIN diode from M/A-COM

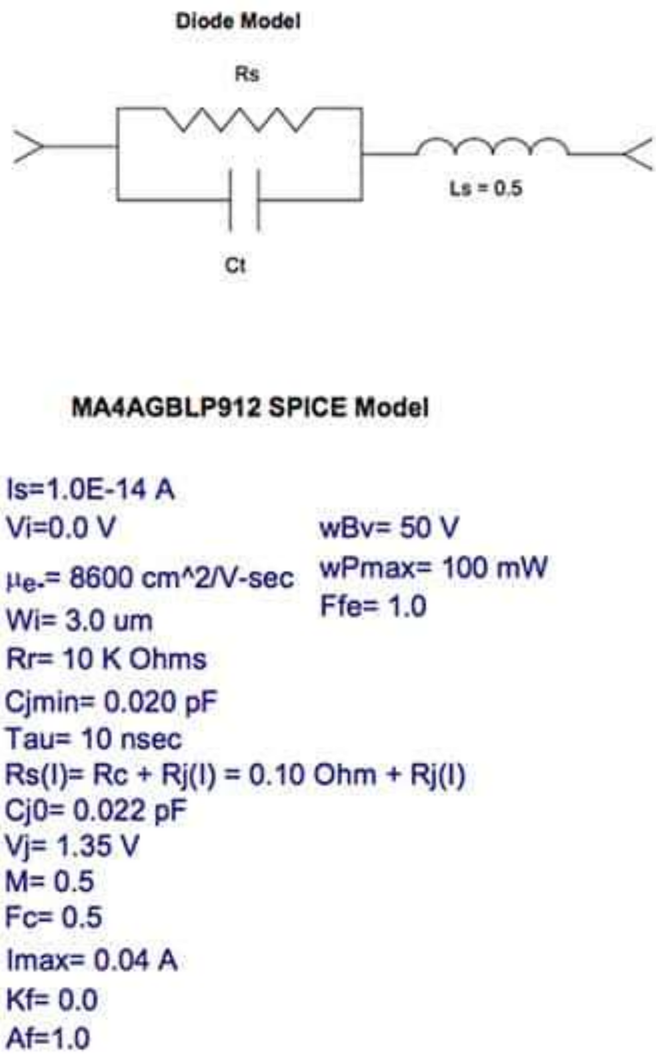



**Figure 5.7:** Spice replica of the MA4AGBLP912 PIN diode

Skyworks Solutions' SMP1345 series of plastic preplaced, surface-mount PIN diodes is intended for high-volume, low-noise-block (LNB), wireless native space network (WLAN), and switch applications ranging from ten MHz to six gigahertz. Extremely low capacitance and resistance can be found in the devices in the family [19]. The main presentation constraints of enclosure loss and remoteness loss show that the previous one differs by approximately 0.2 decibel, whereas the final one differs by approximately 35 decibels from zero to six gigahertz.

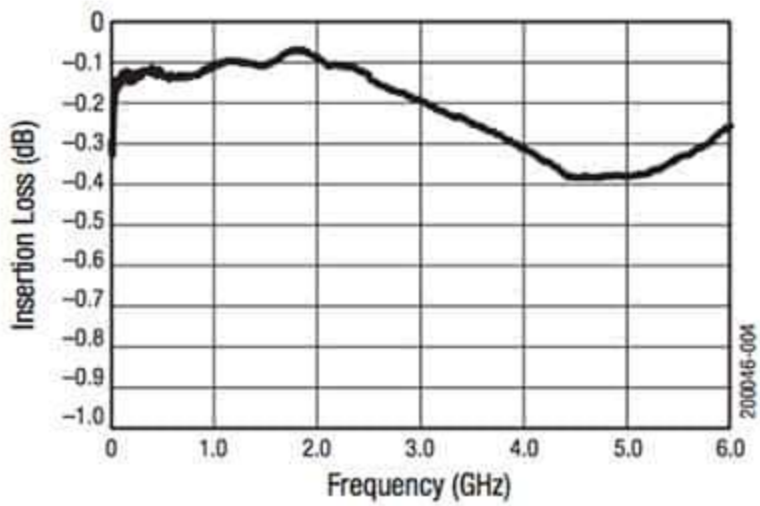



**Figure 5.8:** The insertion loss plot of Skyworks Solutions' SMP1345 PIN diode

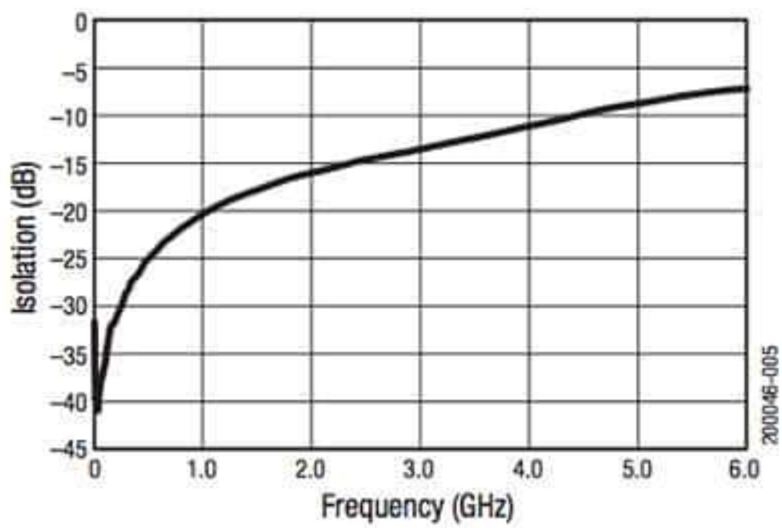



**Figure 5.9:** The SMP1345's isolation performance

The Broadcom ASML-5829 is used to protect the receiver from large input signals while allowing the receiver to operate normally in the absence of a large signal. It is intended for low-voltage circuit applications. This device chains a PIN diode with a Schottky diode to create a low-power circuit . A PIN diode is placed at the input (Figure 12) to protect the Schottky diode from high RF power levels. In a consequence to which, the Schottky-inflated circuit can have a lower restrictive edge than many typical self-biased PIN-only circuits Like many other RF element information sheets (Figure 13) it includes S parameters for a variety of comprehensive RF characterization and analysis.

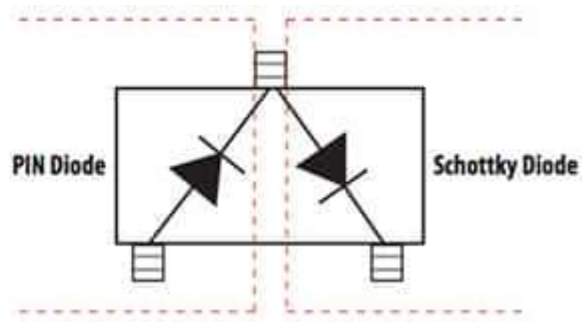



**Figure 5.10:** PIN diode and a Schottky diode

A pin diode has a low capacitance under zero or reverse bias indicating that it is in the off state. Because of the low capacitance, most of an RF signal will not pass through. A pin diode is a good RF conductor because typically it will have an RF resistance of about 1 ohm under a forward bias of 1 mA (the "on" state). As a result, the PIN diode is an excellent RF switch.
RF switches can be a little slow (10 sec of a millisecond) which makes them a little less reliable while a PIN diode can switch much better i.e. 1 millisecond.

PIN diodes are used in large quantities despite not being as widely used as standard PN junction diodes. However, they are ideal for switching and variable attenuator applications because of their switching and variable resistance properties.

## 5.8 Main Advantages of PIN Diode

The PIN diode is used in a variety of applications due to its structure exhibiting some useful properties.

**RF switch**: The PIN diode is an excellent RF switch. The intrinsic layer increases the distance between the P and N regions. When the diode is reverse biased, the capacitance between them decreases, implying an increase in isolation.

**High voltage rectifier**: PIN diode application is a High Power Rectifier that allows higher reverse voltages to be endured. Its intrinsic area provides more separation between the N and PN area.

**Photo detector**: When light is converted into current within a photodiode's depletion region, it tends to improve the performance by increasing the volume in which light conversion may occur and adds the intrinsic layer which ultimately increases the depletion area [2].

## 5.9 Switching Network Used

In the project switching network has been designed in order to achieve beam switching and beam steering capability. When the switching network will be in ON state the corresponding patch antenna will work and vice versa in OFF state. For the purpose of the simulation switching network has been implemented in Advanced Design System software with the help of lumped components and SMP 1345-079LF diode. This diode belongs to the SMP 1345 series and it has very low capacitance. These diodes are plastic packaged silicon PiN diodes. The SMP1345 series of plastic packaged, surface mountable PIN diodes is designed for high volume Low-Noise Block (LNB), Wireless Local Area Network (WLAN), and switch applications from 10 MHz to 6 GHz. These diodes have very low insertion loss of 0.4 dB with a capacitance of 0.15 pF. The RF performance of the SMP1345 series is assured by virtue of their very low capacitance (0.15 pF) and low resistance (1.5 Ω at 10 mA) [19]. In addition to SMP 1345-079 LF diode lumped components have been used. SMD capacitors, inductors and resistors have been used. Capacitors used are of 10 pF and inductor of 50 nH.

### 5.9.1 Results

Schematic and results of the switching network as designed in Advanced Design System Software are given below.

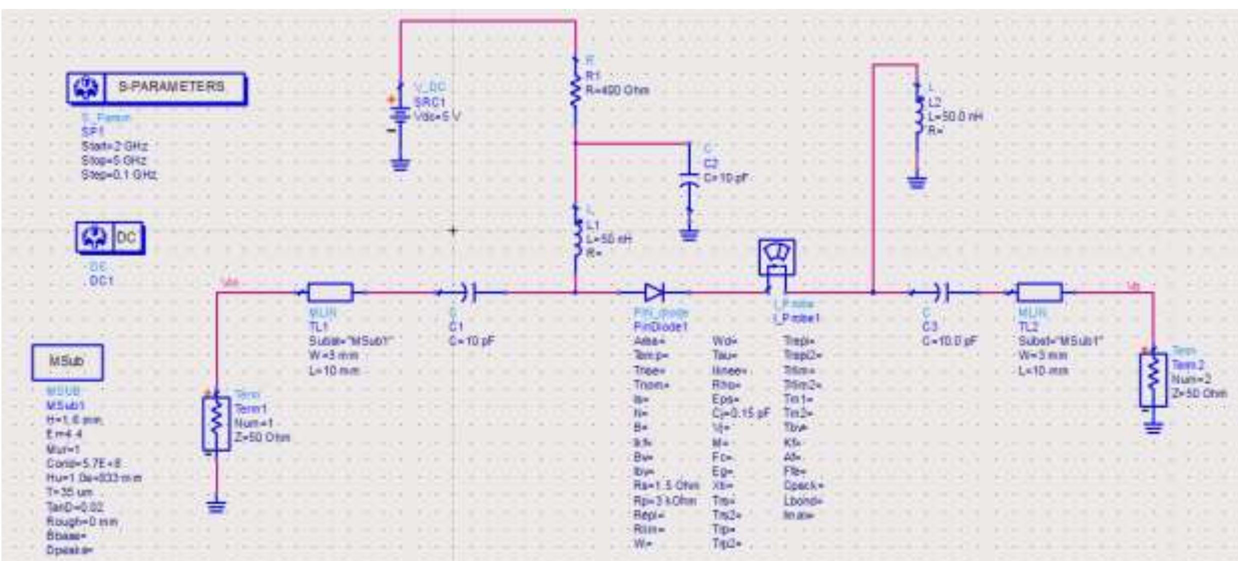



**Figure 5.11:** Schematic of switching network when Vdc is 0V

The results achieved for the simulation of switching network in ON state are given below.

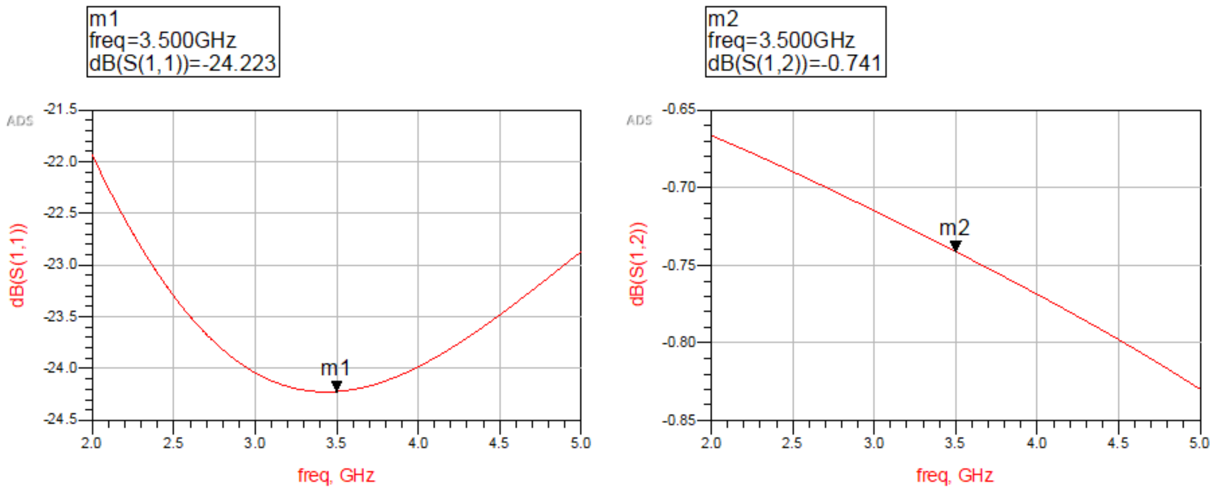



**Figure 5.12:** S1,1 and S1,2 results of Switching network in ON state

From the above results it can be seen that in ON state the insertion loss is -0.74 dB at 3.5 GHz. Return loss is -24.2 dB at 3.5 GHz which shows that the both ports are matched.

| freq | I_Probe1.i |
|---|---|
| 0.0000 Hz | 10.17 mA |

**Figure 5.13:** Current bias in ON state

In the figure given above it can be seen that in the ON state the diode is biased at 10.17 mA.

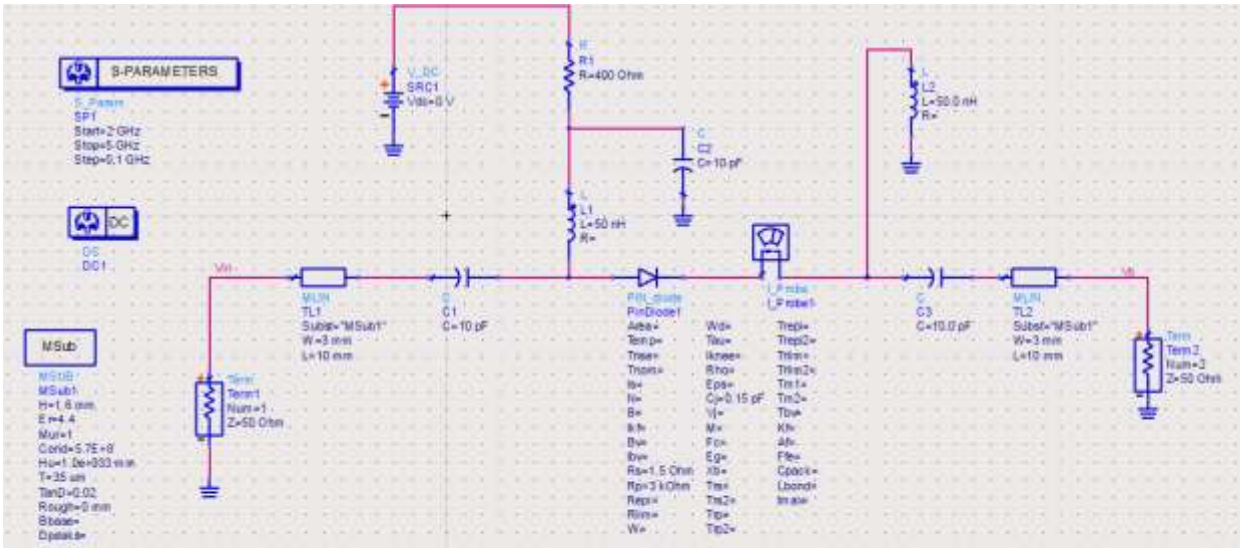



**Figure 5.14:** Schematic of switching network when Vdc is 0V

The results achieved for the simulation of switching network in OFF state are given below.

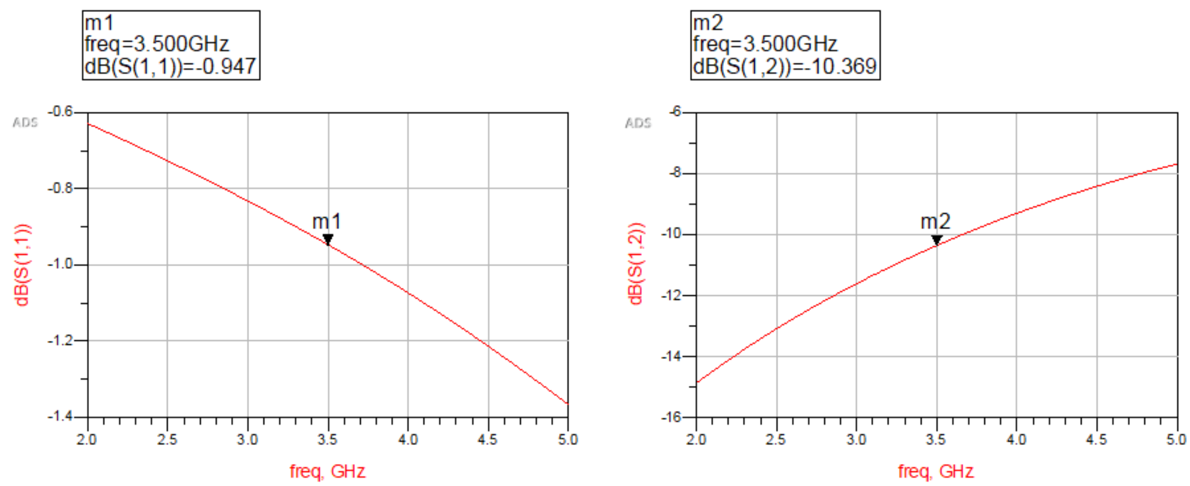



**Figure 5.15:** S(1,1) and S(1,2) results of Switching network in OFF state

From the above results it can be seen that in OFF state the isolation is -10.36 dB at 3.5 GHz. Ports are mismatched because return loss is -0.947 dB at 3.5 GHz.

| freq | I_Probe1.i |
|---|---|
| 0.0000 Hz | 0.0000 A |

**Figure 5.16:** Current bias in OFF state

In order to measure the transient response AC source was added in place of terminal 1. The schematic after the insertion of AC source is as given below.

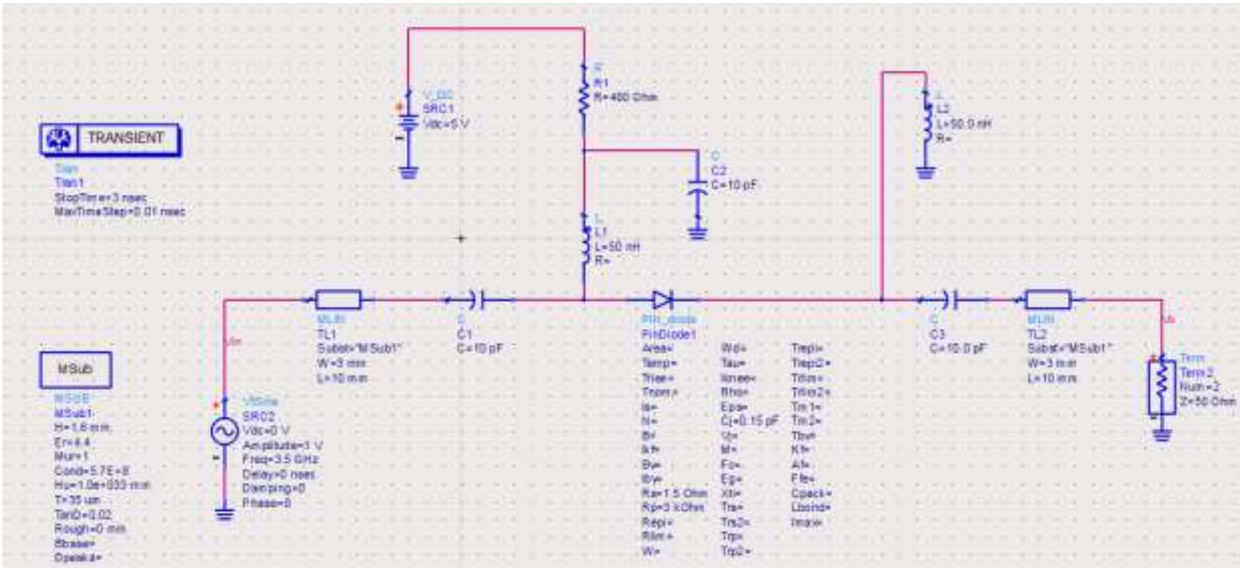


**Figure 5.17:** Schematic of switching network with AC source

When the simulation for this configuration was run following results were achieved.

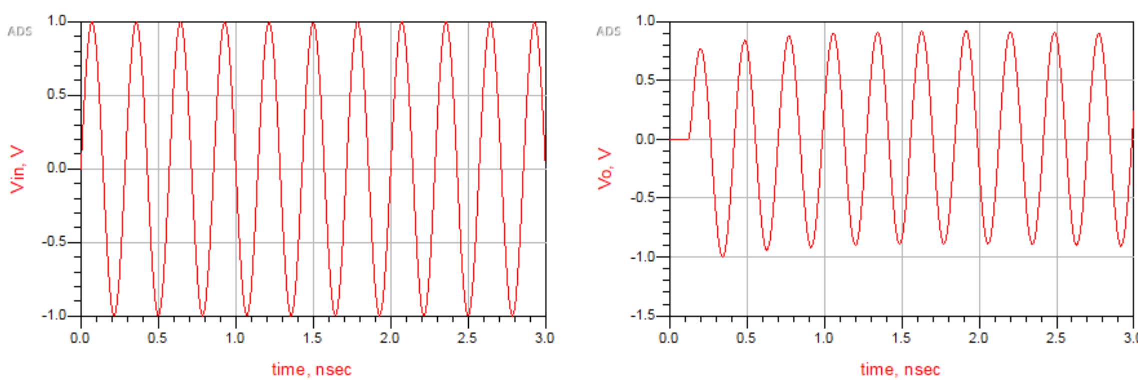


**Figure 5.18:** Transient response of Switching network in ON state

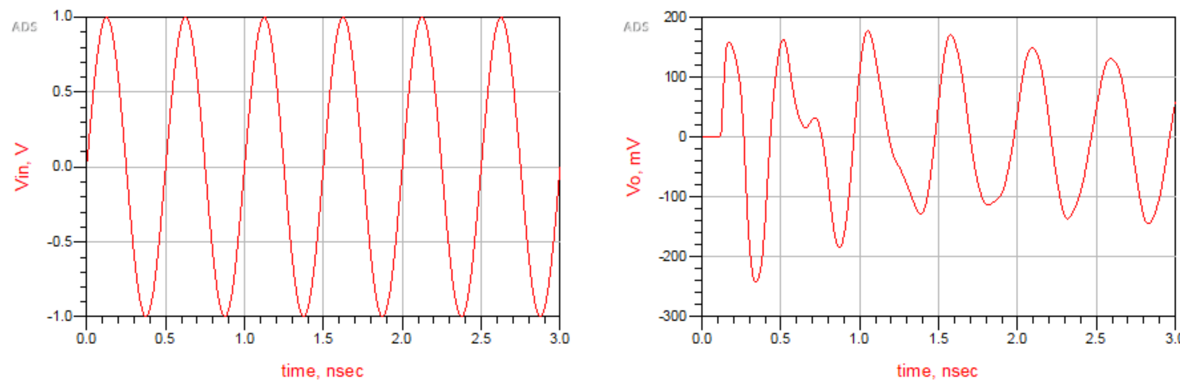



**Figure 5.19:** Transient response of Switching network in OFF state

The fabrication of switching network has been done along with the 1 x 8 Wilkinson power divider. At each output of power divider switching network has been placed. This switching network is being operated with the help of DC source. The physically fabricated switching network is given below.

**Figure 5.20:** PiN Diode Switching Network assembly with SMD components soldered and wires for VCC and Gnd input added

# CHAPTER 6: FINAL DESIGN

As a final part of this project all four modules were interconnected to get the final design. The final design has power amplifier which takes input from a RF source, amplifies it and gives the output. Output from the power amplifier is fed to the input of 1 x 8 Wilkinson Power Divider. On all 8 outputs of the power divider PiN diode switching assembly is added which is being operated manually with the help of a microswitch. This microswitch does the job of biasing the diode with 5V DC by closing the switch. After the switching assembly antenna patches are connected with the help of male-to-male SMA connector. Final project design is given below.

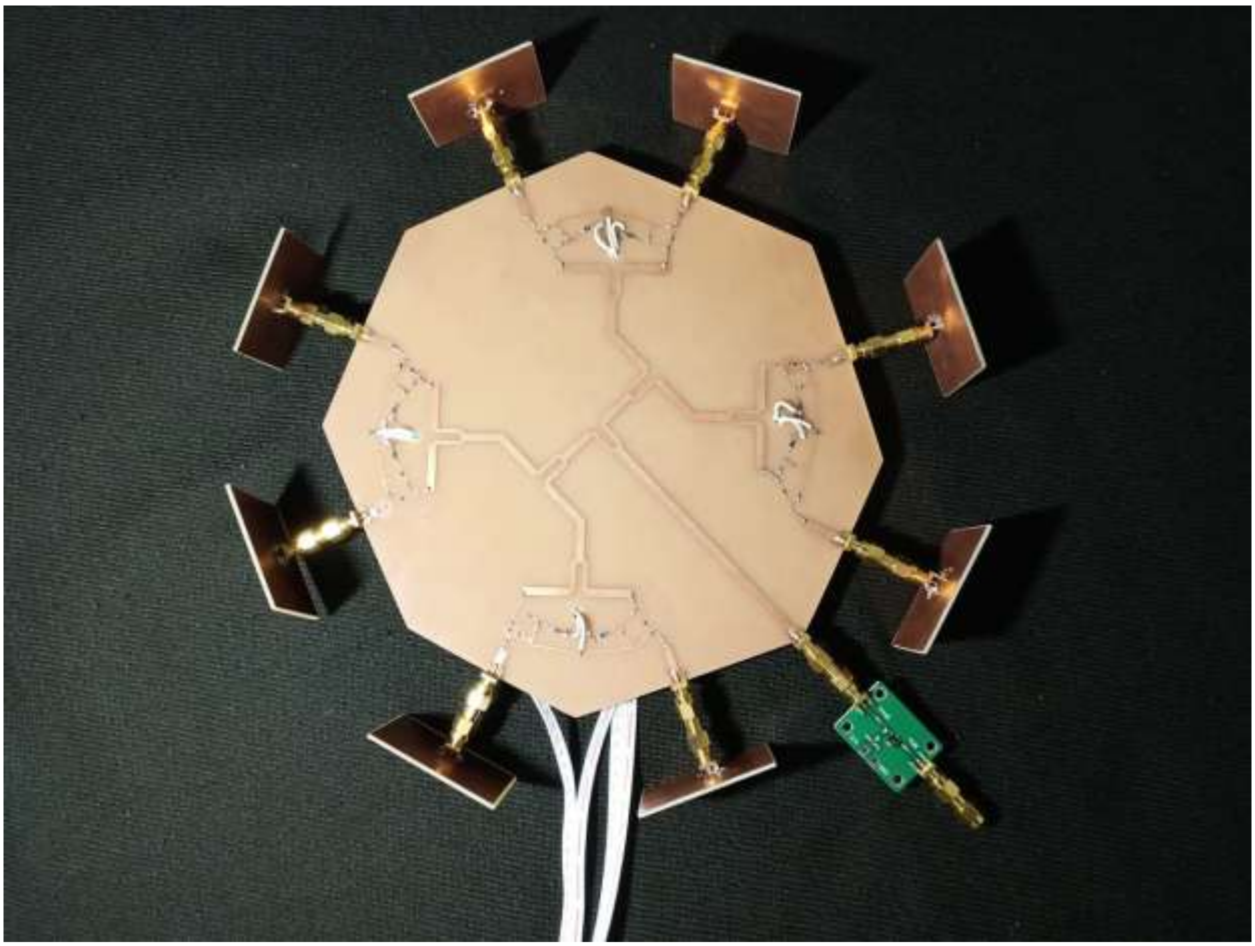


**Figure 6.1:** Integration of all four modules of project

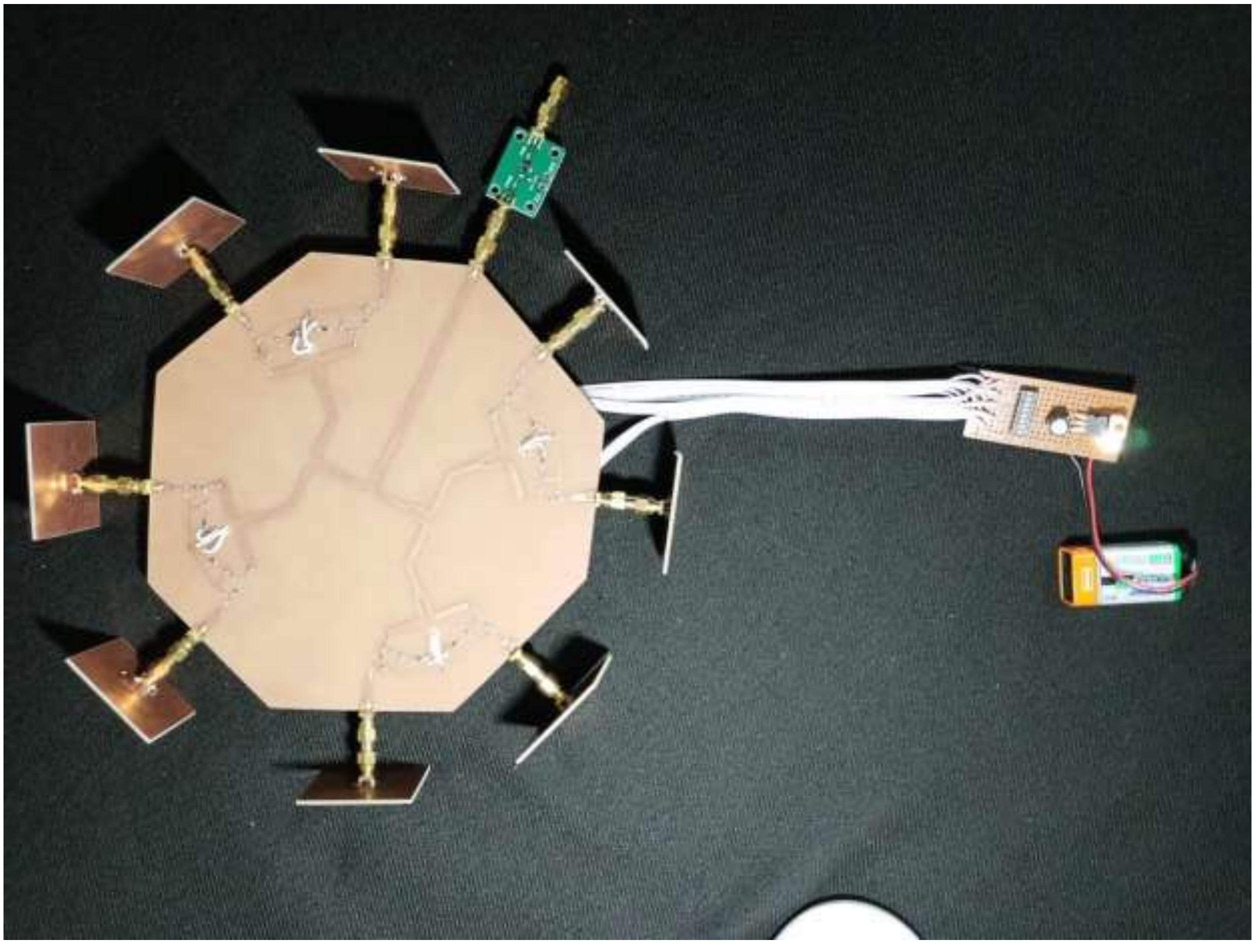


**Figure 6.2:** Complete view of the project assembly along with microswitch

# CHAPTER 7: CONCLUSION AND FUTURE WORK

A base station antenna for 5G networks at 3.5 GHz capable of both omni-directional and beam-steering radiation is presented. The presented antenna is a conformal antenna which has been mounted over a 1x8 Wilkinson power divider along with PIN diode switching network. In order to use it as a base station antenna and to increase the power output, a power amplifier has also been added. The switching network has the capability of switching the radiated beam among each patch as per the requirement. Switching network has been made with SMP-1345-079 LF PIN diode and lumped components. Directional pattern as well as omni-directional pattern can be easily achieved with the proposed antenna. The final antenna structure which constitutes of power amplifier, Wilkinson power divider and switching network can be used as a base-station antenna in the 3.5 GHz range.

In continuation to the research work done for this project. In our earnest endeavor we shall be working on and studying lower and higher frequencies of this band, analyzing their band notches, gains, radiation patterns and isolations etc to improve this project further. Manual switching of beams done in this project can be replaced with electronic beam-switching via Arduino or some other microcontroller.

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