DESIGN OF MICROSTRIP ANTENNA ARRAY FOR BEAMFORMING APPLICATIONS

The dissertation-II report submitted in partial fulfillment of the requirements for the award of the degree of

Master of Technology in Electronics and Communication

By

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Under The Guidance Of

MR. R Madhusudhan Goud

LOVELY PROFESSIONAL UNIVERSITY

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DISSERTATION TOPIC APPROVAL PERFORMA

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1. Design of Microstrip Antennas array for beam forming applications (SMART Antennas)
2. Design of Microstrip rectangular Patch Antenna
3. Ultra Wide Band applications of Microstrip patch antenna.

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PAC Remarks:

Approved

APPROVAL OF PAC CHAIRPERSON: Signature: Date: 30/10/14

*Supervisor should finally encircle one topic out of three proposed topics and put up for approval before Project Approval Committee (PAC)

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*One copy to be submitted to Supervisor.

ABSTRACT

This report presents the design of phased array system using planar technology for beamforming applications. The prototype comprises of V-antenna, integrated with butler-matrix. The novelty in this approach is the design of V-antenna using planar technology which results in high directivity and multiband operation. The designed array structure is having maximum directivities by the individual antennas in the direction -44°, 136°, -136° and 44° which are approximately equal to theoretical values. The operating frequency of design is 2.4GHz. And the complete phased array structure is working at multiple frequencies, that is, at 2.4GHz as well as at 4.5GHz. As the size of the V antennas is smaller than the conventional microstrip antennas, the complete phased array system is compact in size. This is an added advantage along with multi band operation that can be used in devices of smaller size. The proposed design is well suited in satellite communications. The simulations were carried out in Advanced Design System Tool.

ACKNOWLEDGEMENT

The present work is an effort to do the study on “**DESIIGN OF MICROSTRIP ANTENNA ARRAY FOR BEAMFORMING APPLICATIONS”**. The work would not have been possible to come to the present shape without the able guidance and supervision of my mentor Mr. R Madhusudhan Goud.

I wish to convey my thanks to my family members for their morale during the course of study.

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Above all, I express my profound gratitude to the almighty for all his grace and light which gave me strength as well as inspired me throughout this work.

DECLARATION

I hereby declare that the Report of the Project Work entitled "**DESIIGN OF MICROSTRIP ANTENNA ARRAY FOR BEAMFORMING APPLICATIONS"** which is being submitted to the **LOVELY PROFESSIONAL UNIVERSITY, Phagwara**, in partial fulfillment of the requirements for the award of the Degree of **Master of Technology in COMMUNICATION ENGINEERING,** in the department of Electronics and Communication Engineering, is a bonafide report of the work carried out by me. The material contained in this Report has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to certify that the Realization of Dissertation-II Project titled "**DESIIGN OF MICROSTRIP ANTENNA ARRAY FOR BEAMFORMING APPLICATIONS"** that is being submitted by "**Janendra Gupta (11004280)**" in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY DEGREE, is a record of bonafide work done under my /our guidance. The contents of this project, in full, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

(MR. R Madhusudhan Goud)

Project Supervisor

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Objective and the Realization of Dissertation-II Project is satisfactory

Examiner I   Examiner II

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The concept of antenna dates back to the James Clerk Maxwell, in 1873, when he proposed the Maxwell equations. In these Maxwell equations he unified the work and theory of electromagnetics. Professor Heinrich Rudolph Hertz, in 1886, demonstrated the first wireless system. But the main antenna technology came into existence during the World War II.

Antenna is the traditional structure between the waveguide and the free space. It follows the property of reciprocity, i.e. it can be used to transmit as well as receive the electromagnetic waves.

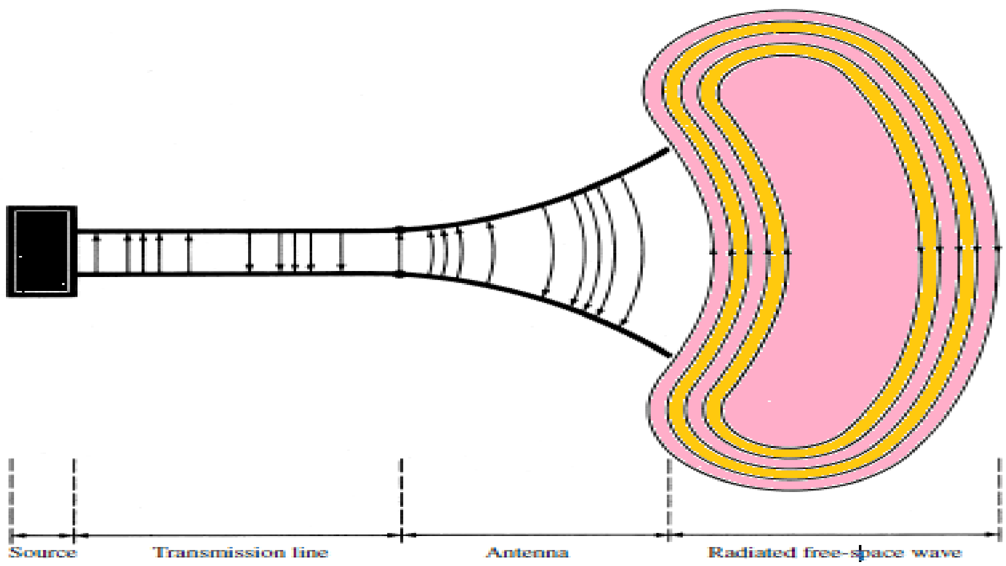


Figure1.1 Transmitting antenna

Figure 1.1 shows the transmission mechanism of the antenna. The signal is generated by the source which travels through the transmission line or the waveguide. The antenna is attached to the waveguide. The antenna converts the signal from one form to another, i.e. it converts the signal from current form to electromagnetic form which can be radiated into free space.

1.2 RADIATION MECHANISM

The conditions which led to the radiations are listed below:

i. If a charge is not moving, current is not created and there is no radiation.

ii. If charge is moving with a uniform velocity:

a) There is no radiation if the wire is straight and infinite in extent.

b) There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated.

iii. If charge is oscillating in a time-motion, it radiates even if the wire is straight.

1.2.1 Radiation Mechanism with the Help of a Dipole

We can describe how the electromagnetic waves are generated from the antenna with the help of a dipole.

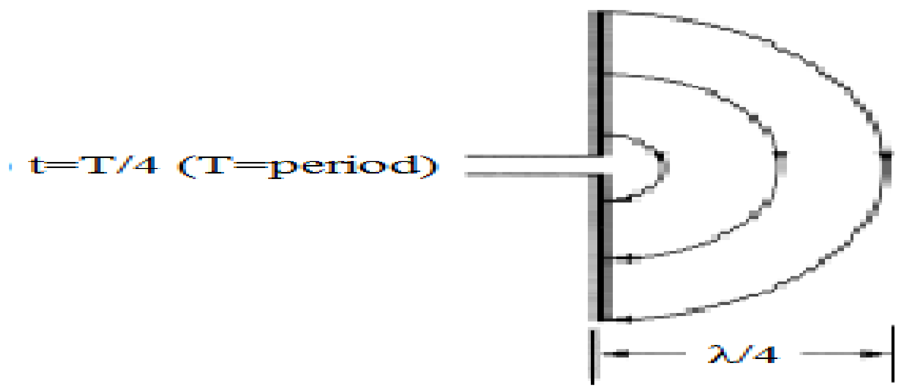


Figure1.2 Formation of electric field lines from a dipole

Figure 1.2 displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance $\lambda/4$.

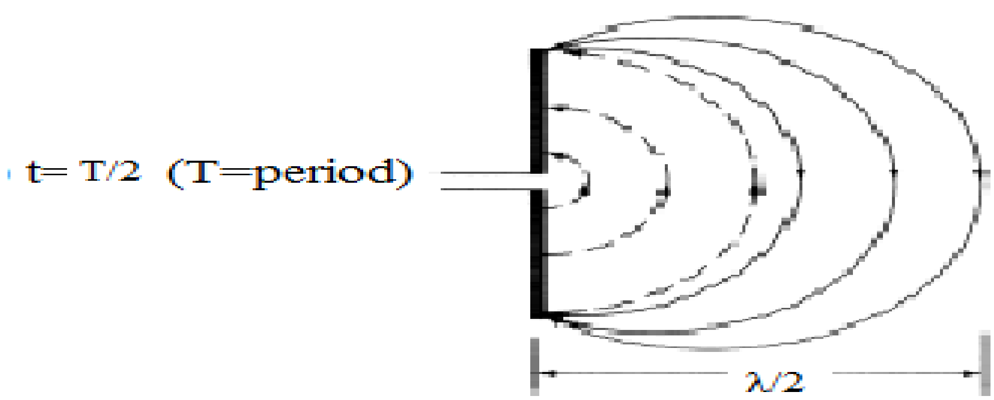


Figure1.3 Formation of electric field lines from a dipole

In Figure 1.3 the next quarter of the period, the original three lines travel an additional $\lambda/4$ (a total of $\lambda/2$ from the initial point) and the charge density on the conductors begins to diminish. This can be thought of as being accomplished by introducing opposite charges which at the end of the first half of the period have neutralized the charges on the conductors. The lines of force created by the opposite charges are three and travel a distance $\lambda/4$ during the second quarter of the first half.

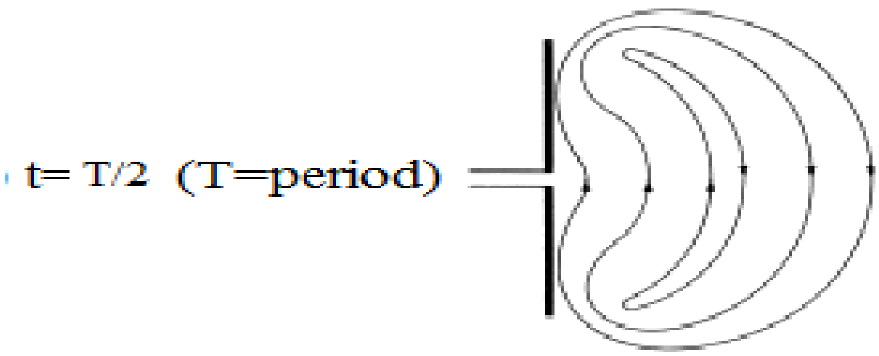


Figure1.4 Formation of electric field lines from a dipole

Figure 1.4 shows the end result that there are three lines of force pointed upward in the first $\lambda/4$ distance and the same number of lines directed downward in the second $\lambda/4$. Since there is no net charge on the antenna, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops.

CHAPTER 2 FUNDAMENTALS

2.1 BASIC PARAMETERS OF ANTENNA

In this section I will be discussing about various parameters of the antenna to pronounce the performance of antenna. There are parameters such as the radiation patterns, antenna gain, directivity, antenna efficiency, input impedance, polarization and S-parameters. These are required to characterize an antenna.

2.1.1 Antenna Gain

Antenna gain is the intensity of an antenna in a given direction to the intensity that would be produced by a isotropic antenna that radiates equally in all directions and has no losses.

Let's take in account the power density which is radiated by an isotropic antenna with input power P_0 at a distance R which is given by –

$$S = P_0 / 4\pi\eta R^2$$

An isotropic antenna radiates equally in all directions, and it's radiated power density S is found by dividing the radiated power by the area of the sphere $4\pi R^2$. An isotropic radiator is considered to be 100% efficient

2.1.2 Antenna efficiency

The surface integral of the radiation intensity over the radiation sphere divided by the input power P_0 is a measure of the relative power radiated by the antenna, or the antenna efficiency.

$$\frac{P_r}{P_0} = \int_0^{2\pi} \int_0^{\pi} \frac{G(\theta, \phi)}{4\pi} \, Sin\,\theta d\,\theta d\phi = \eta_e$$

Where,

P_r Is the radiated power

η_e Is efficiency

2.1.3 Radiation pattern

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

The various radiation patterns that antenna radiates in are as follows:

a) Isotropic Pattern: This pattern is uniformly radiated along all the directions.

b) Directional Pattern: this pattern is regarded as by more efficient radiation in one particular direction than the other.

c) Omni directional Pattern: It is a pattern that is uniform in a given plane.

d) Principal Plane Pattern: These are the E-field and H-field of the linearly polarized antenna. The horn antenna is linearly polarized in both fields i.e. E-field and H-field.

Radiation patterns are described by their radiation lobes. The various definitions of lobe are:

a) Radiation Lobe: Is a peak in the radiation intensity surrounded by the weaker intensity.

b) Main Lobe: It is a radiation lobe with the maximum radiation.

c) Side lobe: A radiation lobe in any direction except the main lobe.

d) Back Lobe: Is a Lobe opposite to the main lobe.

e) HPBW (half-power beam width): It is the angular width of the main beam at the half-power point. We achieve a half-power beam width at about 11 degrees.

2.1.4 Directivity

The measurement of the intensity of radiation in the particular direction is known as directivity.

$$Directivity = \frac{U_{max}}{U_0}$$

Where, U_{max} is maximum radiation intensity.

U_0 is average radiation intensity

Directivity and gain differ only by the efficiency, but directivity is easily predicted from radiation patterns.

The relation between directivity and gain is given by following equation:

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

$$G(\theta,\phi) = e_{cd}D(\theta,\phi)$$

Where,

e_{cd} is the radiation efficiency

G represents the gain

D is the directivity

2.1.5 INPUT IMPEDENCE

The input impedance of an antenna is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point". Therefore, the antennas' impedance can be written as given below.

$$Z_{in} = R_{in} + jX_{in}$$

Where, Z_{in} is the impedance of antenna at the terminals.

R_{in} is the antenna resistance at the terminals.

X_{in} is the antenna reactance at the terminals.

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance R_r and the loss resistance R_L . The power associated with the radiation resistance is the power actually radiated by the antenna, whereas due to dielectric or conducting losses, the power dissipated in the loss resistance is lost as heat in the antenna itself.

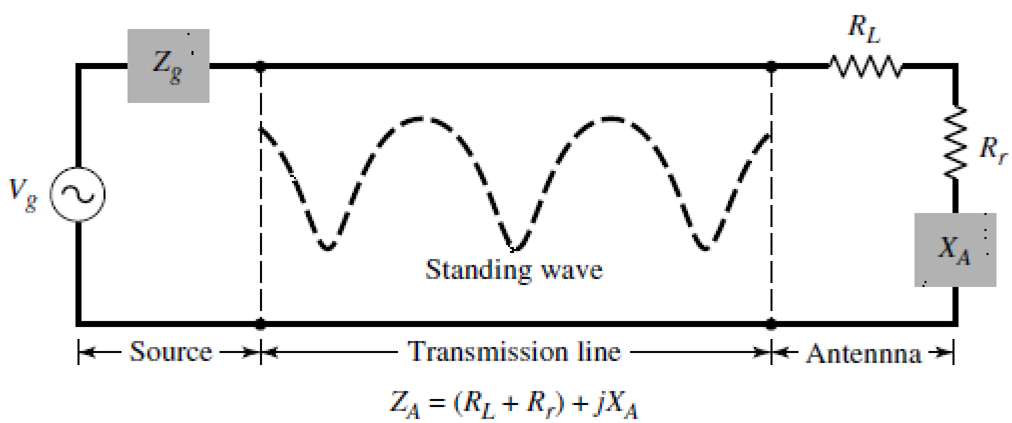


Figure2.1 Thevenin equivalent circuit of antenna

2.1.6 Beamwidth

One of the important parameter, Beamwidth of an antenna is easily determined from its 2D radiation pattern. The angular separation of the half-power points of the radiated pattern is known as Beamwidth.

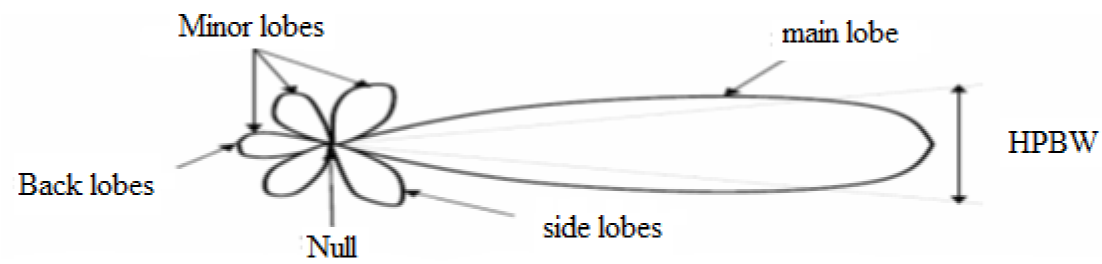


Figure2.2 Beamwidth

2.1.7 S-Parameters

S-parameters describe the response of an N-port network to voltage signals at each port.

i. The first number in the subscript refers to the responding port.

ii. The second number refers to the incident port.

Hence S21 means the output at port 2 due to an input given at port 1.

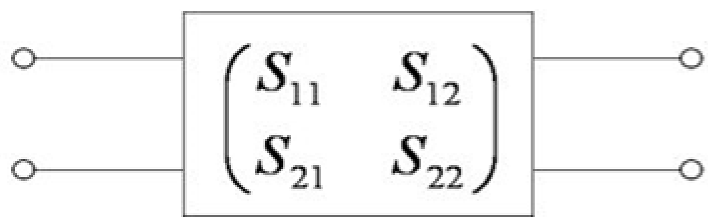


Figure2.3 Two port network

$$S_{11} = \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

$$|\Gamma| = \frac{SWR - 1}{SWR + 1}$$

Where,

S_{11} or Γ is reflection coefficient

$Z_L$is the load impedance

$Z_S$is the source impedance

SWR is the standing wave ratio and is given as:

$$SWR = \frac{1 + \sqrt{\frac{P_r}{P_f}}}{1 - \sqrt{\frac{P_r}{P_f}}}$$

Where,

P_r is the reflected power

P_f is the forward power

2.2 TYPES OF ANTENNA

The antennas can be classified into major categories stated as below:

2.2.1 Wire antennas

They are the very basic type of antenna as they can be seen on most of the buildings, automobiles, homes etc. They can be various shapes and sizes such as straight, loop or helical.

2.2.2 Aperture Antennas

These antennas have found themselves in common use these days. They are mostly used on the aircrafts as they can be easily flush mounted on their surface without disturbing their aerodynamics.

2.2.3 Microstrip Antennas

Microstrip antennas are the radiating elements which have low profile, easy to manufacture, low cost, has a very compact size and are used at high frequencies of the range of GHz. These radiating elements can be easily flush mounted on the surface of aircrafts. Because of their small size they have found themselves in number of applications.

2.2.4 Array Antennas

In some of the applications we require more directivity and gain, for those applications single antennas may not perform up to the mark. Therefore, array antennas with different configurations are being used in many applications.

2.3 MICROSTRIP ANTENNAS

The basic microstrip antenna is form with the help of three layers i.e.

i. Patch layer: It is the conducting and radiating part.
ii. Substrate Layer: It helps to provide better efficiency and bandwidth.

iii. Ground Layer: It is used to complete the microstrip circuitry.

There are four common feeding techniques in the microstrip antennas. They are inset feed, co-axial feed, aperture coupled feed and proximity coupled feed. In this project we have focused on inset feed only. It is easy to design and fabricate.

2.4 BUTLER MATRIX

Butler-Matrix is a part of smart antennas which is used in beamforming networks. It consists of the following components:

i. Hybrid coupler: It is also known as 3db coupler.

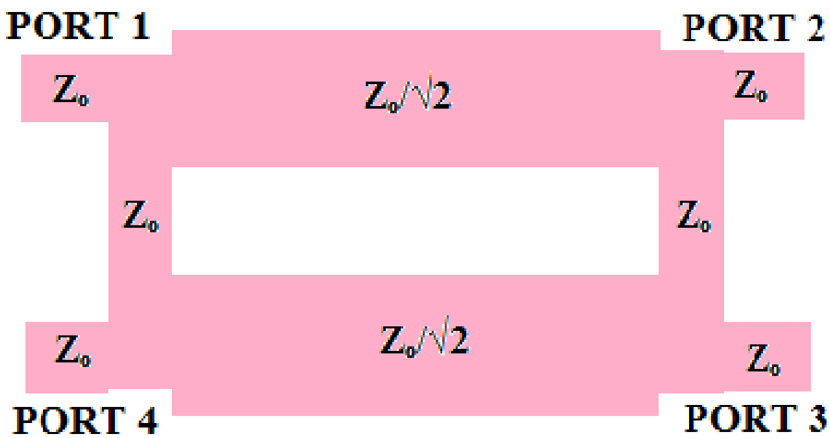


Figure2.4 Hybrid Coupler

The input at port 1 creates an output 90° out of phase at port 3 and is isolated from port 4. The output at port2 and port3 are equal in magnitude.

ii. *Cross-Coupler:* This coupler is used to efficiently cross two transmission lines with minimal coupling.

The input at port1 is transmitted to port3 without any loss. And no or we can say negligible power gets reflected back at port1, port2 and port4.

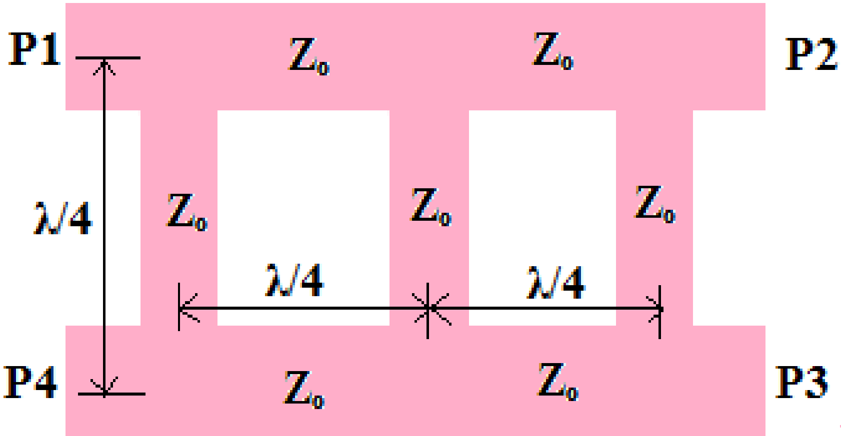


Figure2.5 Cross-Coupler

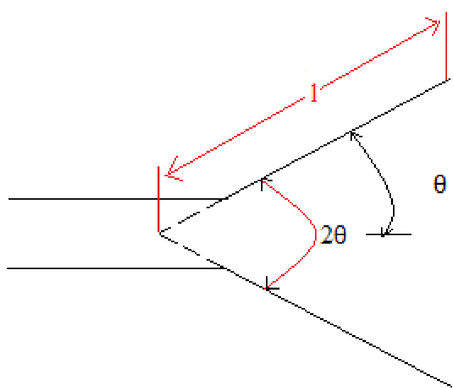
iii.*45° Phase Shifters:* The Phase shifter is designed using the transmission line calculation provided in the ADS software.

$$\frac{\lambda_o}{2} = \frac{C_o}{2f} = \frac{3\times10^8 \mathrm{m/s}}{2\times2.4\times10^9\ \mathrm{Hz}} = 62.5\mathrm{mm}$$

2.5 V-ANTENNAS

It is an antenna created from an array of wires which overcome the effects such as low directivity, high side lobes posed by long wire antennas.

The structure is described in the figure below



The angle 2θ is given by the following equation [1]:

$$2\theta = \left(-149.3\left(\frac{l}{\lambda}\right)^3 + 603.4\left(\frac{l}{\lambda}\right)^2 - 809.5\left(\frac{l}{\lambda}\right) + 443.6\right);$$ For $0.5 \le l/\lambda \le 0.9$

The length of each leg of each V-Antenna must not be greater than 5λ, to keep the leakage of field in control.

CHAPTER 3 LITERATURE REVIEW

1. In [3] Muhammad Mahfuzul Alam et al proposed the design of a microstrip phased antenna array using a rectangular microstrip patch antenna and a 4 port butler matrix. The butler-matrix forms a beamforming network. It produces beams which are orthogonal to the adjacent beams and can be steered into different directions. The rectangular microstrip patch antennas used here are operated at the frequency of 2.4GHz. Other microwave devises such as hybrid coupler, cross coupler are also used in the design of butler matrix. Finally a 4x4 butler matrix is designed to excite the 4 microstrip antennas attached to it. This design can be applied on the current photolithographic technology. The operating frequency of butler matrix is from 2.15GHz to 3.0GHz, but after full integration of butler matrix with the microstrip antennas, the operating frequency of the whole design becomes 2.4GHz.

2. In [6] Reed. J. et al have proposed the analysis of four arm symmetrical networks such as directional double stub coupler or the hybrid ring. The input wave divided into an even and an odd mode and the vector amplitude out the various arms is calculated from the sums or differences of the reflection or transmission coefficients for the two modes. In this a 0 decibel directional coupler is also discussed. In this paper the bandwidth of all the couplers is calculated and the power with respect to frequency of 0 decibel coupler is also calculated. And standing wave ratio, evenness of power split has been compared.

3. In [8] Theodoros N. Kaifas et al have proposed the design of butler matrix for the UMTS applications. The current design can be implemented on the current photolithographic technology. The butler matrix here forms a beamforming network. It produces beams which are orthogonal to the adjacent beams and can be steered into different directions. Microwave devises such as hybrid coupler, cross coupler, lange coupler are also used in the design of butler matrix. And the small discussion over the smart antennas is also done in this paper. Butler-Matrix consists of: 3dB 90^0Hybrid Coupler, cross coupler, fixed phase shifter and array antenna.

4. In [11] Shiann-Shiun Jeng et al have discussed about the application of smart antennas in the wireless communication systems. And have told about how the smart antennas are used to supress the multipath fading with the help of antenna diversity. The have also talked about how to increase the system capacity by supporting multiple co-channel users in reception and transmission. In this paper the experimental results of interference cancellation, diversity gain, and mitigation of multipath fading are derived by using a smart antenna system in typical wireless scenarios. Plus the different beamforming algorithms have also been discussed and these results are obtained at the 900MHz frequency.

5. In [12] Tsoulos, G.V. Have discussed how the spatial filtering using smart antennas has emerged as a promising technique to enhance the performance of cellular mobile systems in RF environment. This paper work pronounces the functioning of smart antennas in terms of various parameters such as key characteristics, benefits and advantages, challenges due to RF environment and also there is also a view towards future generation personal communication systems.

6. In [13] Tayeb A. Denidni et al proposed the design and simulation of a four port wide band network of microstrip matrix to feed a switched beam antenna array for the wireless applications. It works at 1.9GHz. Other microwave devises such as hybrid coupler, cross coupler are also used in the design of butler-matrix. The main concentration in this paper is to develop a feeding network based on the concept of butler matrix in order to cover the PCS band (1900MHz to 2200MHz). The butler matrix here forms a beamforming network. It yields beams which are orthogonal to the adjacent beams and can be steered into different directions. This system can be used to reduce the interference problems.

7. In [14] Eleftheria Siachalou et al have proposed a switched beam base station antenna. The butler matrix is improved by the introduction of the antenna. The input port of the antenna is excited by using the butler matrix network. The designed system can cater small- and medium-sized enterprises (SME), as well as small offices and home offices. The various services provided may be high speed internet access, video streaming services. The two schemes used in this paper are one with the 90° and the other with 120° angular coverage. In this paper the

network generated produces narrower beam switched beams than the conventional butler matrix.

CHAPTER 4 OBJECTIVE AND SCOPE OF STUDY

4.1 OBJECTIVE

This report presents the design of phased array system using planar technology for beamforming applications. The prototype comprises of V-antenna, integrated with butler-matrix. The novelty in this approach is the design of V-antenna using planar technology which results in high directivity and multiband operation. The designed array structure is having maximum directivities by the individual antennas in the direction -44°, 136°, -136° and 44° which are approximately equal to theoretical values. The operating frequency of design is 2.4GHz. And the complete phased array structure is working at multiple frequencies, that is, at 2.4GHz as well as at 4.5GHz. As the size of the V antennas is smaller than the conventional microstrip antennas, the complete phased array system is compact in size. This is an added advantage along with multi band operation that can be used in devices of smaller size. The proposed design is well suited in satellite communications. The simulations were carried out in Advanced Design System Tool.

4.2 SCOPE OF STUDY

Since the advent of telecommunications, Omni-directional antennas were used. Most of the time the specific location of the mobile user is unknown. Therefore, a lot of power is wasted to increase the power level so as to increase the number of users in a telecom system. This problem, to some extent, was solved by the use of sectored antennas. Although increased frequency reuse leading to increased gain is achieved by treating each sector as an individual cell, transmit power is still not efficiently utilized because the antenna beams are still fixed in direction and do not adapt to radio conditions and the environment. With the innovation of smart antennas, the power was directly intended to the desired user and a lot of power is saved. Beamforming applications of smart antennas in the field of cellular systems, also in satellite systems, and act as countermeasure to electronic jamming in electronic warfare etc. are being harnessed these days. Smart antenna is an antenna technology which aids to increase the system capacity by reducing the co-channel interference and increase the quality by reducing the fading effects.

Butler matrix is an integral part of the smart antennas. It is used to create a phase difference without causing any interference between adjacent radiating antennas.

In designing the complete phased array system we require the butler matrix and V-antennas using the microstrip layout.

CHAPTER 5 DESCRIPTION OF SOFTWARE (ADVANCED DESIGN SYSTEM 2014.01)

5.1 WHAT IS ADS

ADS stand for advanced design system. It is simulation software which can be used by RF engineers to design and simulate electromagnetic structures. Advanced design system provides various options of simulation ranging from frequency and time domain to electromagnetic circuits. With the help of advanced design systems we can characterize as well as optimize the electromagnetic circuits.

In my entire work I have used the software advanced designed system 2014.01 version. In this particular version we have the feasibility of accessing the different layers and work upon them simultaneously. We can also define the parameters of the substrate according to the specifications required. The advanced design system has the following parts.

5.2 SCHEMATIC WINDOW

Schematic window is the skeleton window i.e. in this window we draw the hardware in its basic form using the lumped components. Here we also have the option for line calculation. We can synthesize and analyze the dimensions of a waveguide.

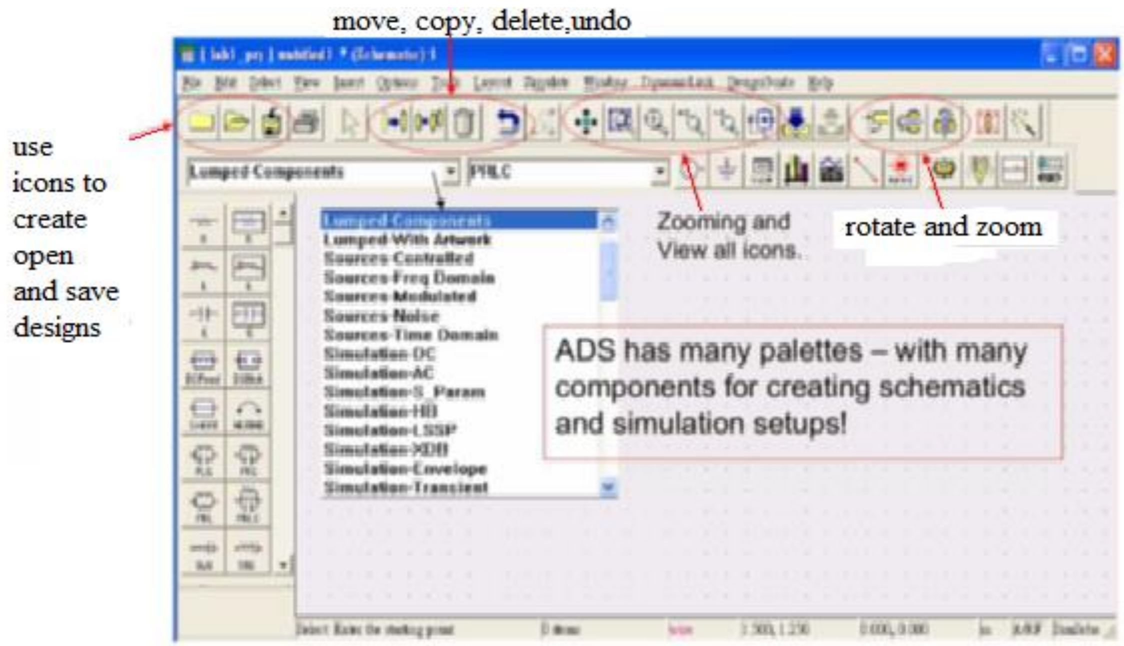


Figure5.1 Schematic Window

One of the important parameter of schematic window is the line calculation. If we know the substrate parameters, we can easily calculate the length and width of the microstrip waveguides at particular input impedance and the orientation angle.

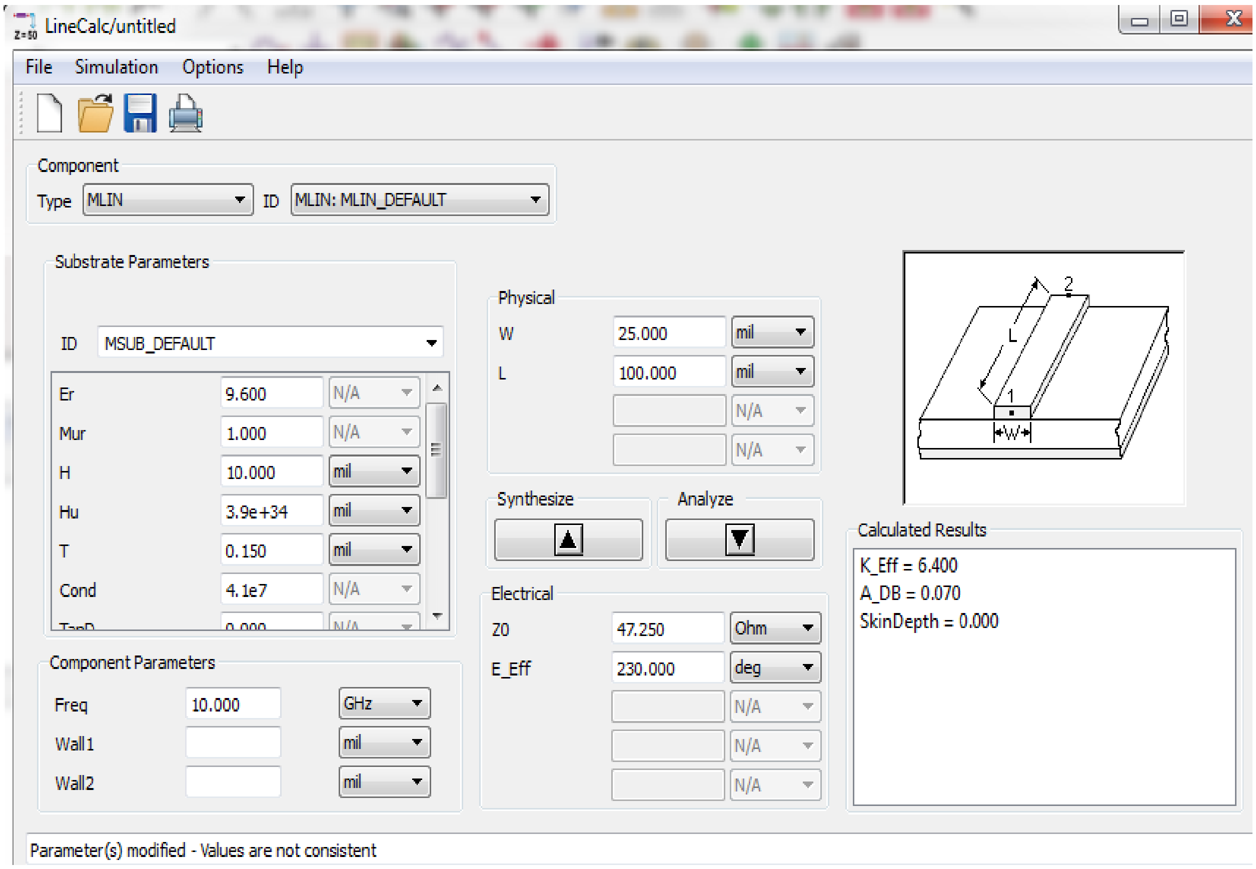


Figure5.2 Line Calculation Window

5.3 LAYOUT WINDOW

Layout window is the body window i.e. here the body of the hardware is designed. Here we can do port editing or we can say match the input and output ports. The circuit layout can be generated either by connecting various elements in the layout window itself or by generating the layout from the schematic. Creating the layout by connecting various elements in the layout window is similar to creating a schematic.

Electromagnetic simulation, substrate definitions, design parameters are all set in this window. In this following window we also have the options to view the far field simulation as well as the radiation pattern of the design.

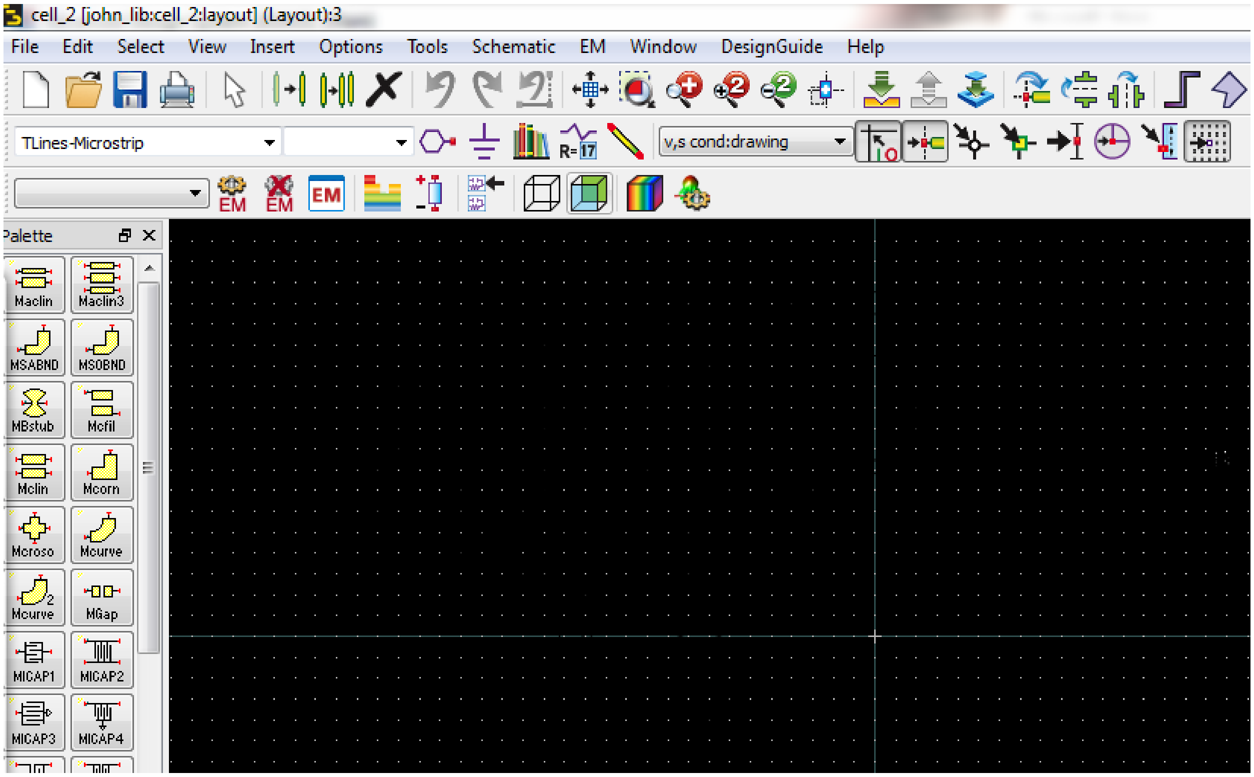


Figure5.3 Layout Window

5.4 SUBSTRATE WINDOW

The substrate can be defined from the substrate window and each layer of substrate can be accessed and can be assigned different material according to the specification of the design.

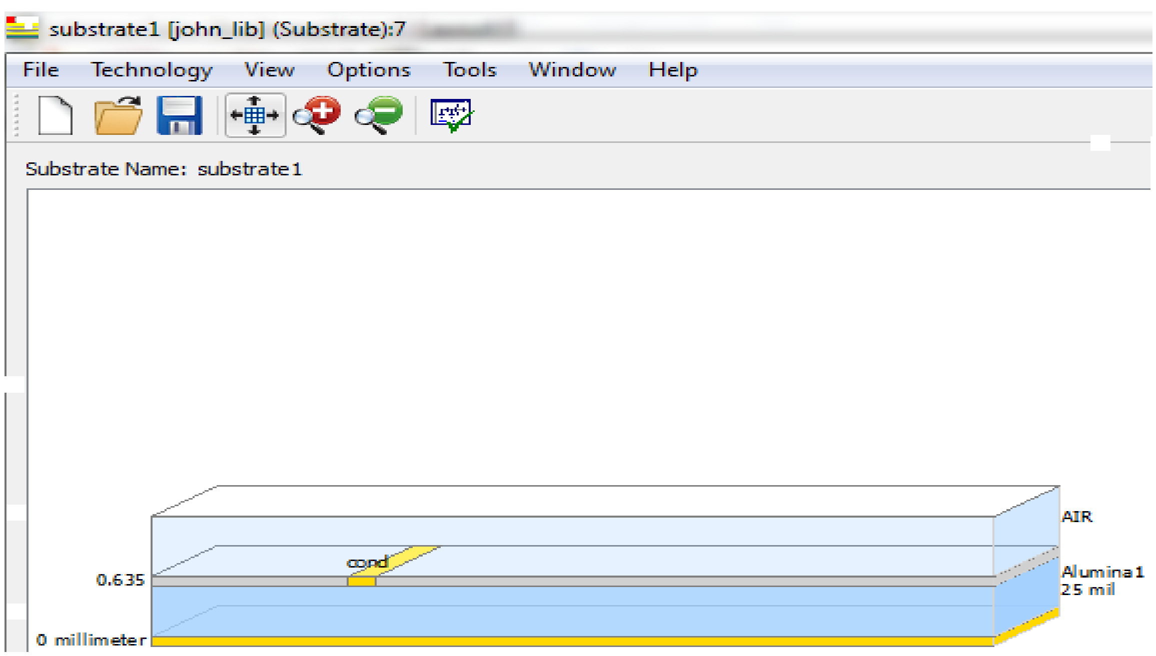


Figure5.4 Substrate Window

CHAPTER 6 RESEARCH METHODOLOGY

DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA

According to the base paper, rectangular microstrip patch antenna was designed at frequency 2.4GHz.

↓

DESIGN OF BUTLER MATRIX

The butler matrix is designed as stated in the base paper, at the operating frequency of 2.4GHz. it consists of four hybrid couplers and two cross couplers.

↓

INTEGRATION OF RECTANGULAR MICROSTRIP ANTENNA WITH BUTLER MATRIX

The complete phased array structure is designed by joining the rectangular microstrip patch antenna with the butler matrix and optimum results are obtained.

↓

IMPROVEMENT

↓

DESIGN OF V-ANTENNA

The V-Antenna designed have higher directivity as well as more return loss than rectangular microstrip antenna.

↓

INTEGRATION OF V-ANTENNA WITH BUTLER MATRIX

The V-Antenna designed is combined with the butler matrix and the optimised results are obtained.

CHAPTER 7 RESULTS AND DISCUSSION

7.1 DEFINING THE SUBSTRATE

The substrate used in the entire project is ROGER FR_4. The parameters or we can say the definition of the substrate is given in the table below:

Substrate Parameters	
Permittivity (ε_r)	4.6
Operating frequency (f)	2.4 GHz
Height of substrate (h)	1.6 mm
Thickness of substrate (T)	35 µm

Table7.1 Substrate Parameters

The substrate will be defined as stated in the below sections.

7.1.1 Default Substrate Window

The figure 7.1 shows the default substrate window. In this window we have to click on technology and go to the material definitions.

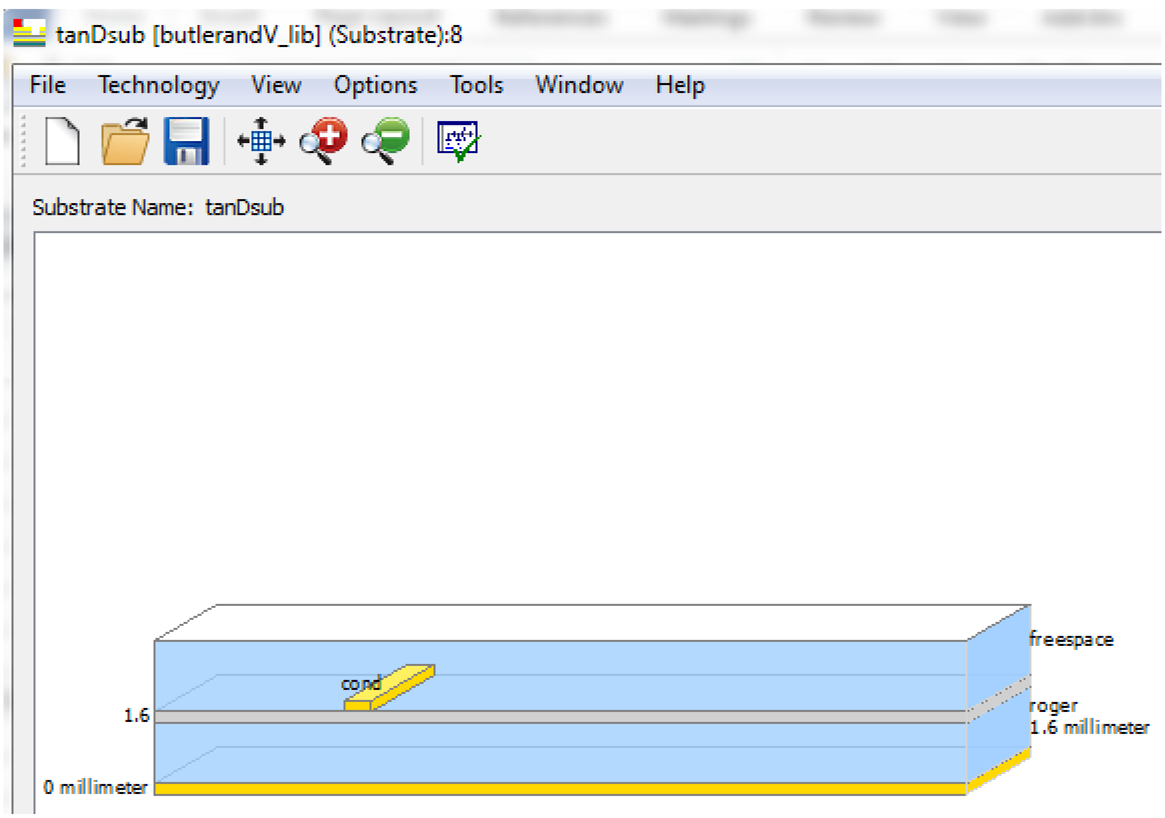


Figure7. 1 Default Substrate Window

7.1.2 Material Definition

In this section we define the material used for the substrate, i.e. the dielectric used (ROGER FR_4) and the free space box used in the simulation.

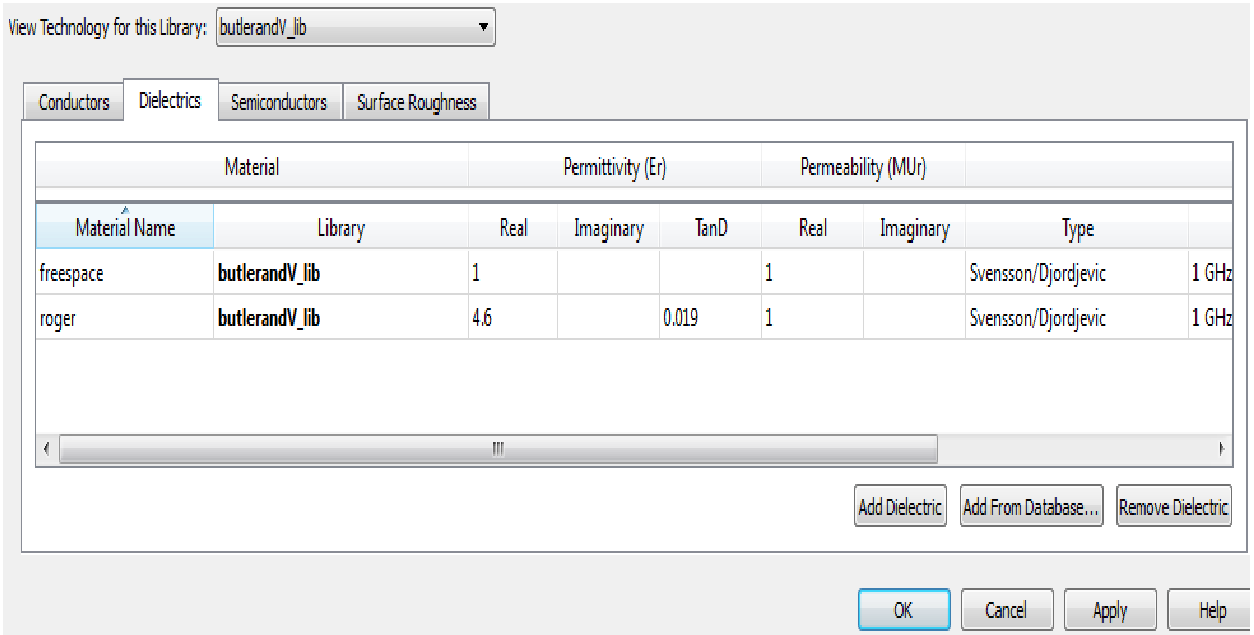


Figure7.2 Definition of Dielectrics Used

In this window we can add the dielectrics from the databases that are predefined or we can also define the dielectrics on our own.

The next part is to define the conductor that is used as the patch of the antenna.

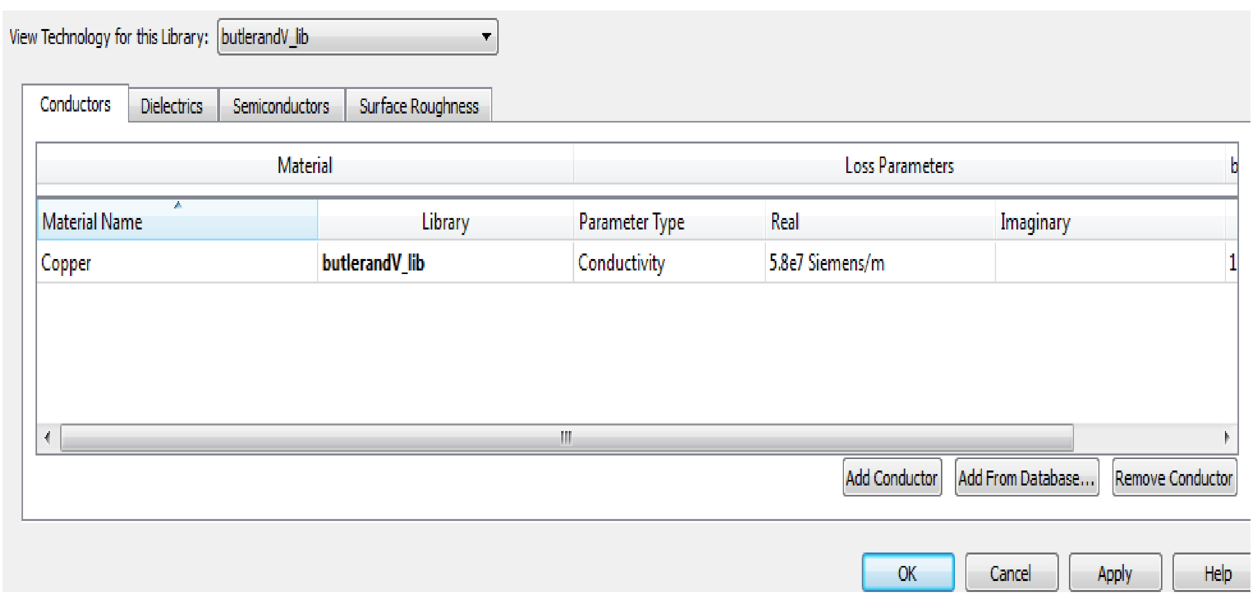


Figure7. 3 Definition of Conductor Used

7.1.3 Layer Definition of Substrate

After the definition of the material we save the window and come back to default window and select each layer and assign the corresponding material to each layer.

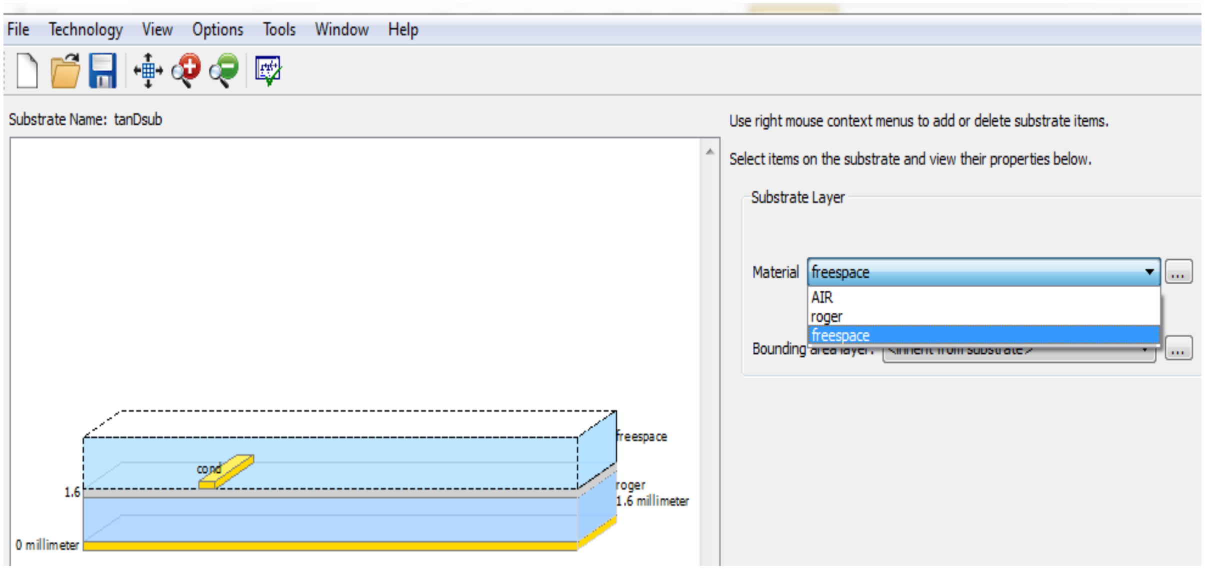


Figure7. 4 Air Box

In figure7.4 the air box layer is selected and the material is selected as the freespace already defined in the materials.

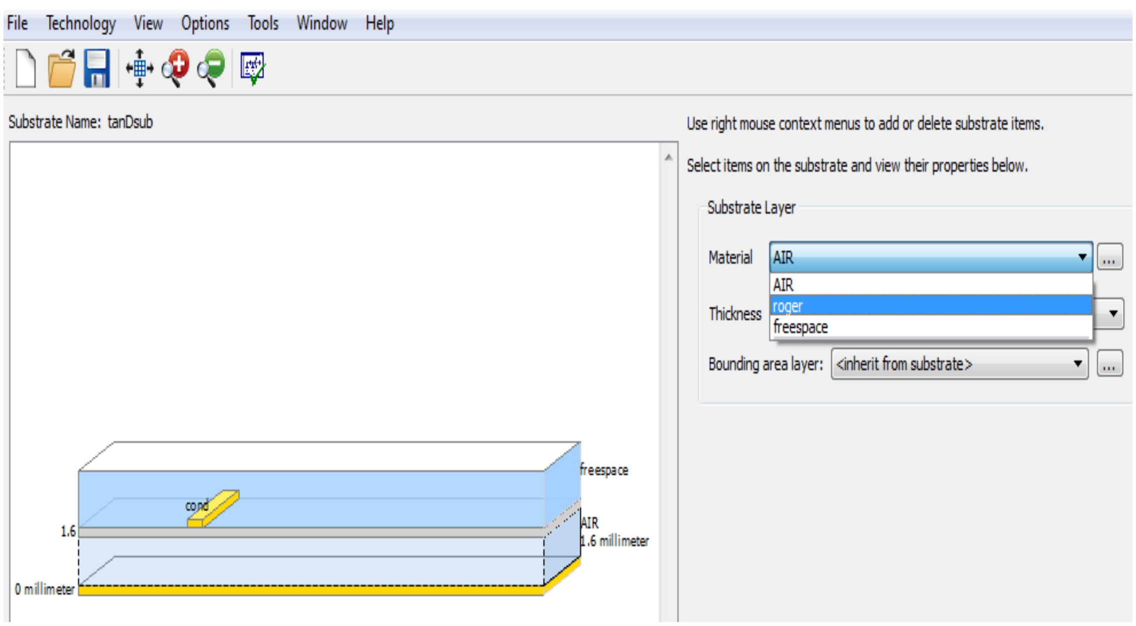


Figure7.5 Substrate Layer

In figure7.5 the substrate layer is selected and the material is assigned as roger predefined earlier. And the thickness is taken as 1.6 millimeter.

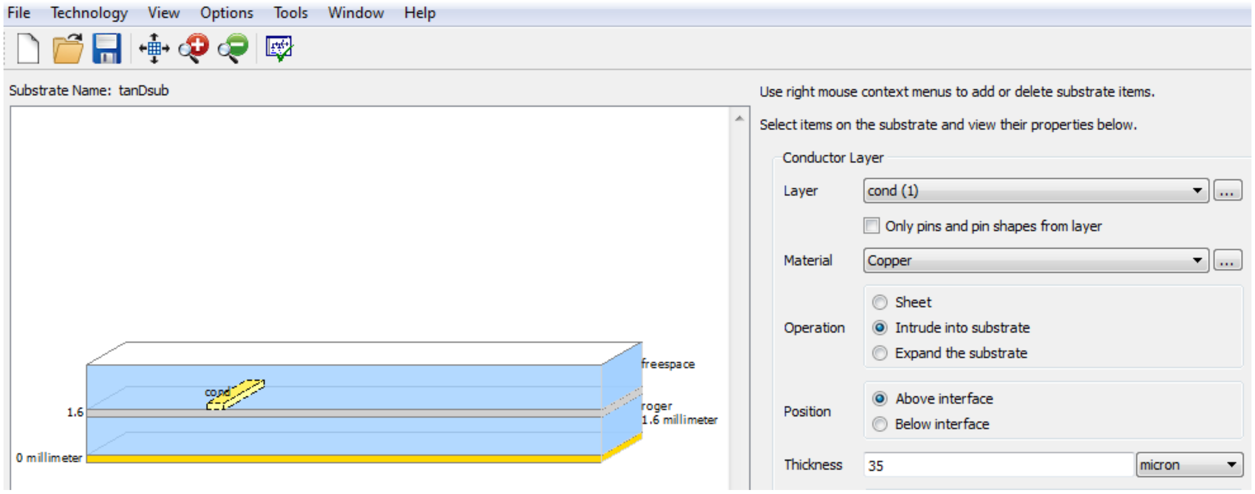


Figure7.6 Conductor Layer

In conductor layer the material is chosen as copper and the thickness is 35 micrometer.

7.2 RECTANGULAR MICROSTRIP PATCH ANTENNA

In this section I will be discussing about the rectangular microstrip patch antenna design and the equations involved in the same.

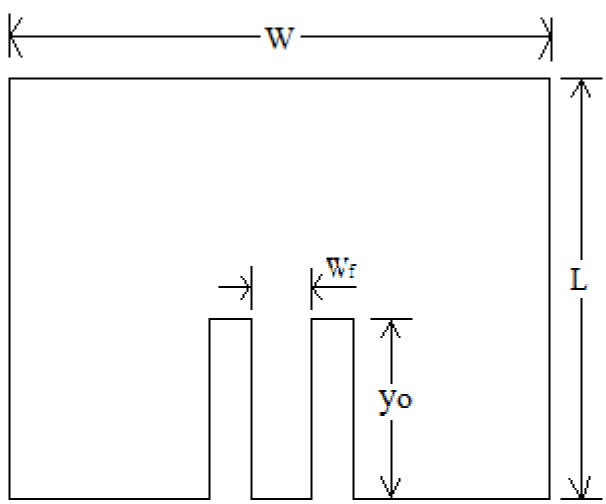


Figure7.7 Basic Rectangular Microstrip Patch Antenna

Now we will be calculating the width, length and other dimensions required for the design according to the equations mentioned below.[2]

i. $W=\frac{v_0}{2fr}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{(3\times10^8)}{2(2.4\times10^9)}\sqrt{\frac{2}{4.6+1}}$ =37.350894mm

ii. $\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1\quad[1+12h/w]^{-1/2}}{2}$ = 4.262861695

iii. $\frac{\Delta L}{h}=0.412\frac{(\varepsilon_r+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_r-0.258)(\frac{w}{h}+0.8)}$ = 0.458983666

ΔL = 0.734373867

iv. $L=\frac{1}{2f_r(\sqrt{\varepsilon_{reff}})\sqrt{\varepsilon_0\mu_0}}-2\Delta L=\ 28.80243527\text{mm}$

From (http://mwrf.com/Articles/Index.cfm?ArticleID=6993) we can get the exact inset length for 50ohm input impedance through the mathematical model

v. $y_o=\ 10^{-4}\{0.001699\varepsilon_r^7+0.1376\varepsilon_r^6-6.1783\varepsilon_r^5+93.187\varepsilon_r^4-\ 682.69\varepsilon_r^3+2561.9\varepsilon_r^2-4043\varepsilon_r^1+6697\}\frac{L}{2}$; For 2≤εr≤10

y_o= 8.98mm

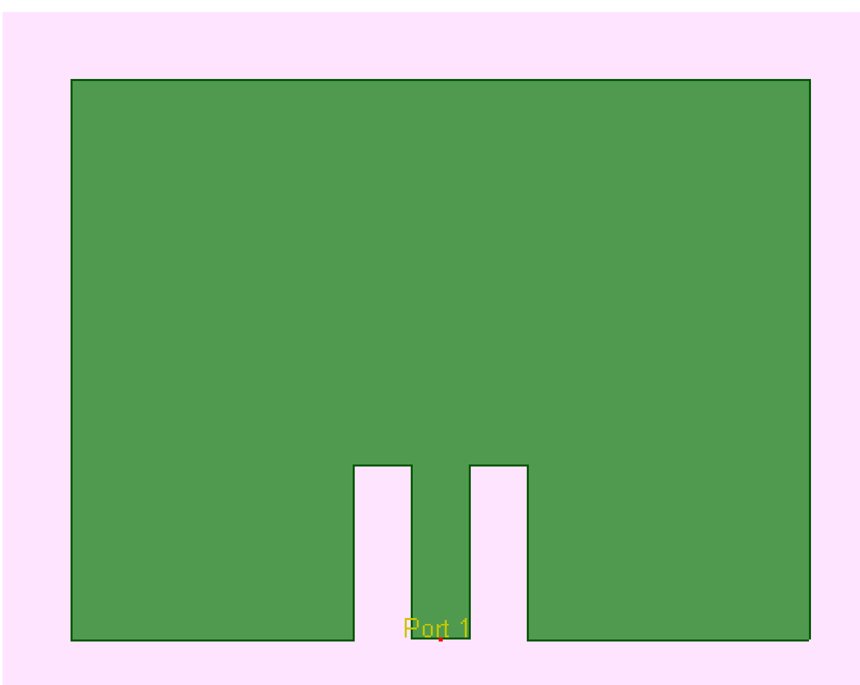


Figure7.8 Simulated Rectangular Microstrip Patch Antenna

Figure 7.8 shows the simulated rectangular microstrip patch antenna. The antenna is excited through inset feed technique via port 1. The input impedance of the port is taken same as the characteristic impedance that is, 50ohms.

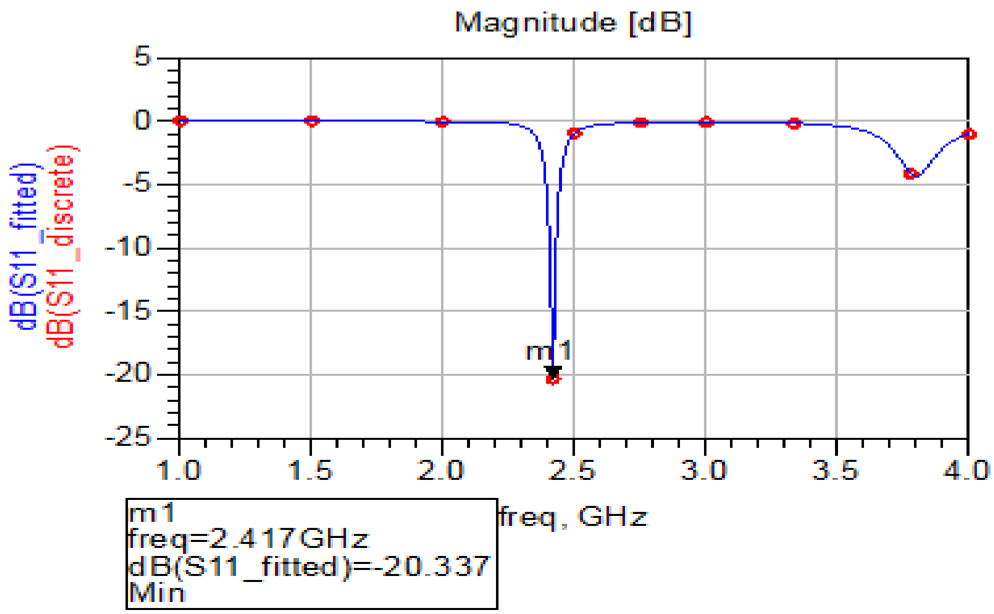


Figure7.9 Return loss

The return loss of the simulated rectangular microstrip patch antenna is given by figure7.9 that is, -20.337db.

7.3 BUTLER MATRIX

The 4x4 butler matrix consists of four hybrid couplers and two cross couplers as stated in the section 2.4 of this report.

The simulated designs as well as their corresponding outputs will be discussed below.

7.3.1 Hybrid coupler

The length and the width of the waveguides used to make hybrid couplers are done with the help of line calculations in the schematic window of advanced design software 2014.01.

For $z_0 = 50 ohms$; L=15.736800 mm and W= 2.918820 mm

For $\frac{z_0}{\sqrt{2}} = 35.3553\ ohms$; L= 15.275700 mm and W = 5.033790 mm

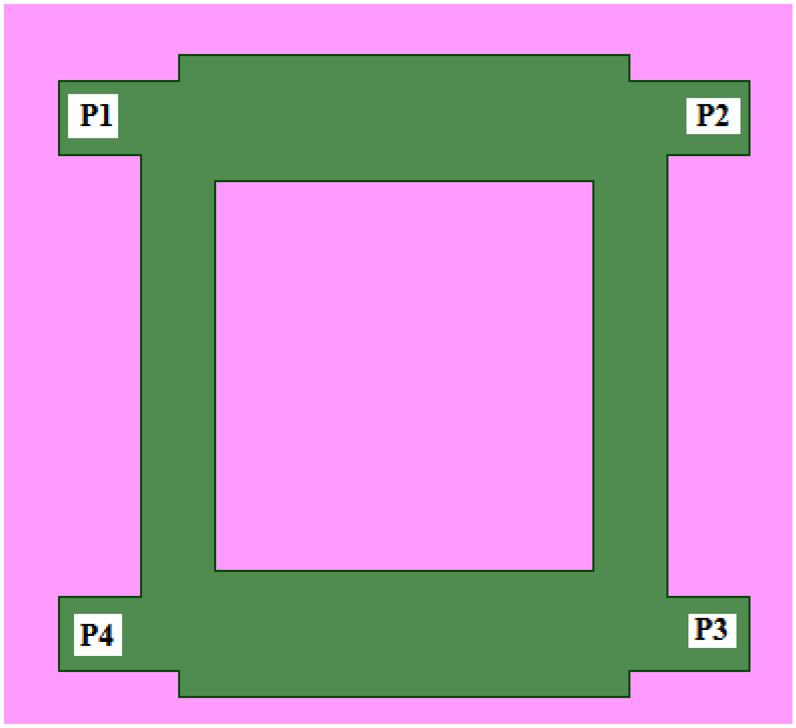


Figure7.10 Simulated Design of Hybrid Coupler

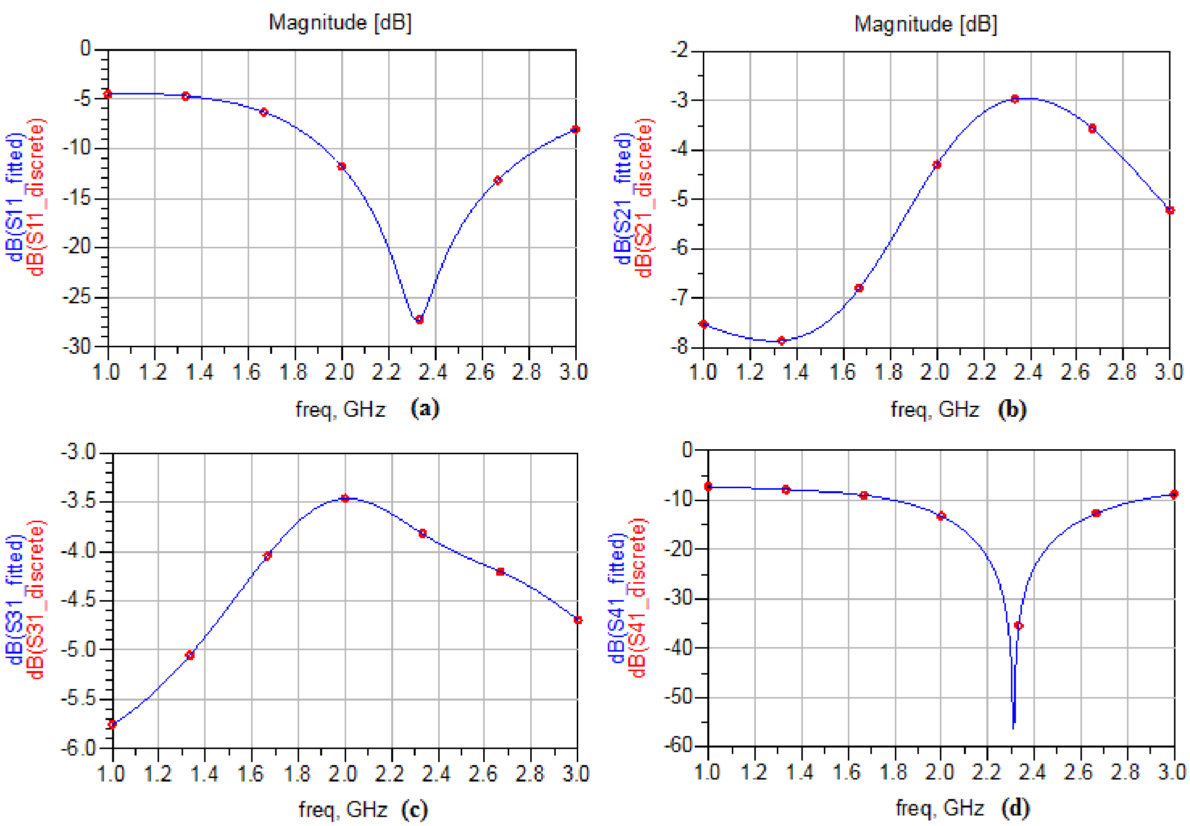


Figure7.11 Return losses of Hybrid Coupler

Figure 7.11(a) shows that the reflected waves at port1 is very less when input is given at port1 itself. As we know that hybrid coupler is also known as -3db coupler, figure 7.11(b) and figure 7.11(c) shows the output at port2 and port3 and validates that the output is equivalent to -3db. And again the output at port4 is very less that is, negligible waves are transmitted to port4 when input is given at port1.

7.3.2 Cross Coupler

As described earlier in section2.4 that cross-coupler is an efficient means of crossing two transmission lines with minimal coupling. Figure7.12 shows the simulated cross-coupler in ads.

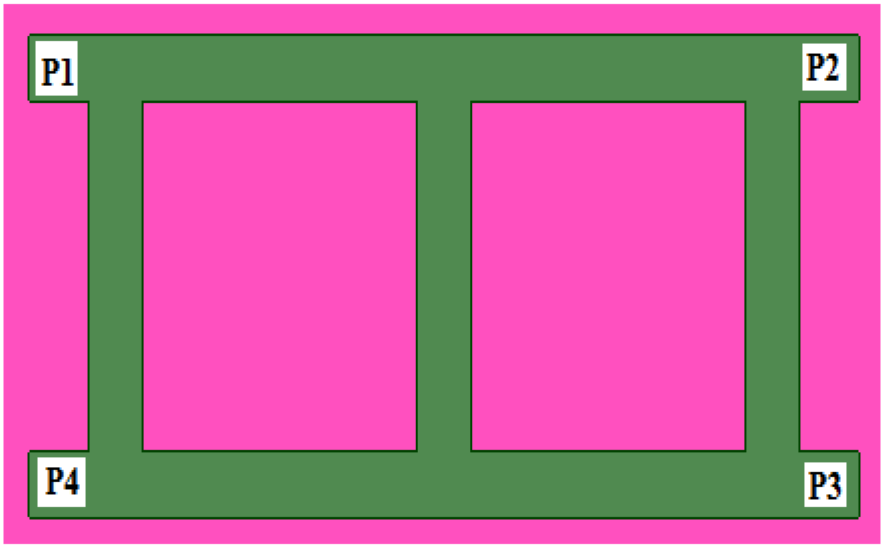


Figure7.12 Simulated Cross-Coupler

Figure 7.13 shows the output results of the cross-coupler at various ports when input is given at port1. Ideally no power or negligible power is reflected back at port2 and port4 and no power loss at port3.

The results totally comply with the theoretical values as we can see in figure 7.13 (a), (b) and (d) that reflected power is very less. And at port3 the whole power is transmitted when input given at port1.

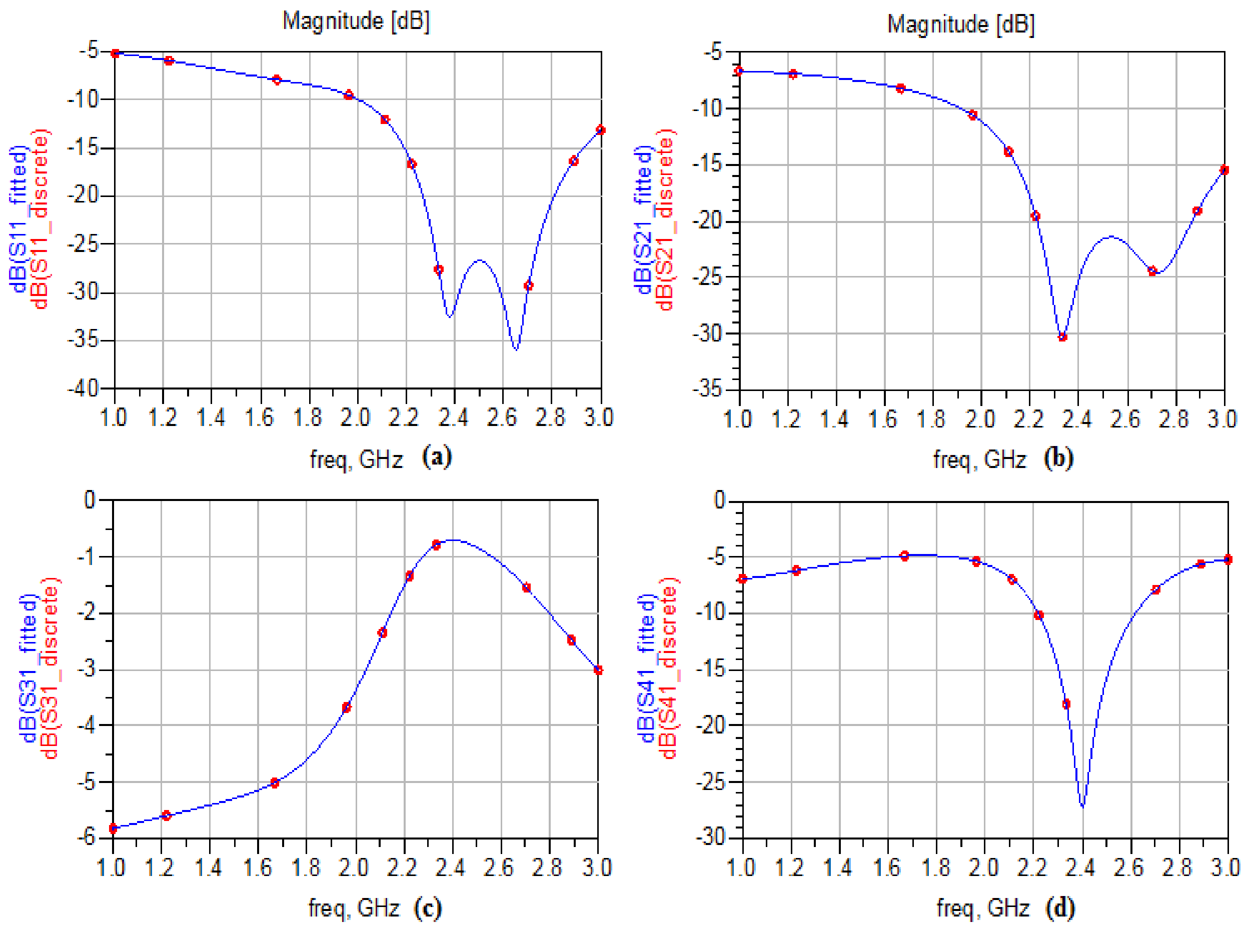


Figure7.13 (a) Return loss at port1 when input is given at port1 (b) Return loss at port2 when input is given at port1 (c) Return loss at port3 when input is given at port1 (d) Return loss at port4 when input is given at port1

7.3.3 Complete 4x4 Butler Matrix

With help of two cross-couplers, four hybrid couplers and two 45 degree phase shifters, the 4x4 butler matrix is created.

The length and width of the waveguides have been optimized to give the best results possible. The length and width in the design described below in figure 7.14 is not equal to the dimensions derived from the formulas as it would have increased the size of the phased array structure. Therefore, optimization techniques have been used to make the dimensions compact and feasible for the fabrication.

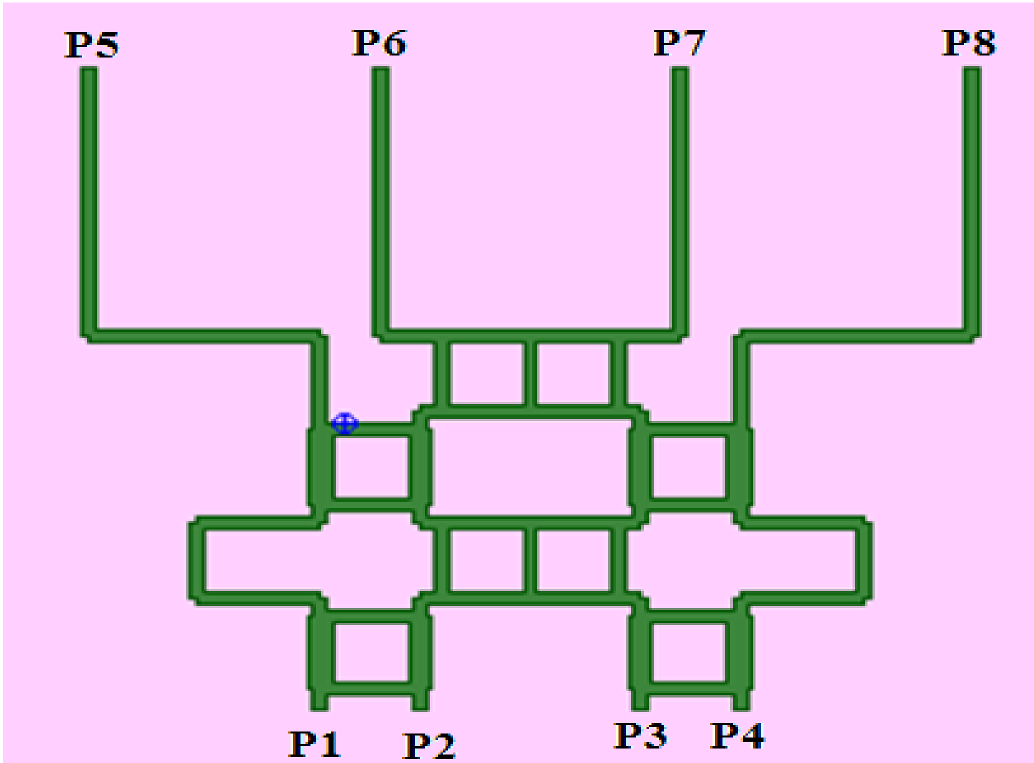


Figure7.14 4x4 Butler Matrix

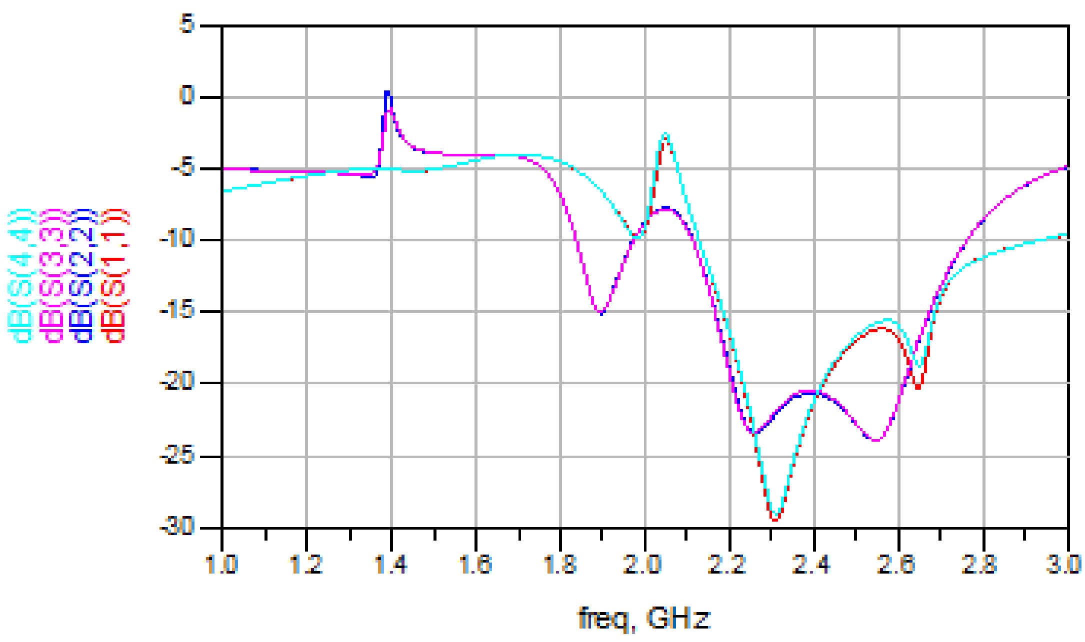


Figure7.15 Return loss at various input ports

Figure 7.15 shows the return loss at the four ports when input is given at port1, port2, port3 and port4 respectively.

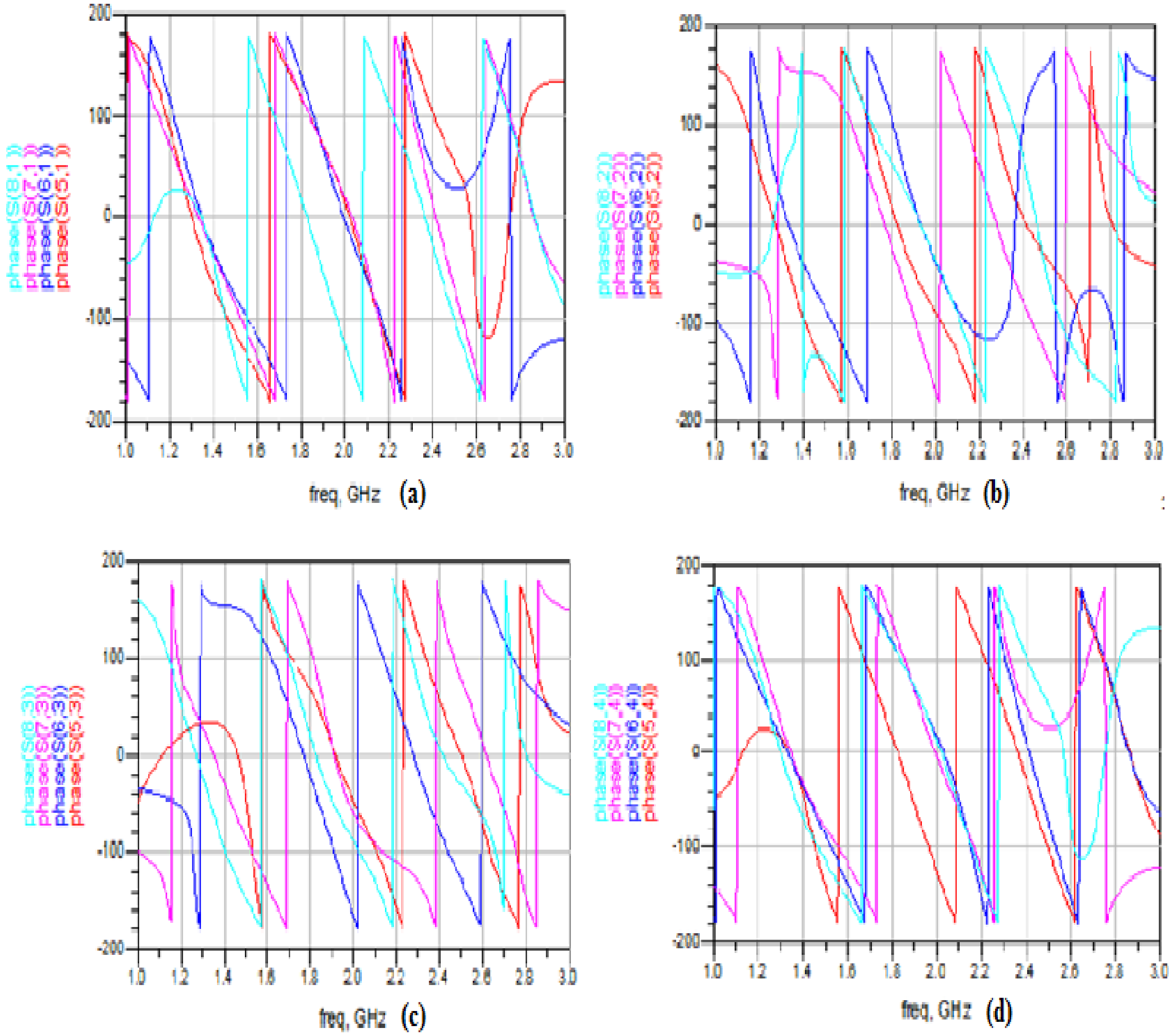


Figure7.16 (a) Phase at output ports when input is given at port1 (b) Phase at output ports when input is given at port2 (c) Phase at output ports when input is given at port3 (d) Phase at output ports when input is given at port4

Input Ports	Phase Difference (theoretically)	Phase Difference (practically)
P1	-45	-44
P2	135	136
P3	-135	-136
P4	45	44

Table7.2 Difference between theoretical and practical values in phase difference

7.4 INTEGRATED DESIGN OF BUTLER MATRIX AND RECTANGULAR MICROSTRIP PATCH ANTENNA

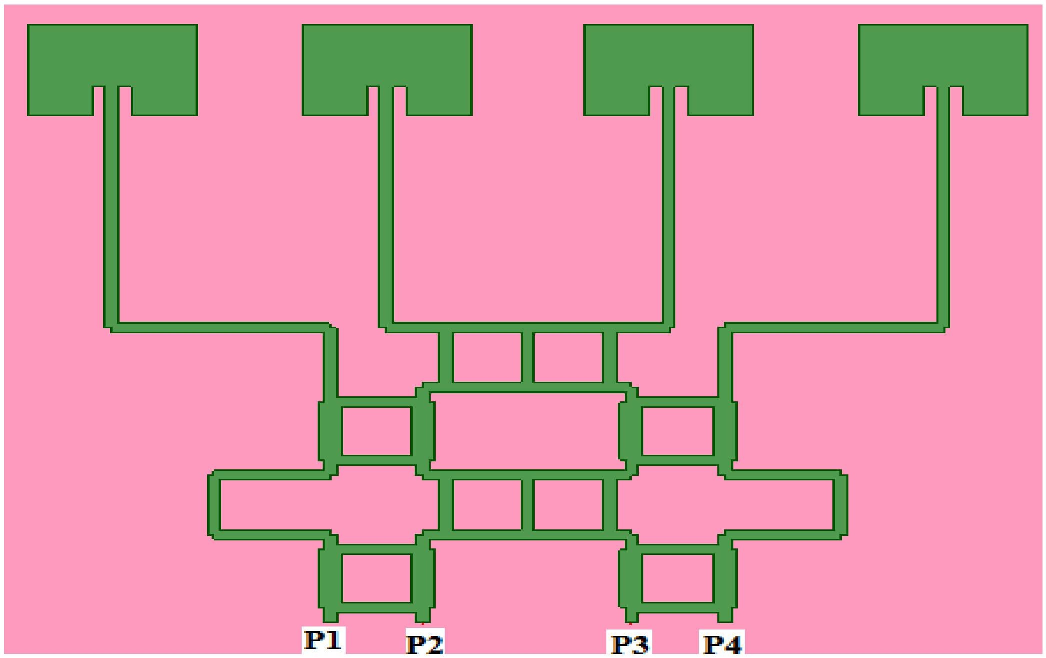


Figure7.17 Integrated Design Of Butler Matrix And Rectangular Microstrip Patch Antenna

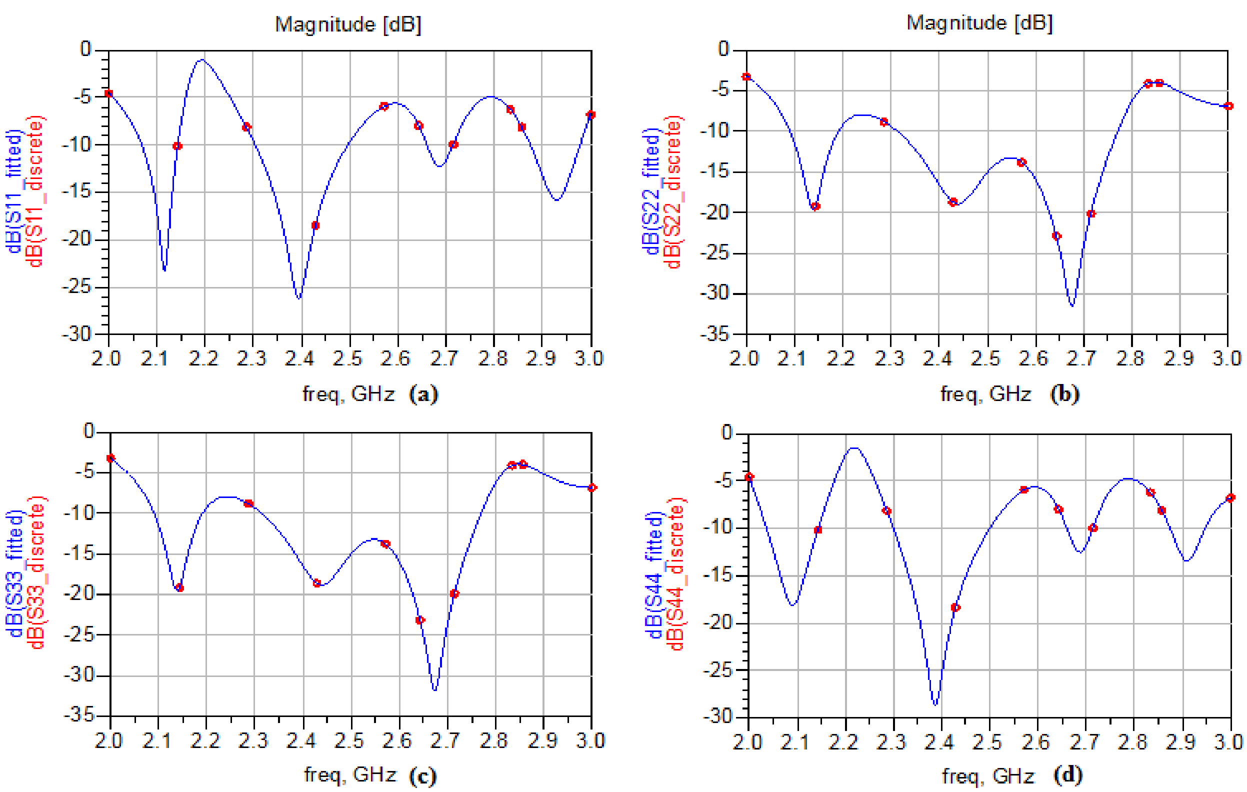


Figure7. 18 (a) Return loss at port1 (b) Return loss at port2 (c) Return loss at port3 (d) Return loss at port4

Figure 7.17 shows the integrated design of the 4x4 butler matrix with the rectangular microstrip patch antenna. The input is given at four different ports to generate different beams at different phase differences.

Figure 7.18(a) shows the return loss of about (-25db) at port1 when input is given at port1, Figure 7.18(b) shows the return loss of about (-30db) at port2 when input is given at port2, Figure 7.18(c) shows the return loss of about (-30db) at port3 when input is given at port3, Figure 7.18(d) shows the return loss of about (-29db) at port4 when input is given at port4.

7.5 V-ANTENNA

Considering the following equation:

$2\theta = \left(-149.3\left(\frac{l}{\lambda}\right)^3 + 603.4\left(\frac{l}{\lambda}\right)^2 - \quad 809.5\left(\frac{l}{\lambda}\right) + \quad 443.6\right)$; For $0.5 \leq l/\lambda \leq 0.9$

Now taking the value of l//λ equal to 0.5 we compute the value of θ.

θ = 85.51875 and 2θ = 171.0375

At λ= 0.125 mm the length l = 62.5 mm

The length obtained with the formula above matches with the line calculations done in the advanced design software. The length and width obtained were:

Length = 62.5 mm

Width = 15 mm

But optimization techniques were used and the best results are obtained at the following parameters:

Length = 15.625 mm

Width = 3.75 mm

Input impedance = 8 ohms

Figure 7.19 shows the simulated design of V-Antenna.

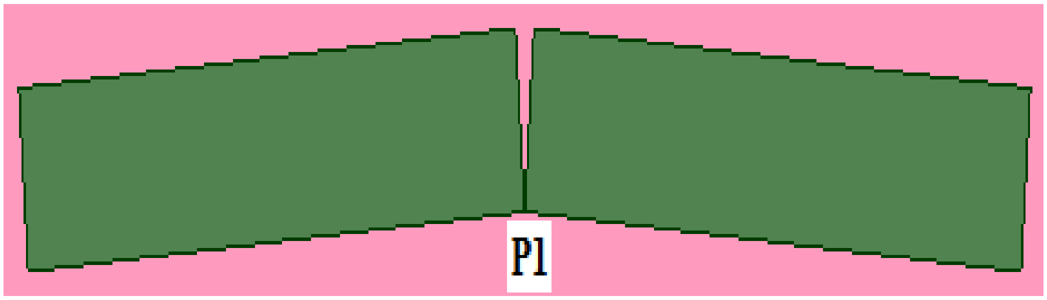


Figure7.19 V-Antenna

Figure 7.20 shows the return loss of the V-Antenna. It is very high and about (-50db). We can analyze from the output that the directivity is very high. And negligible amount of power is being reflected back. As directivity is directly proportional to gain so we can also say that this designed V-Antenna has high gain too.

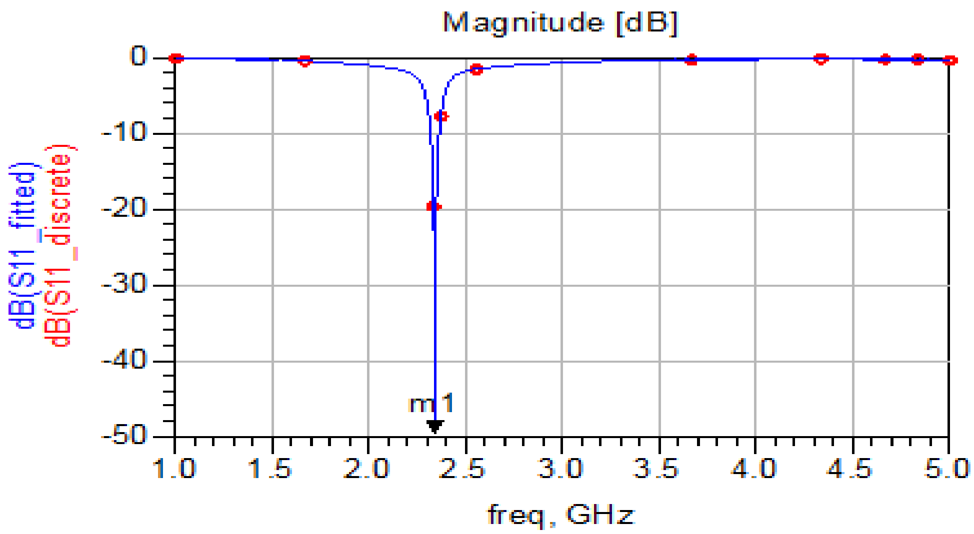


Figure7.20 Return loss

7.6 COMPLETE PHASED ARRAY STRUCTURE WITH V-ANTENNAS

As an improvement to this project we have replaced the rectangular microstrip patch antenna with the V-Antenna designed in section 7.5. As the input impedance of 4x4 butler matrix is 50ohms and the input impedance of V-Antenna is 8ohms, so the impedance matching waveguide is being designed. The length and width is as follows:

Length = 15.718800 mm

Width = 10.891700 mm

The length and width are calculated at effective impedance given by:

$$Z_{eff} = \sqrt{Z_{in} \cdot Z_o}$$

$$Z_{eff} = \sqrt{50 * 8} = 20\text{ohms}$$

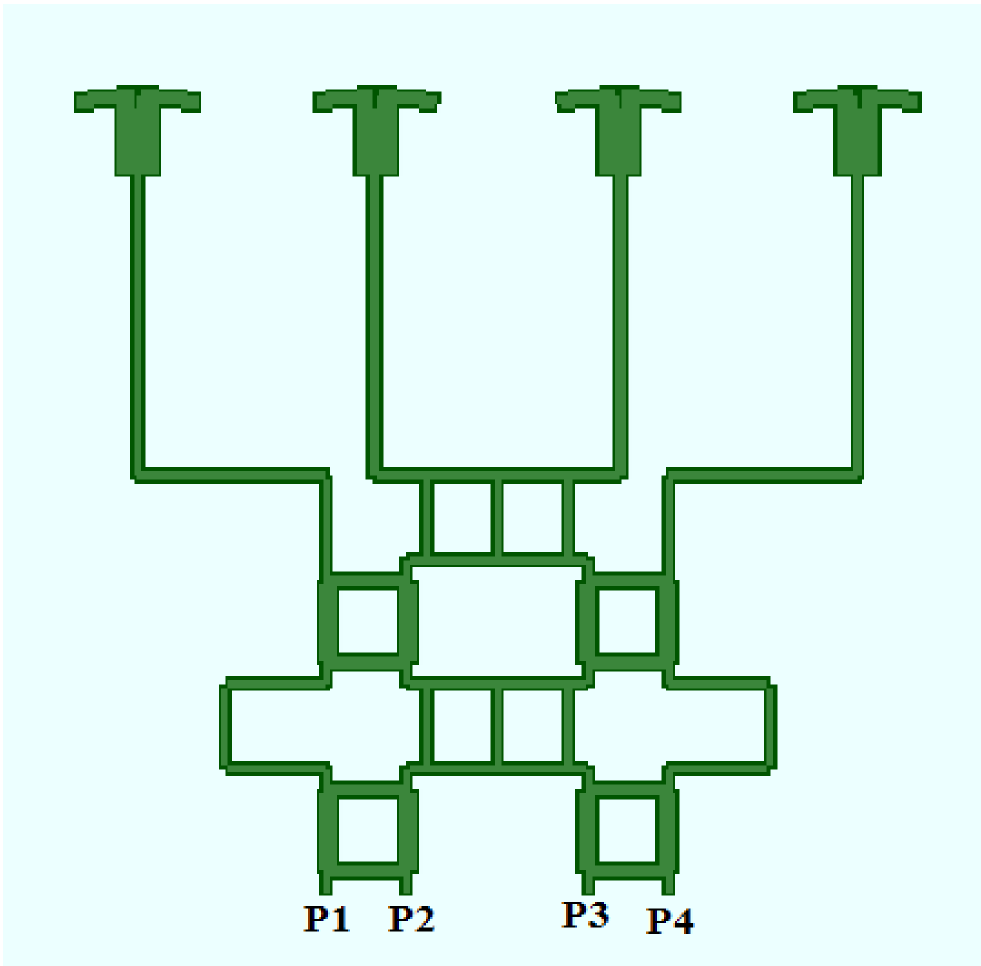


Figure7.21 COMPLETE PHASED ARRAY STRUCTURE WITH V-ANTENNAS

The matching waveguide is being placed between the 4x4 butler matrix and the V-Antennas. And the V-Antennas are mounted over the matching waveguide in the complete phased array structure.

We can analyze from the simulated design that this design is small and more compact as compared to the design simulated in section 7.4

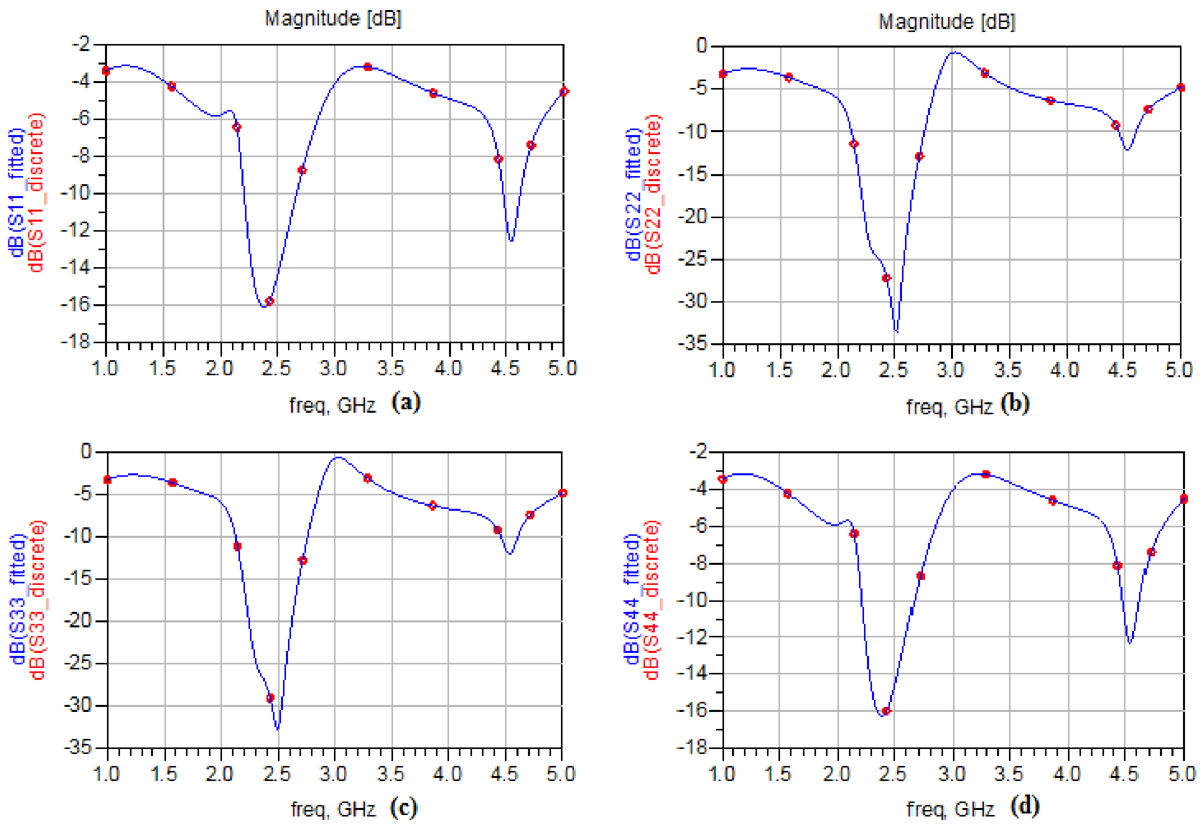


Figure7.22 (a) return loss at port1 (b) return loss at port2 (c) return loss at port3 (d) return loss at port4

Figure 7.22(a) shows the return loss of about (-16db) at operating frequency of 2.4GHz and (-12db) at 4.5GHz at port1 when input is given at port1, Figure 7.22(b) shows the return loss of about (-35db) at operating frequency of 2.4GHz and (-12db) at 4.5GHz at port2 when input is given at port2, Figure 7.22(c) shows the return loss of about (-35db) at operating frequency of 2.4GHz and (-12db) at 4.5GHz at port3 when input is given at port3, Figure 7.22(d) shows the return loss of about (-16db) at operating frequency of 2.4GHz and (-12db) at 4.5GHz at port4 when input is given at port4.

CHAPTER 8 CONCLUSION

The butler matrix which is the integral part of the smart antennas is being designed and simulated in Advanced Design Software 2014.01 and its output results are being discussed in this report. The Rectangular Microstrip patch antenna is also being designed and simulated individually whose return loss is about (-20db). The 4x4 Butler matrix is demonstrated, which is being used for generating beams at different angles when input is given to different ports. The values achieved in the design simulation are at par with the theoretical values. Then we have integrated the butler matrix with the rectangular microstrip antennas and simulated the same design and have got good return loss for the individual input ports at the operating frequency of 2.4GHz. The idea of this whole work has been taken from the base paper [3].

As the improvement part in the thesis project we have replaced the rectangular microstrip antennas with the V-Antennas. This approach is completely new and has never been adopted before.

The V-Antennas working as the radiating elements, when analyzed individually have a high return loss of about (-50db) and very high directivity is also seen from the results obtained.

In the design of complete phased array structure we also saw that it's working at multiple frequencies that is, at frequency 2.4GHz as well as at frequency 4.5GHz. So the designed antenna is not only used in the ISM band but can also be utilized in satellite communication operating at C-band. From the complete phased array structure design we can conclude that it is compact in size, that is, the size of V-Antennas is much smaller than the traditionally used rectangular microstrip patch antennas. And with compact size these structures can easily be flush mounted on smaller devices. And the bandwidth obtained in the later design is more than the formal design.

Future Scope: In this whole project we have tried to reduce the overall size and have tried to improve the performance of the phased array structure. In future the bandwidth can improved further. Till now this design is working on the ISM Band and C-band, the other satellite bands such as the K-band and Cu-band can also be harnessed by modifying the design with the use of some other antennas.

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