ACTIVE PHASED ARRAY ANTENNA TECHNOLOGY DEMONSTRATOR

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ABSTRACT

ACTIVE PHASED ARRAY ANTENNA - TECHNOLOGY DEMONSTRATOR

A microstrip patch antenna array is developed for an S-band active phased array antenna. The antenna operates at 3.2 GHz. Active antennae are usually phased array antennae at which instead of a central high-power amplifier, every radiating element is attached with a small power amplifier in the antenna directly. This has the advantage that the necessary phase shifters must only process a small power and gives distributed failure in case of malfunctioning of the amplifier. Switched line PIN diode phase shifting is used for beam steering in four discrete angles. The individual RF output from each patch will be combined in the space – known as space amplification. The design specifications are required to be validated using anechoic chamber at NUST HQ.

Having small size, light weight and low cost, these phase shifters with patch array have wide range of applications from communication systems such as satellite or mobile communication to radars such as synthetic aperture radar (SAR) or radars installed in fighter jets where fast beam steering is required, as well as, in ground radar stations in which wear and tear happens in case of mechanical beam steerin

CERTIFICATE OF CORRECTNESS AND APPROVAL

It is certified that the work contained in this thesis titled "Active Phased Array Antenna-Technology Demonstrator", carried out by Owais Riaz Siddiqui, Afnan Riaz, Ahmed Saad and Asad Amjad, under the supervision of Lt. Col. Dr. Naveed Ahmed in partial fulfillment of the Bachelors of Telecommunication Engineering, is correct and approved.

Approved by

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Lt. Col. Dr. Naveed Ahmed

Project Supervisor

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DEDICATION

All our efforts are dedicated to our beloved parents and teachers who have been a constant source of encouragement for us throughout our lives. May Allah bless them with long lives and always provide us their loving and thorough guidance.

ACKNOWLEDGEMENTS

There is no success without the will of Allah. We are grateful to Allah, Who has given us guidance, strength and enabled us to accomplish this task. Our syndicate would like to acknowledge that this project would not have been possible without the guidance of our supervisor, Lt. Col. Dr. Naveed Ahmed and special assistance of Dr. Farooq Ahmed Bhatti, Dr. Moazam Maqsood and Asst. Prof. Zeeshan Zahid. Our group is extremely thankful to all the instructors who imparted knowledge on the course of our engineering studies.

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LIST OF ABBREVIATIONS

Abbreviations	Meanings
ADS	Advanced Digital Design
APAA	Active Phased Array Antenna
FYP	Final Year Project
HFSS	High Frequency Structural Simulator
LPKF	Leiterplatten Kopier Fräsen
NRTC	National Radio and Telecomm. Corporation
PCB	Printed Circuit Board
RIMMS	Research Institute of Microwave and Millimeter Studies
S-Parameter	Scattering Parameter
SMA	SubMiniature version A
SMD	Suface Mount Device
SMT	Surface Mount Technology
T/R	Trasmit/Receive
UG	Undergraduate
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

Chapter 1

INTRODUCTION

1.1 **Background/Motivation**

Electronically steerable phase arrays have matured greatly over the last 35 years. There are now radar systems all over the world that have incorporated this technique for antenna steering, the latest of which incorporate low cost MMIC components. These advances now allow the phased array to be used in high volume ground and airborne applications. Keeping in view the latest advancements and history of projects done in our university, an active phased array antenna project was proposed.

1.2 Problem Statement

Low losses are observed in active antenna as compared to passive antenna as well as graceful degradation is achieved by the distributed amplification. So active phased array antenna will be designed, simulated and fabricated.

1.3 Project Description and Salient Features

Active phased-array antennae are antennae in which the transmit power is produced by many transmit/receive (T/R) - modules – where each T/R module is of low output power. Active antennae are usually phased array antennae at which instead of a central high-power oscillator/amplifier, every radiating element got a small power amplifier in the antenna directly. These antennas are mostly used in applications which need high speed beam steering.

A microstrip patch antenna array was developed for an S-band active phased array antenna. The antenna will operate at 3.2 GHz with a bandwidth of 200 MHz. It was a rectangular patch array fed by a corporate feed network.

Availability of solid state power amplifiers (SSPA) make it convenient to design and develop a low cost S-band APAA that will be instrumental to develop low cost radars or EW jammers in future. Nowadays, solid state RF components come as single package (MMIC) in the form of transmit/receive modules (T/R Modules). These T/R modules contain SSPA, low noise amplifiers (LNA), circulators and digital control. The individual output power of these modules is very low (few watts only). To achieve a high RF output, these are used in large numbers in parallel configurations. To synchronize the output power amplification and to steer the beam, phase of the individual T/R modules is controlled. These antennas are mostly used in applications which need high speed beam steering. But these T/R modules are domestically unavailable rather internationally they are available for only defense sectors to be used by aircrafts such as used in F-16 block 50/52 and JF-17 Thunders (by Pakistan) or they are space qualified to be used in the satellites such as NOVA SAR-S.

Syndicate tried its level best to procure T/R modules at S-band. However, the best quote received showed a single T/R module would cost ~ $5000 and four of them were needed in the project so the total cost becomes ~$20000. In this backdrop, procurement of such a costly component (that too minimum of 4 of these in numbers) was extremely difficult at UG FYP level. Alternatively, another approach was adopted which utilized active components to fulfill our project goal of active phased array antenna using MMIC amplifiers and switched line PIN diode phase shifters. So as an alternative the receiving part of T/R module was designed, simulated and being fabricated.

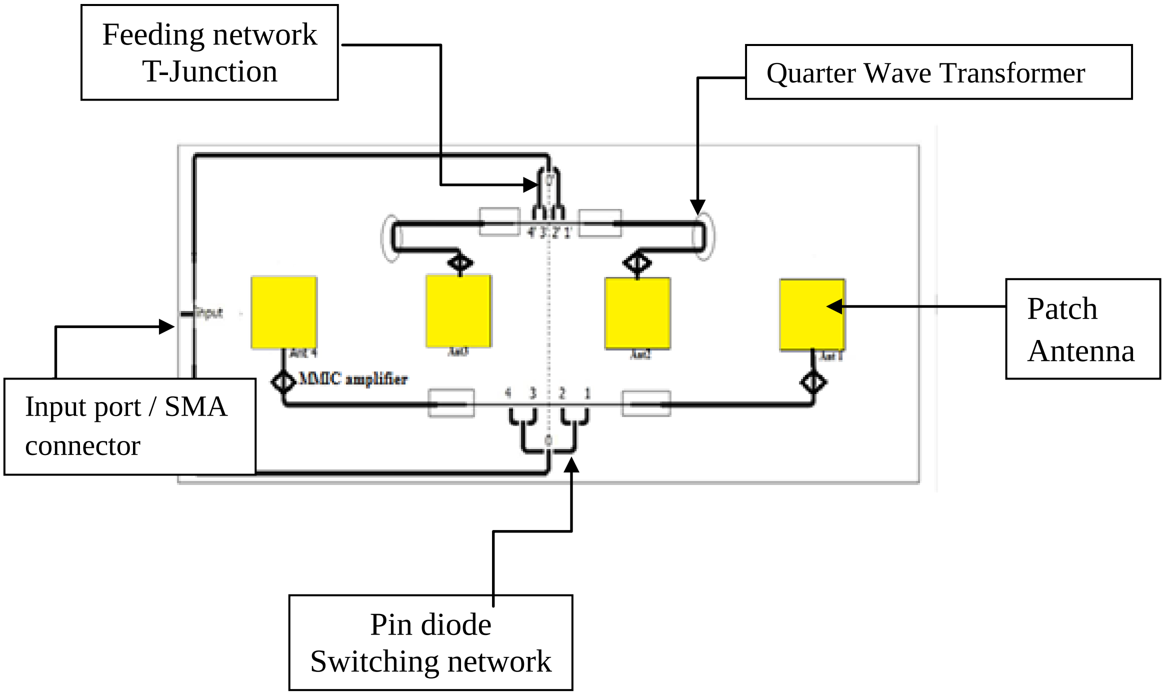


Fig.1.1 Block Diagram of APAA

Fig.1.1 shows the basic design of active phased array antenna design. At the input port T-junction splits the input signal equally in two 100 ohm transmission lines. It is further split equally by using another T-junction. Afterwards, PIN diodes are used for beam shifting. Quarterwave transformers are used for impedance matching.

1.4 Scope, Specifications and Deliverables of the Project

1.4.1 Scope of the Work

The project encompasses the conception of overall theme of active phased array antenna with a view to devise techniques which will facilitate in designing the array antenna along with in-depth experience of the RF power amplifiers. This project helped the syndicate to design and develop relevant RF phase shifters etc. necessarily required for beam steering.

1.4.2 Specifications

A microstrip linear active phased antenna array operating at a center frequency of 3.2

GHz. A simple, low cost and low insertion loss beam switching feed network designed to achieve beam coverage of ±30° about the bore sight. Fabricated antenna is tested using the "vector network analyzer" and the "Antenna Test and Measurement System" (anechoic chamber at NUST H-12) to observe the radiation characteristics and the beam scanning properties of the antenna.

The antenna design criterion's set as goals for this project are tabulated in table-A

Table-A (Phased Array Antenna Specifications)

Features	**Required Values**
Center Operating/Resonant Frequency	3.2 GHz
Phase Shifter Type	Switched Line PIN Diode
Number of Patches	4
Array Antenna Configuration	Linear
Microstrip Radiator Used	Rectangular Patch
Polarization	Linear
Antenna Gain	9 dB
Antenna Beam Scan Range	+/- 30^0
Amplifier	PHA-1+
Amplifier Gain	11 dB

1.4.3 Deliverables

The project design has been divided into three phases. First the radiating part i.e. the 1x4 linear patch array antenna has been designed on HFSS for the resonant frequency of 3.2 GHz. Then the feeding network is designed and simulated on ADS, which is then integrated with the antenna on HFSS and simulated again to check for the impedance matching. This antenna and feeding network has been fabricated and tested for the impedance matching and radiation properties of the antenna. The testing results are shown in the later part of the report. Then the switching network for beam switching is simulated on ADS as well as on HFSS. This switching network after integration and impedance matching with the rest of circuit is fabricated and tested at the anechoic chamber, RIMMS. Fig.1.2 shows the final PCB design of our active phased array antenna.

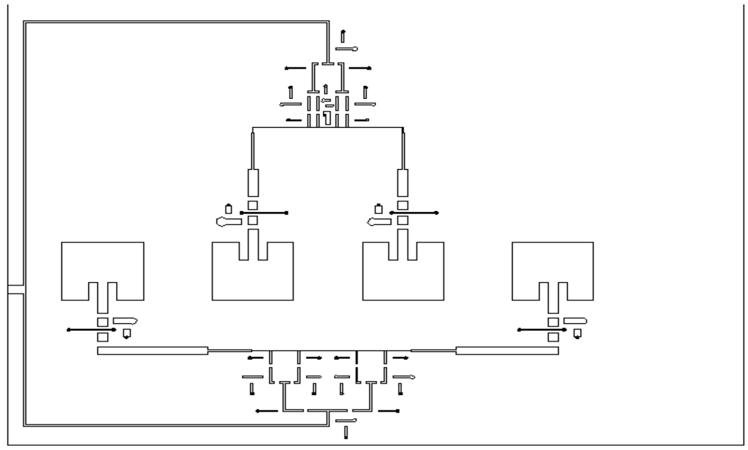


Fig.1.2 Auto CAD Design for PCB Fabrication of APAA

Fig.1.2 has been designed on AutoCAD software. It is complete and final PCB design including microstrip patch array antennas, feeding network and the switching network. This design is used for fabrication.

Chapter 2

LITERATURE REVIEW

2.1 Antenna

An antenna according to Webster's dictionary is defined as **a metallic device for radiating or receiving radio waves**. The IEEE standard definitions of terms for antenna (IEEE Std. 145- 1983) define the antenna as **a means for radiating or receiving radio waves**. Antenna is the transitional structure between the free space and the guiding device. This guiding device may be a co-axial line or a waveguide used to transport electromagnetic energy from the transmitter to the antenna or from the antenna to the receiver. In the former case, the antenna is called a transmitting antenna and is called a receiving antenna in the latter case. In addition to the receiving or transmitting energy, an antenna is an advanced wireless system usually required to optimize the radiation energy in some direction and suppress it in others [1].

2.2 Types of Antennas

The advances in antenna technology have led to development of following various types of antennas.

- Wire antennas
- Aperture antennas
- Reflector antennas
- Microstrip patch antennas
- Array antennas
- Microstrip patch array antennas

2.2.1 Microstrip Patch Antennas

Microstrip antennas developed primarily for space borne applications are shown below. They are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to fabricate, mechanically robust, compatible with MMIC designs and versatile in terms of resonant frequency, polarization, pattern and impedance. These antennas can be mounted on the surface of aircraft, spacecraft, satellites, missiles, cars and even hand-held mobile phones.

The most popular models for the design analysis of microstrip patch antennas are the transmission line model, cavity model, and full wave model.

Transmission line model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non–homogenous line of two dielectrics, typically the substrate and air.

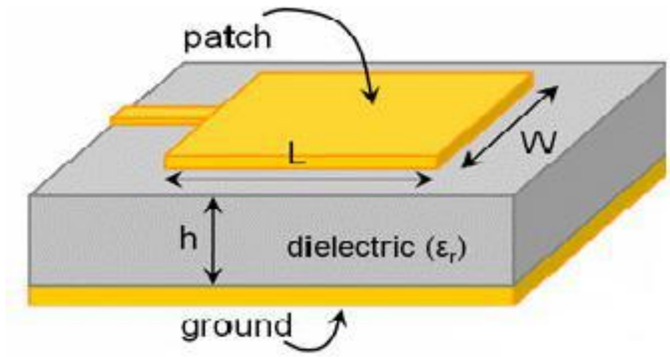


Fig.2.1 Transmission Line Model of Micro Strip Patch Antenna

2.2.2 Arrays and Microstrip Patch Array Antennas

Single antenna gain is increased as length is increased but as length is increased above λ spurious radiations (side/ backlobes) increases. To tackle this problem more than one antenna is used in the form of array, so gain is increased without having too many minor lobes. Example of array antenna includes microstrip patch array antennas. Microstrip patch array antennas can be Linear or Planar.

Few factors that control the radiation pattern of array antenna are:

Spacing between the patches (it is done in such a way to have desired constructive interference).

Input power (More the power better the chances to get received).

Input excitation phase (it is controlled to move the beam in desired direction).

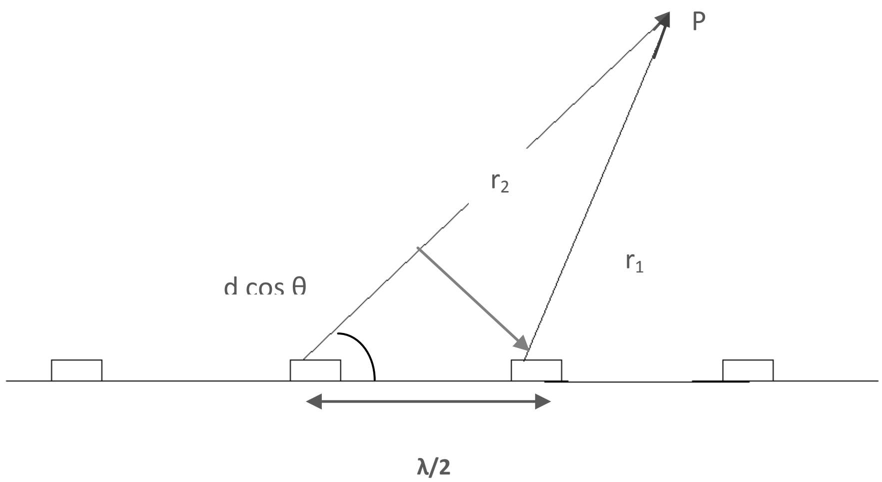


Fig.2.2 Far Field Geometry of 4 Element Array

At the point of interest i.e. required direction/point we get

$$\mathbf{A=Ae^{-j\psi}} \tag{2.1}$$

$$\boldsymbol{\psi} = \mathbf{kdcos}\boldsymbol{\theta} + \boldsymbol{\beta} \tag{2.2}$$

where ,

ψ = phase of the received signal

kdcosθ = phase due to path difference

β = excitation phase

Now to get the maximum amplitude in

$$\mathbf{A=Ae^{-j\psi}} \tag{2.3}$$

ψ should be equal to 0.

Thus

$$\mathbf{kdcos}\boldsymbol{\theta} + \boldsymbol{\beta}\mathbf{=0} \tag{2.4}$$

So this condition can give us phase due to path as **β and d** are already known

$$\boldsymbol{\theta} = \mathbf{cos\text{-}1(}\boldsymbol{\beta}\mathbf{/kd)} \tag{2.5}$$

2.3 Phased (Scanning) Array

It is logical to assume that the maximum can be oriented in any direction to form a scanning array. Let us assume that the maximum direction of an array is required to be oriented at **θ ($0^o \leq \theta \leq 180^o$).** To accomplish this phase excitation **β** between the elements must be adjusted so that

$$\boldsymbol{\psi = kd\cos\theta + \beta = 0 \qquad \theta\ (0^o \leq \theta \leq 180^o)} \qquad (2.6)$$

$$\boldsymbol{\beta = -kd\cos\theta} \qquad (2.7)$$

thus by controlling the progressive phase shift between the elements, the maximum radiation can be squinted in any direction to form a scanning array. This is the basic principle of electronic in scanning phased array operation.

2.4 Phase Shifting in T/R Modules

The phase shifter supplies the incremental phases to each element that is what drives the beam in different directions. Because phase shift is required in both transmit and receive, it is usually placed in a path that is common. In this case the phase shifter can be a passive reciprocal device (it usually is). It is possible to design an active phase shifter.

Phase shifters have phase errors, they are not perfect. But a not-so-well understood phenomenon of phase shifters is that their phase errors get worse if they see a crummy VSWR. When one design a T/R module he needs to take this into account; first off one should place the phase shifter between well-matched components (usually one side of the phase shifter is connected to the attenuator which always provides a nice match)

2.5 Phase Shifting Using PIN Diodes

An innovative yet simple technique, in order to achieve switching capability which could give greater than 15 dB isolation between switching branches. The proposed technique use PIN diodes to provide an open or short circuit at the point of contact. Careful selection of PIN diodes can provide minimum insertion loss while keeping the overall antenna size small and low cost.

2.6 T- Junction Power Divider

A T-junction is a power divider used in corporate feed network so first we would discuss corporate and series feed networks.

2.6.1 Corporate and Series Feed Networks

Corporate and series feed networks are the most common methods of signal distribution to elements in an array. A corporate or parallel feed uses power dividers to distribute transmit and/or receive signals in an array. Power dividers funnel off signals from a transmission line or route the signal to other transmission lines. Figure below shows corporate feed network in a microstrip patch antenna array.

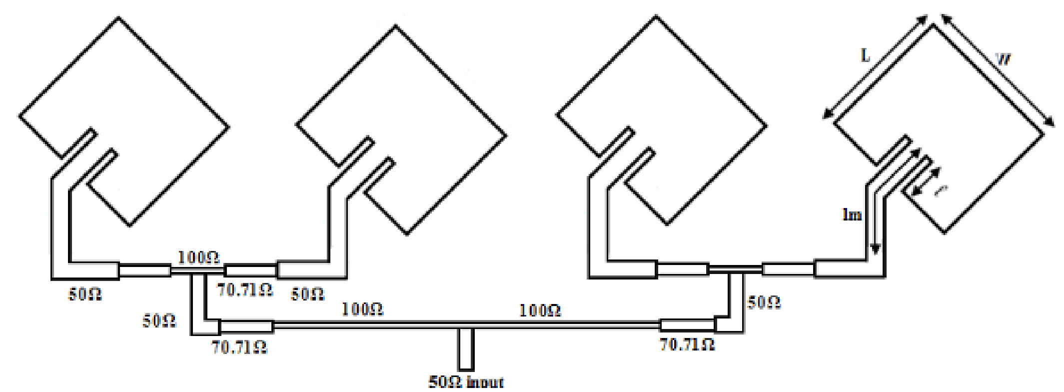


Fig.2.3a Corporate Feed Network Using T-Junction

Elements connected to a series feed network all tap the same transmission line or waveguide which is shown on next page:

Fig. 2.3b Series Feed Network
Fig.2.3 Feed Network

2.6.2 Transmission Line Model

The T-junction power divider is a simple three-port network that can be used for power division or power combining, and it can be implemented in virtually any type of transmission line medium. The T-junction cannot be matched at all ports. The lossless T-junction can all be modeled as a junction of three transmission lines, as shown below

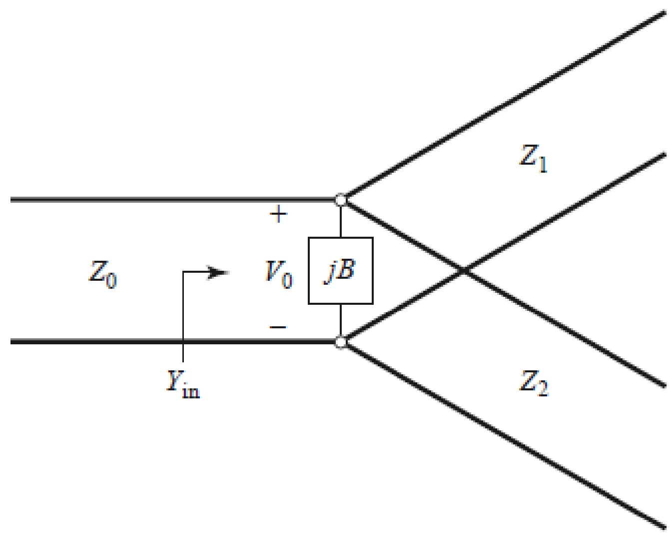


Fig.2.4 Transmission Line Model of a Lossless T-Junction Divider

In order for the divider to be matched to the input line of characteristic impedance Zo, we must have

$$\mathbf{Y_{in} = jB + 1/Z_1 + 1/Z_2 = 1/Z_0} \quad (2.8)$$

If the transmission lines are assumed to be lossless (or of low loss), then the impedances are real. If we also assume B = 0, then (1) reduces to

$$\mathbf{1/Z_1 + 1/Z_2 = 1/Z_0} \quad (2.9)$$

In practice, if B is not negligible, some type of discontinuity compensation or a reactive tuning element can usually be used to cancel this susceptance, at least over a narrow frequency range [2].

The output line impedances, Z_1 and Z_2, can be selected to provide various power division ratios. Thus, for a 50 Ω input line, a 3 dB (equal split) power divider can be made by using two 100 Ω output lines.

2.7 The T/R Module

An active phased array uses a special type of solid state transmitter module. All components are assembled in one single T/R module. This module integrates the electronic phase shifter, the digital controlled attenuator, the solid-state power amplifier, the low noise amplifier (LNA) and two circulators and a Duplexer. It is also usual for the module to have self test and status features so that the overall performance of the system can be assessed. A limiter is sometimes added between the LNA and antenna. This reduces very strong incoming signals from jammers or large targets (with very high Radar Cross Section) close to the radar.

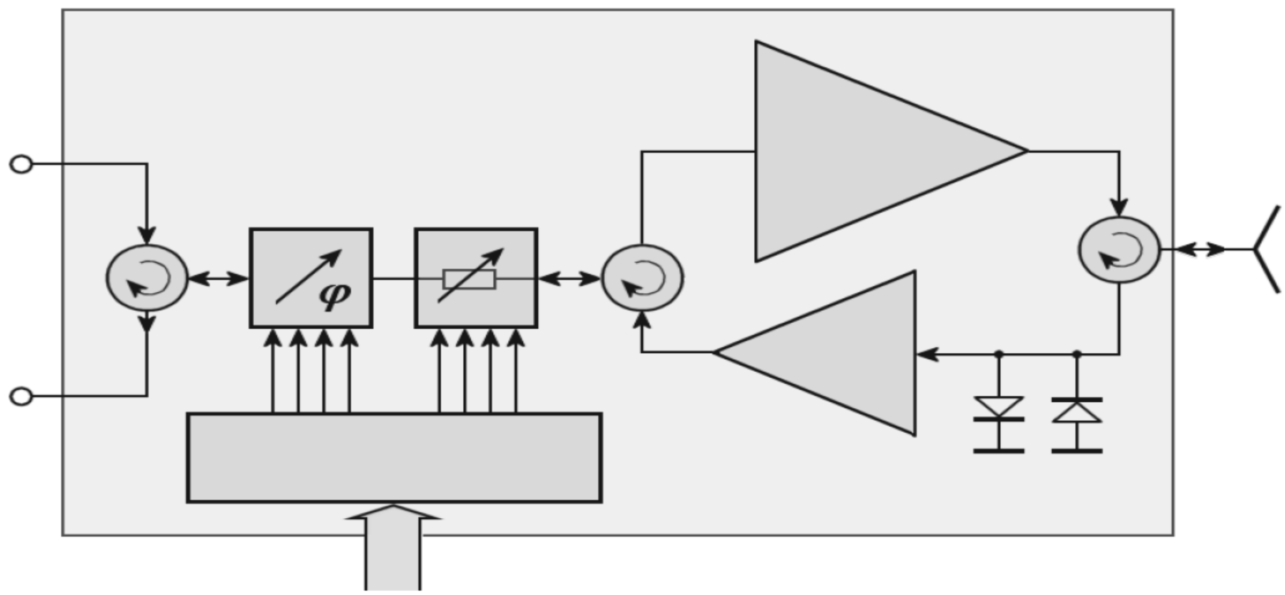


Fig.2.5 A Typical T/R Module

2.7.1 Phase Shifter

The phase shifter supplies the incremental phases to each element that is what drives the beam in different directions. Because phase shift is required in both transmit and receive, it is usually placed in a path that is common. In this case the phase shifter can be a passive reciprocal device (it usually is).

2.7.2 Low Noise Amplifier (LNA)

The LNA sets the noise of the system, but all losses between the antenna and the LNA add to the overall noise and must be minimized.

2.7.3 Attenuator

The attenuator is used to add an amplitude taper across the array, to reduce sidelobes. This is typically only done in receive, in transmit you want to splash as much radiation as you can. The attenuator often performs a second function of aligning the amplitudes of the individual elements. Typically a digital attenuator is used.

2.7.4 Duplexer (Circulator)

The duplexer is what allows the antenna to be shared between transmit and receive. It can be a ferrite circulator, or sometimes just a SPDT switch. In the case of a circulator, this is not a solid-state component, so it doesn't have to be within a hermetic housing. Sometimes you might see the T/R module's circulator outside the housing.

2.7.5 Isolator

One other issue that the duplexer has to deal with is that at extreme scan angles, the VSWR of the antenna can get ugly. When this mismatch is passed on to the power amp, its power can degrade due to load pull effects (worse than the straight mismatch loss). An isolator is often used to solve this problem, it presents a matched load to the antenna (and power amp) no matter what the LNA or limiter is doing to the VSWR. The European TR module shown above does not have an isolator.

2.7.6 Limiter

The limiter prevents damage to the low noise amplifier during transmit or whenever stray radiation is present.

The limiter often performs a second important function. It provides a termination to the circulator during transmit, to absorb power that reflects from the antenna. Significant power can be reflected at large scan angles. Why terminate it? The power amp needs to see the correct impedance or its power will drop due to load pull. In the T/R module above there appears to be a resistive load below the front limiter diode to perform this function.

Chapter 3

DESIGN AND DEVELOPMENT

The design of a beam switching feed network is done for the antenna array. In contrast to the traditional Butler matrix, the proposed feed network consumes less physical space. The compact size of the feed network is achieved by avoiding the branch line couplers that are the basic building blocks of the Butler matrix. Another advantage of the proposed feed network design is the use of reverse biased PIN diodes to stop backward power flow. This improves isolation between switching branches at designed frequency. The design of the proposed beam switching network is described in detail below:

3.1 Feeding Network

A corporate type 1 to 4 power splitter is used as the basic design for the feed network. A single 50Ω input transmission line is split into two 100Ω lines to achieve equal power split which in turn is split into 200Ω line. Each 100Ω section is transformed back to 50Ω transmission line by using an impedance matching quarter wavelength transformer (marked by rectangles). Fig.3.1 shows the layout of the basic feed network. It is worth mentioning that two of the four patches are physically inverted and thus 180° phase compensation should be provided in order to achieve maximum gain in the required direction. This is achieved by adjusting the line length of the top (feed) part (shown by ovals) [3].

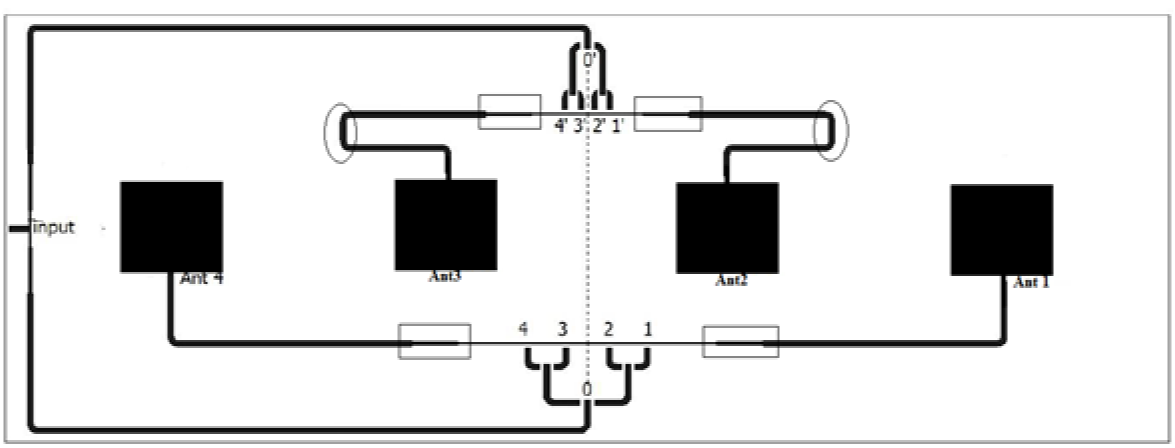


Fig.3.1 1 x 4 Power Split Feed Network

3.2 PIN Switch

The next task was to employ a switching mechanism ensuring an appropriate phase difference between consecutive branches for multiple switching states. The proposed beam switching network uses small microstrip lines with PIN diodes to achieve the appropriate phase difference between antenna elements and to achieve better isolation between the switching legs. Careful selection of PIN diodes can minimize insertion loss while keeping the overall antenna size small and low cost.

Fig. 3.2 represents the schematic layout of the PIN diode based switch where the highlighted path shows the transmission of the incoming signal for a positive biasing voltage at B1, B2 and B3.

RF choke inductors (100 nH) have been used to isolate the RF energy and DC supply. Further protection is achieved by using shunt capacitors (10µF) at all the biasing points. The series resistance of the RF choke inductors helps in limiting the flow of current. The selection of the PIN diode is based upon the value of the reverse biased capacitance and forward biased insertion loss. The operation of the switch is very simple. Correct biasing (±5V, 40 mA) at the corresponding biasing points put the required PIN diodes in forward bias configuration allowing the RF energy to transmit from the input to one of the four switching branches (state 1 to 4). Similarly the PIN diodes are put in the reverse biased configuration stop the flow of RF energy through them creating an open circuit.

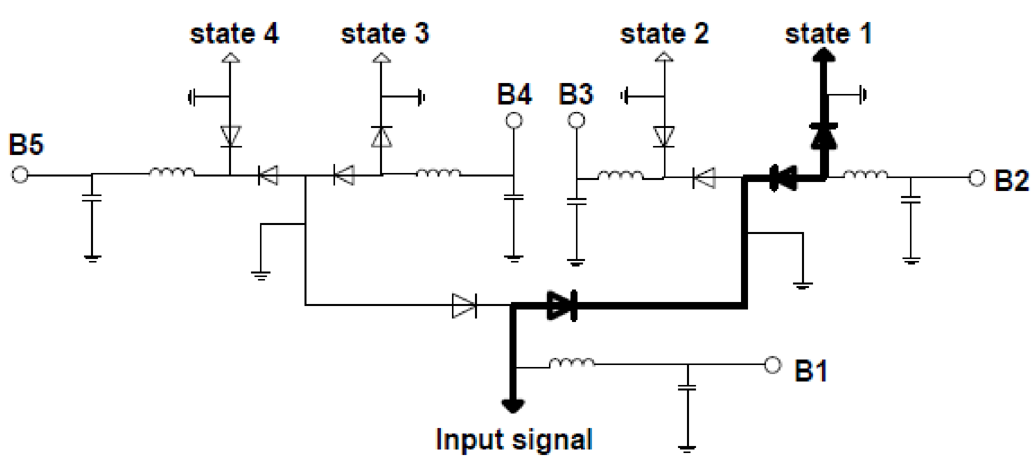


Fig.3.2 Feeding Network Layout of PIN Diode Switch (quarter wave lines not shown)

3.2.1 Beam Switching Mechanism

The beam switching mechanism of the proposed feed network can be explained by considering the standalone antenna elements as the point sources The phase advancement or retardation between the E fields of n number of point sources (on the same line) of equal amplitude and arbitrary phase difference is given as:

$$\psi = kd\cos\theta + \beta \qquad (3.1)$$

where θ is angle between the array axis and any arbitrary direction and d is the distance between the sources and k = 2πd/λ while βis the relative phase difference between consecutive sources.

The E-field maximum is in the direction of θ when ψ is zero. Putting ψ = 0 in (3) leads to (4):

$$kd\cos\theta + \beta = 0 \qquad (3.2)$$

So this condition can give us phase due to path as β and d are already known

$$\theta = \cos^{-1}(\beta/kd) \qquad (3.3)$$

which means that for a fixed array spacing, the antenna beam can be switched in different directions for a selection of β or vice-versa.

3.2.1.1 Mapping of Required Beam Direction to the Switch Position

The required beam switching directions (θ_n) are calculated in order to provide a continuous coverage across boresight. Equation (4) is used to calculate the required relative phase difference (β_n) between the antenna elements. The calculated phase difference is converted to physical distance between the antenna elements (using equation 5) thereby resulting in the selection points 1, 1'; 2, 2'; 3, 3' and 4, 4' (of 3.1).

$$\beta_{dist} = \frac{2\pi \left| d_{\beta_n} \right|}{\lambda_g} \qquad (3.4)$$

The same configuration has been used on both the right and left hand sides of the 00' reference line. Table-B presents the required beam switching directions and the respective positions of the switching lines.

Table-B

Beam Direction θ	**Relative Phase Difference β**	**Relative Phase to distance conversion $d_{\beta\,(mm)}$**	**Required switch and distance from 00'**	
-30^0	90^0	12	1	18
			1'	6
30^0	-90^0	-12	4	-18
			4'	-6
-15^0	47^0	6	2	9
			2'	3
15^0	-47^0	-6	3	-9
			3'	-3

3.3 Power Amplifier

The main features of power amplifier are the circuit power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedance matching to the output device. There are different classes of power amplifiers but Class C is used in radio frequency applications in which there is one fixed or resonating frequency [4].

The power amplifier used in our project is PHA-1+. Since active phased array antenna is being designed, so PHA-1+ is placed behind each patch (radiating element) to provide distributed amplification.

3.4 Linear 1x 4 Array Patch Antenna Calculations

1 x 4 array patch antenna is designed using the HFSS v13.0. FR4 (relative permittivity of 4.4 and height of 1.6mm) is used as a substrate and the center frequency of operation for the patch is taken 3.2 GHz. The detailed calculations for the patch are done as shown below:

W = width of the patch

c_0 = speed of light

f_r= center frequency

ϵ_r= relative permittivity

h = height of the substrate

ϵ_{reff}= effective relative permittivity

y_0 = inset distance

gap = inset gap

3.4.1 Patch Calculations Formulae

(1)

$$W = \frac{c_o}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (3.5)$$

(2)

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}, W/h > 1 \quad (3.6)$$

(3)

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3.7)$$

(4)

$$L = \frac{c_o}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \quad (3.8)$$

3.4.2 Inset Calculations

(5)

$$gap = \frac{Co}{\sqrt{2\times \varepsilon_{eff}}}\frac{4.65\times 10^{-12}}{f} \qquad (3.9)$$

(6)

$$y_o = 10^{-4}\begin{Bmatrix} 0.001699\varepsilon^7{}_r + 0.13761\varepsilon^6{}_r - 6.1783\varepsilon^5{}_r + 93.187\varepsilon^4{}_r - 682.69\varepsilon^3{}_r + \\ 2561.9\varepsilon^2{}_r - 4043\varepsilon_r + 6697 \end{Bmatrix}\frac{L}{2}$$

$$(2 \le \varepsilon_r \le 10) \qquad (3.10)$$

After all the above calculations the values obtained are:

Width of the patch = W = 37.1 mm

Length of the patch = L = 30.8 mm

Inset distance = y_0 =9.4 mm

Inset gap = w_0 =2.43 mm

The feed width and inset gap has been adjusted and tuned to match the impedance of feed with the antenna patch so best results have been found with the feed width of 3.2mm and inset gap of 2.76mm.

3.4.3 Inter Element (Patch) Distance

Grating lobe occurs when steering is done too far with a phased array and the main beam reappears on the wrong side. Elements must be spaced properly in order to avoid grating lobes. The equation for maximum spacing is a function of wavelength of operation and maximum look angle [5]:

$$d_{max} = \frac{\lambda}{1+\sin\theta}$$

where :

$\lambda = wavelength$

$\theta = look\ angle$ (3.11)

For broadside d_{max} (inter element distance) comes out to be equal to λ. So inter element spacing 'd'is kept λ/2 to avoid the grating lobes. It is worth mentioning here that this distance is from centre of one patch to the centre of other.

Chapter 4

PROJECT ANALYSIS AND EVALUATION

4.1 T-Junction Design

T-junction has been simulated on ADS. Fig,4.1c shows reflection coefficient and insertion loss at input and output ports.

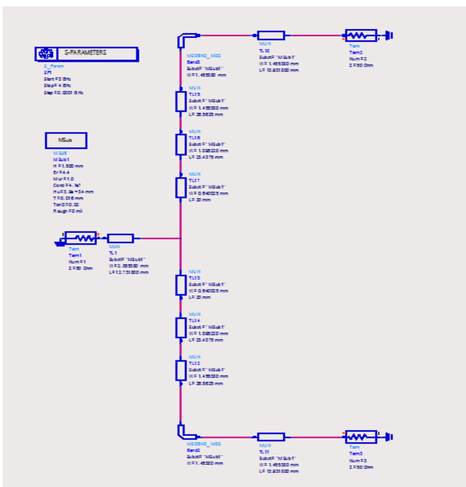


Fig. 4.1a ADS Design

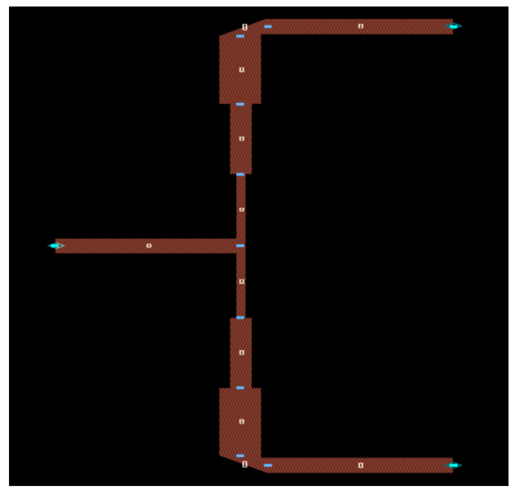


Fig. 4.1b ADS Layout

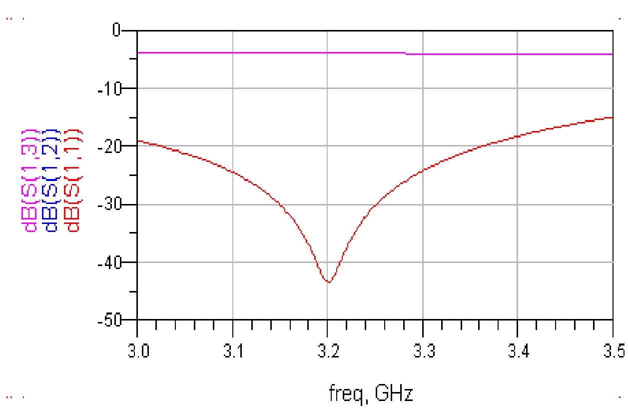


Fig.4.1c. S-Parameter Result

Fig.4.1 ADS Design, Simulation and Results

Fig.4.1a shows the basic T-junction design on ADS. After designing basic T-junction, it is converted into PCB layout as shown in Fig.4.1b. Fig.4.1c shows the reflection coefficient (S_{11}) at resonant frequency 3.2 GHz is -42dB. Reflection coefficient shows the input power that is reflected from the antenna. The small value of S11 shows that very little power is reflected from the antenna while straight line at -3dB shows that power is equally divided among output ports.

4.2 Phase Shifter Design on ADS

Phase Shifter design was simulated on ADS. Obtained results are shown in Fig.4.2.

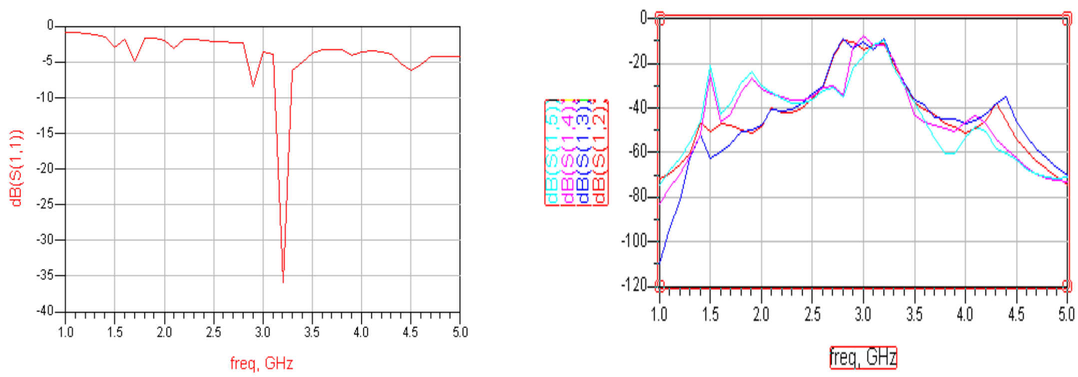


Fig.4.2a S. Parameters

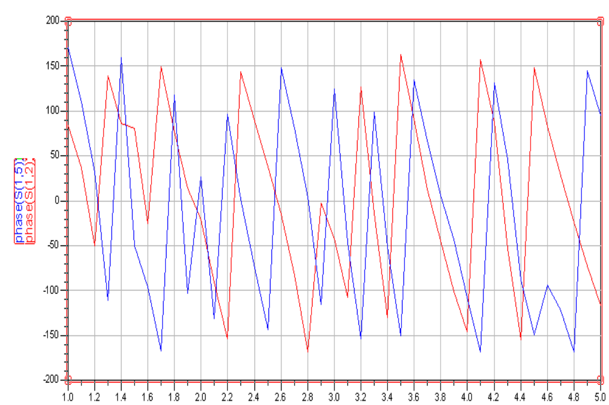


Fig.4.2b Relative Phase Shift for 90°

Fig.4.2 ADS Results of Designed Phase Shifters

Fig 4.2a represents reflection coefficient and insertion loss of the system. Fig. 4.2a shows that S_{11} at 3.2 GHz is -36 dB. Fig 4.2a also shows that power is divided among four output ports equally (-6dB). Fig.4.2b shows the relative phase shift between output port 2 and output port 5.

4.3 Antenna with Feeding Network Design

1x4 linear patch array antenna was simulated in HFSS software. Results are shown in the figures below.

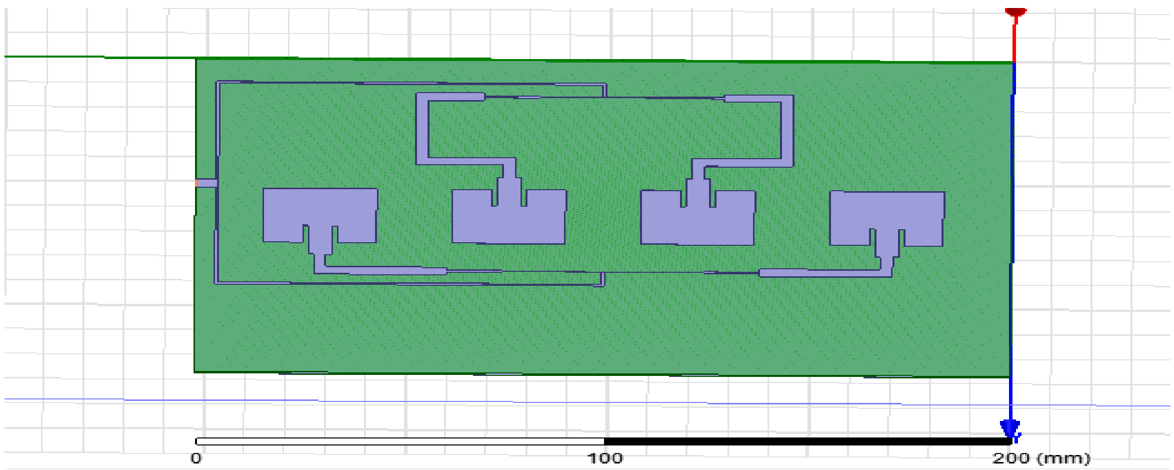


Fig.4.3a HFSS Design

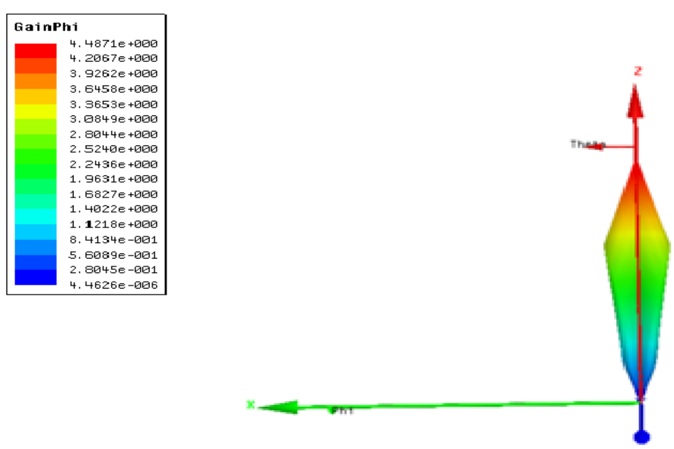
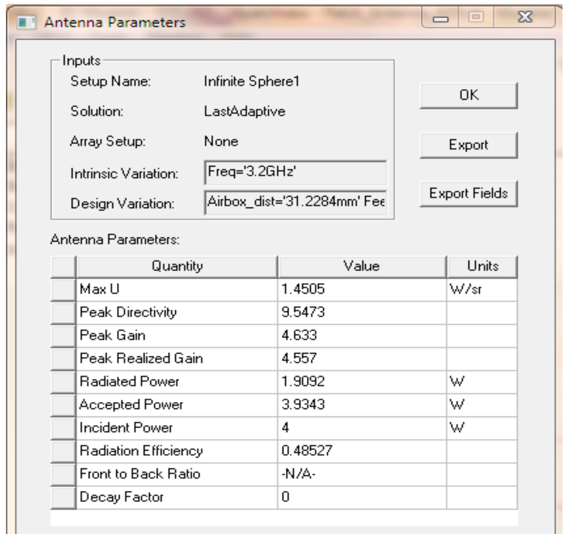


Fig.4.3b Radiation Pattern (Polar plot)

Fig.4.3 HFSS Design and Radiation Pattern

Fig.4.3a shows the HFSS design of feeding network along with patch antennas. Fig.4.3b shows the radiation plot of Fig.4.3a when there is no beam steering, that is why main lobe has been directed at 0 degree.



Antenna Parameters

Inputs
Setup Name: Infinite Sphere1
Solution: LastAdaptive
Array Setup: None
Intrinsic Variation: Freq='3.2GHz'
Design Variation: Airbox_dist='31.2284mm' Fee

OK
Export
Export Fields

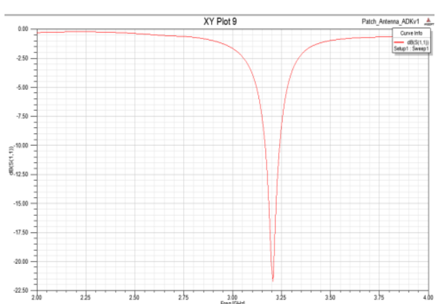
Antenna Parameters:

Quantity	Value	Units
Max U	1.4505	W/sr
Peak Directivity	9.5473	
Peak Gain	4.633	
Peak Realized Gain	4.557	
Radiated Power	1.9092	W
Accepted Power	3.9343	W
Incident Power	4	W
Radiation Efficiency	0.48527	
Front to Back Ratio	-N/A-	
Decay Factor	0	

Fig.4.4 Simulated Antenna Parameters

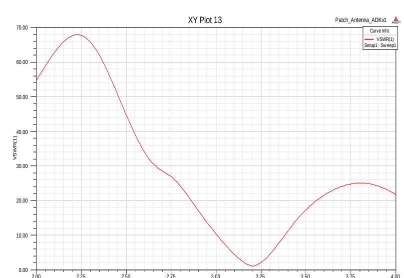
Fig.4.4 shows different simulated antenna parameters of the antenna and switching network designed in Fig.4.3a.

4.3.1 HFSS Antenna Results



Name	X	Y
m1	3.2000	-24.9628

4.5a



Name	X	Y
m1	3.2010	1.1136

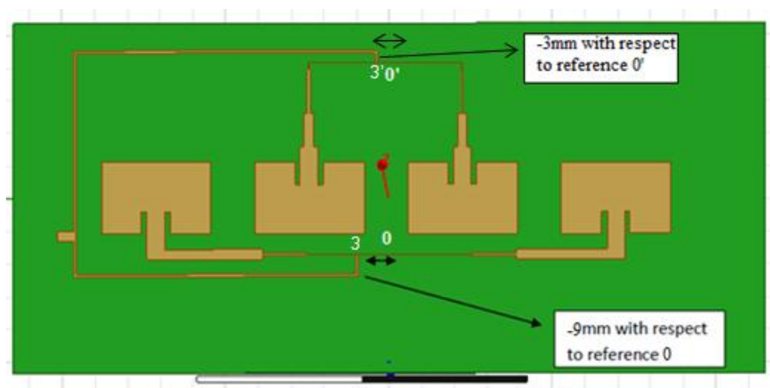
4.5b

Fig.4.5 Simulated Antenna Results

Fig. 4.5a shows S_{11} whose value at 3.2 GHz is -24.96 while Fig. 4.5b shows VSWR along with their values at 3.2GHz in “marker-m1”. Both S_{11} and VSWR tell us about reflections and impedance mismatch.

4.4 Beam Shifting

Calculated results tabulated in Table-B were verified by simulating it in HFSS software. Beam was successfully shifted at all the discrete angles by changing the position of feed line from the reference point to the required distances. Radiation patterns generated in HFSS software are shown in 4.6.



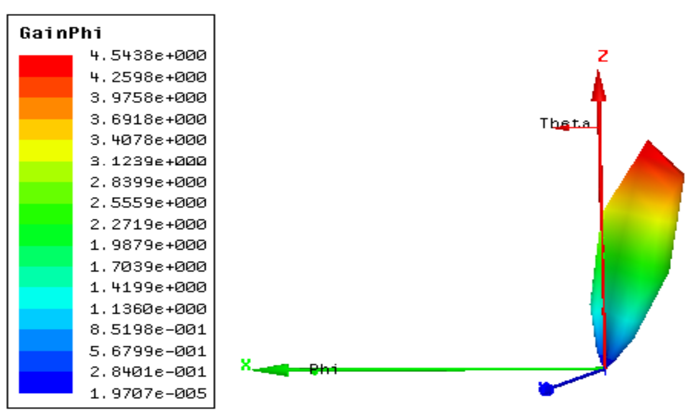
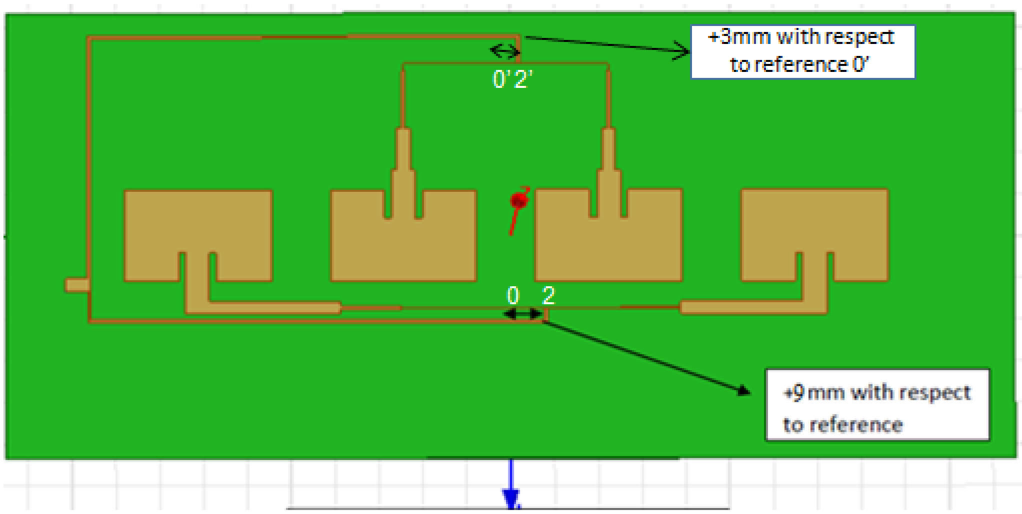


Fig. 4.6a 15^0 Phase Shift

Fig. 4.6a shows that when there is a distance of -3mm from state 3` to reference 0` and a distance of -9mm from state 3 to reference 0, then beam is steered at an angle of 15^o.



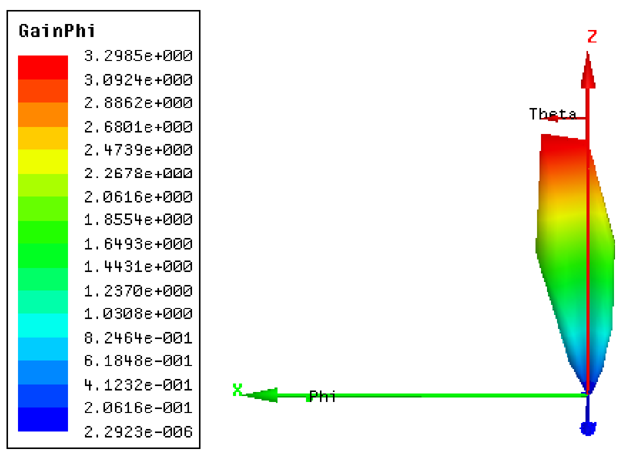


Fig. 4.6b -15^0 Phase Shift

Fig. 4.6b shows that when there is a distance of 3mm from state 2` to reference 0` and a distance of 9mm from state 2 to reference 0, then beam is steered at an angle of -15^o.

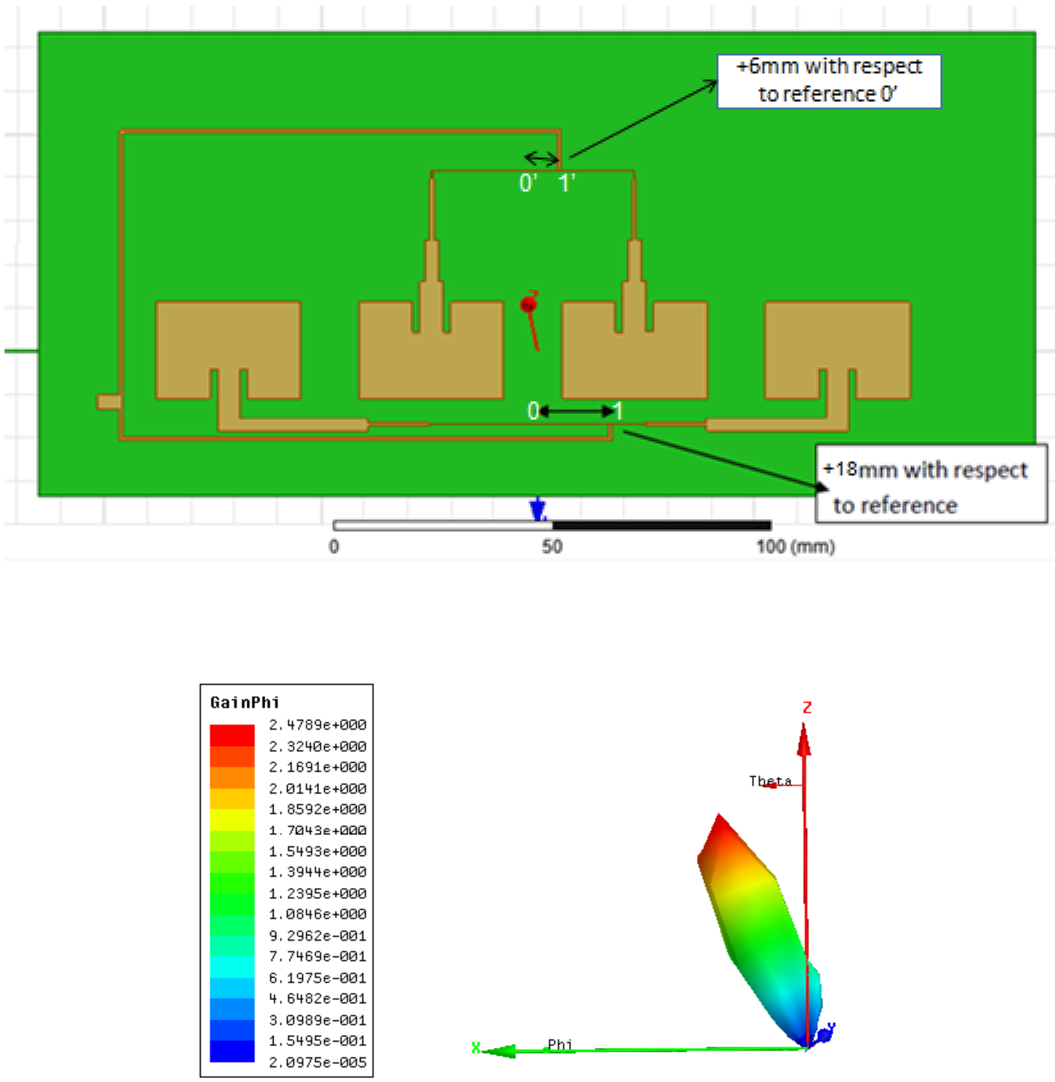
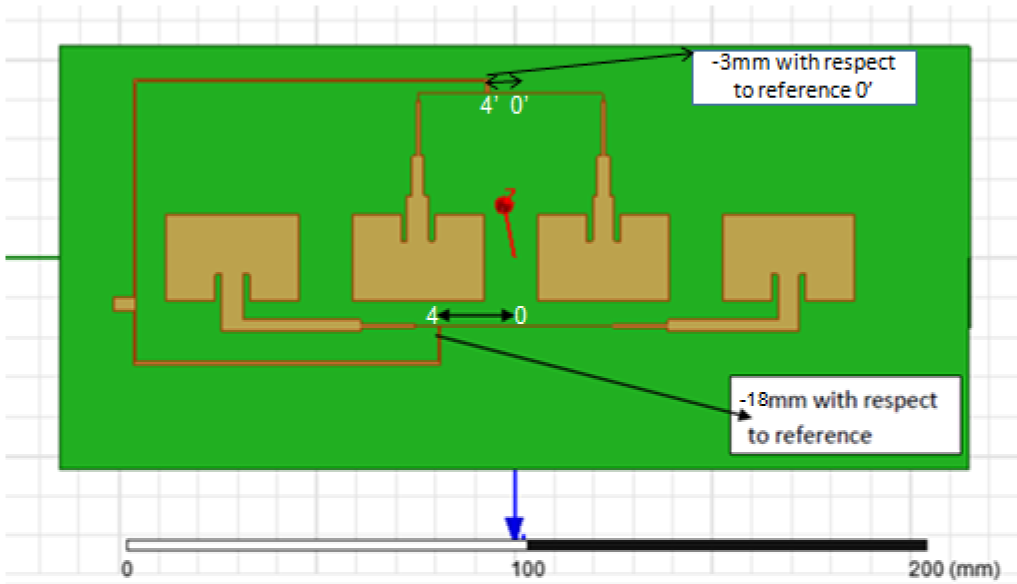
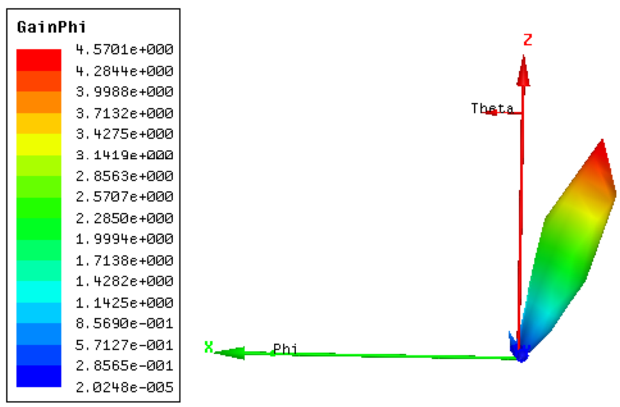


Fig. 4.6c -30^0 Phase Shift

Fig. 4.6c shows that when there is a distance of 6mm from state 1\` to reference 0\` and a distance of 18mm from state 1 to reference 0, then beam is steered at an angle of -30^o.





4.6d 30^0 Phase Shift

Fig.4.6 Beam Shifting

Fig. 4.6d shows that when there is a distance of -3mm from state 4` to reference 0` and a distance of -18mm from state 4 to reference 0, the beam is steered at 30^o.

4.5 Fabricated Antenna with Feeding Network

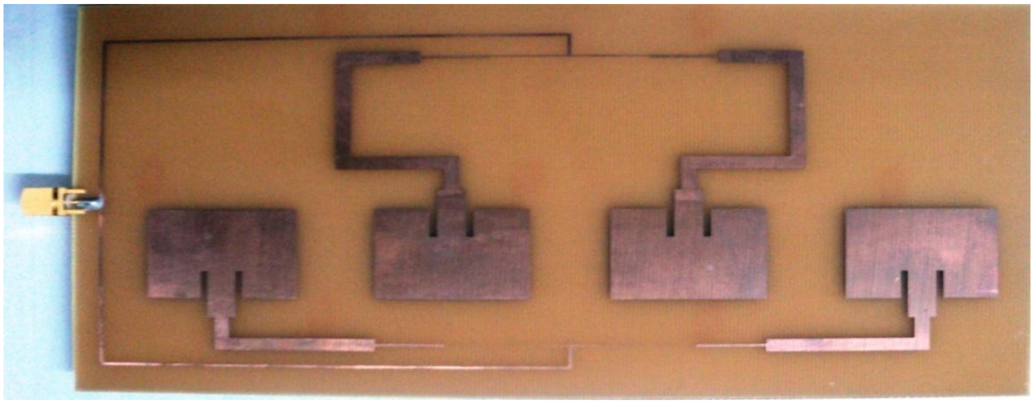


Fig.4.7 Fabricated Antenna

Fig. 7 shows the fabricated antenna with feeding network that has been fabricated by NRTC.

4.5.1 VNA Results

A vector network analyzer is an instrument that measures the network parameters of electrical networks. Vector network analyzers commonly measure s-parameters because reflection and transmission of electrical networks are easy to measure at high frequencies. VNA results are shown in figures below.

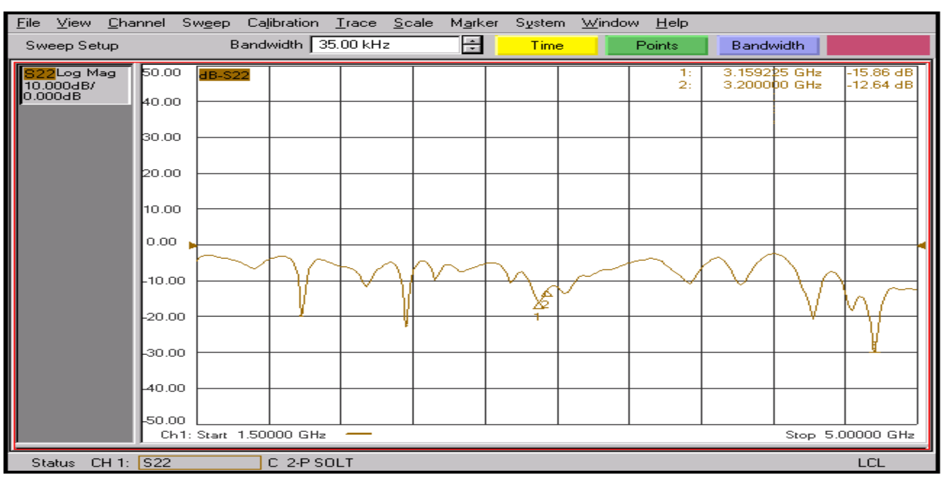


Fig.4.8a. S-Parameter

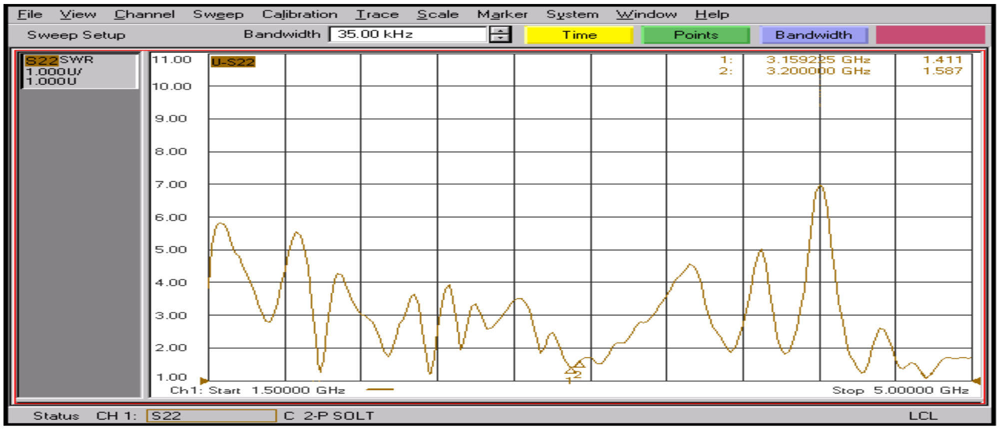


Fig.4.8b VSWR Pattern

Fig.4.8 Fabricated Antenna Results

Fig. 4.8a shows S_{22} parameter generated from VNA at RIMMS, NUST. Its value at 3.2GHz is -12.64dB while Fig. 4.8b shows VSWR to be 1.587 at 3.2 GHz.

4.5.2 Simulation versus Practical Results

Table- C

Parameters	Simulation results	Practical results
S11	-24.9628	-12.64
VSWR	1.1136	1.587

4.5.3 Observations and Radiation Pattern Taken at Anechoic Chamber (RIMMS, NUST)

The antenna has been fabricated by NRTC on LPKF machine. As shown in Table-C variation in practical values as compared to the designed simulation has been observed due to human errors in fabrication process and SMA connector (port) losses. Researches show that more accuracy can be achieved by using gold platted connectors to minimize the port losses if they are carefully soldered.3D Radiation pattern, 2D radiation pattern and H cut are shown in the coming figures. Results were satisfactory.

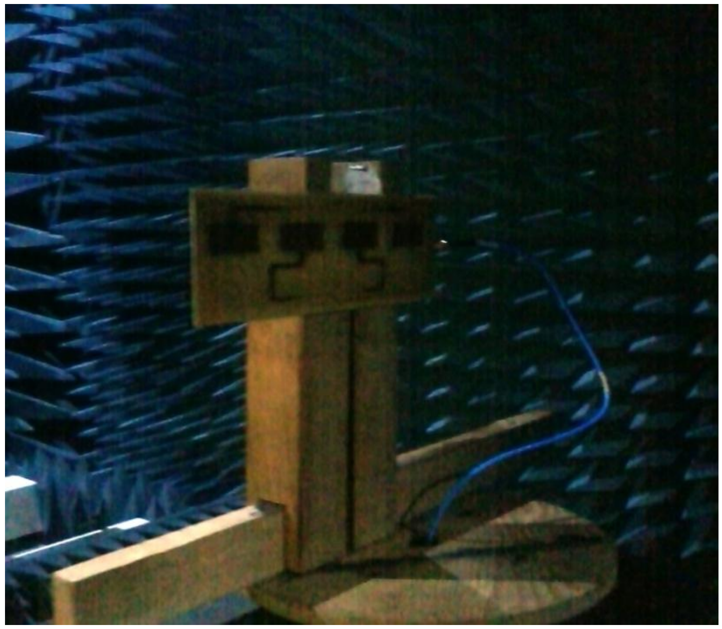


Fig.4.9 Antenna Mounted for Testing

Fig. 4.9 shows the fabricated antenna with feeding network mounted in anechoic chamber at RIMMS, NUST for testing and generation of radiation pattern. Anechoic chamber has no stray radiations and it provides ideal environment for antenna testing.

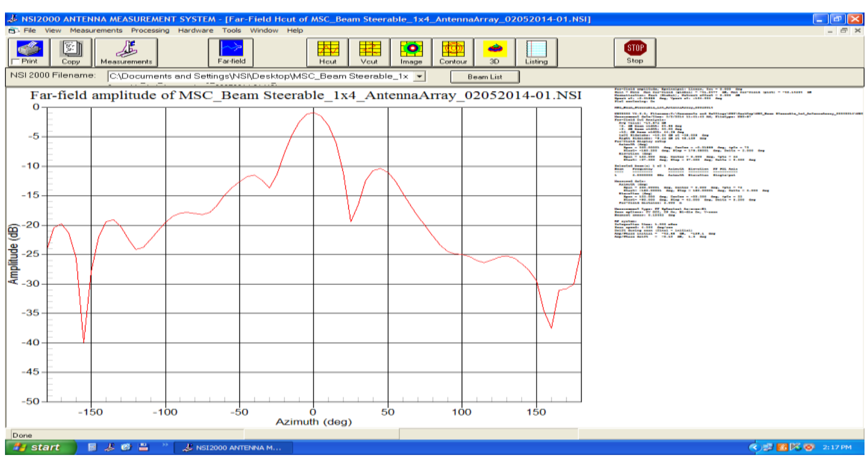


Fig.4.10a H Cut for 0^0 Phase Shift

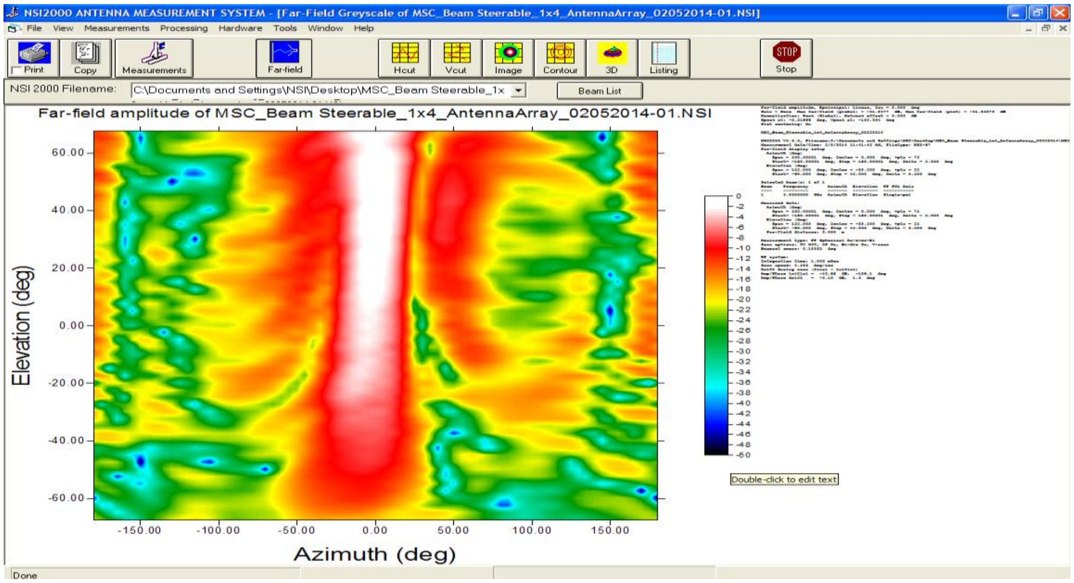


Fig.4.10b 2D Radiation Pattern

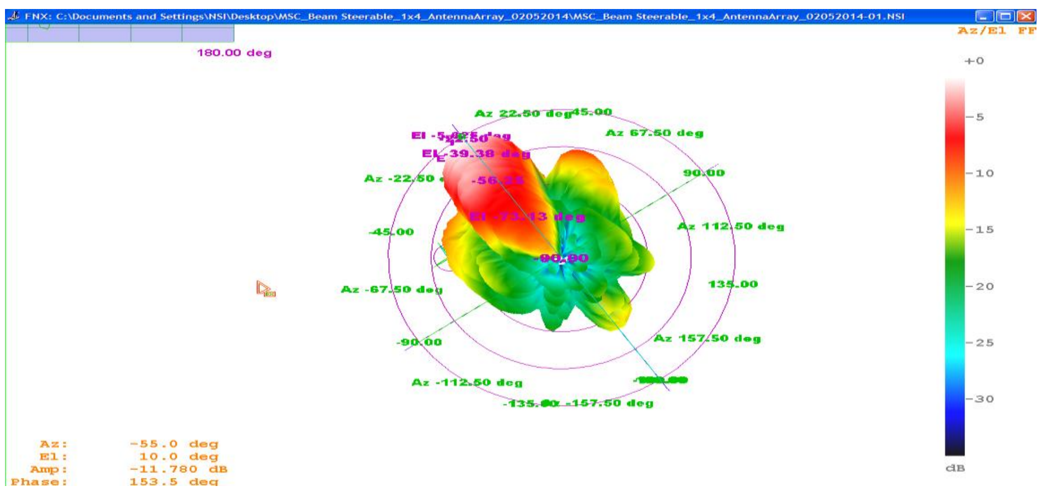


Fig.4.10c 3D Radiation Pattern

Fig.4.10 Anechoic Chamber Results for 0^o Phase Shift

Fig. 4.10a and 4.10b shows the 2D radiation pattern of antenna with feeding network. Fig.4.10c shows 3D radiation pattern in which main lobe is directed at 0^0, which means there is 0^0 phase shift in this case.

4.6 Complete Active Phased Array Antenna

The designed APAA has been fabricated by a private company in Islamabad. The components although being very small (SMD) were mounted on the board by the syndicate itself. The biasing voltages for diodes and amplifiers (MMIC) were provided by the PCB designed to provide required amount of voltage and current. Etching was done using $FeCl_4$ and switches and resistors were mounted. DC wires were used to connect the switches to the biasing points on the APAA. Rechargeable batteries were used as DC power sources. 3D Radiation pattern, 2D radiation pattern and H cut is shown in the coming figures. Results were satisfactory.

Fig. 4.11a APAA with Biasing Wires

Fig. 4.11b Biasing Circuit with DC Power Sources and Switches

Fig.4.11 Fabricated APAA Model

Fig.4.11 shows the complete fabricated design of APAA model along with DC biasing circuit. Rechargeable batteries are used for the operation of APAA, so it is a standalone model.

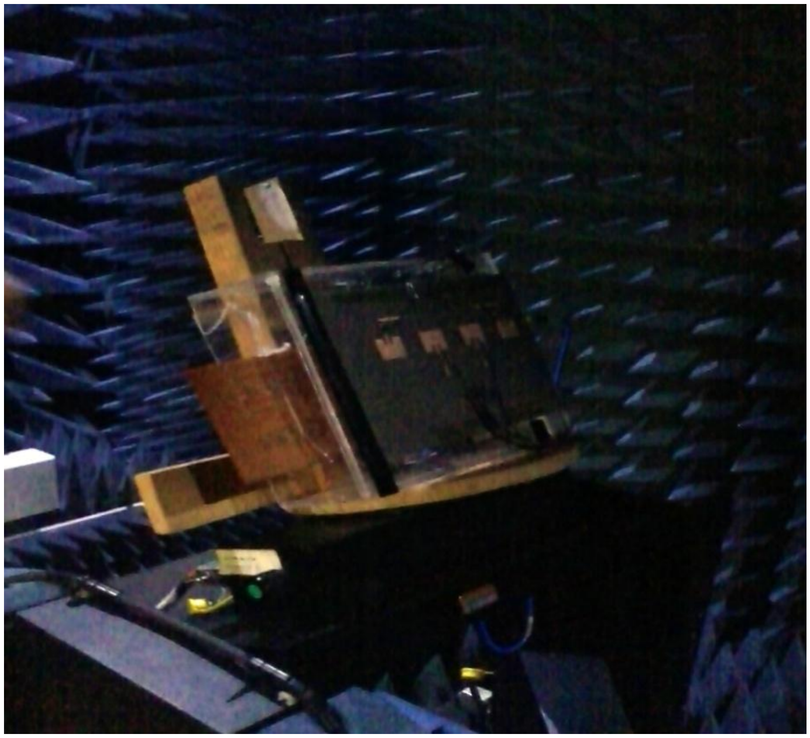


Fig. 4.12 APAA Mounted for Testing

Fig.4.12 shows the complete fabricated APAA model which is mounted in anechoic chamber at RIMMS, NUST.

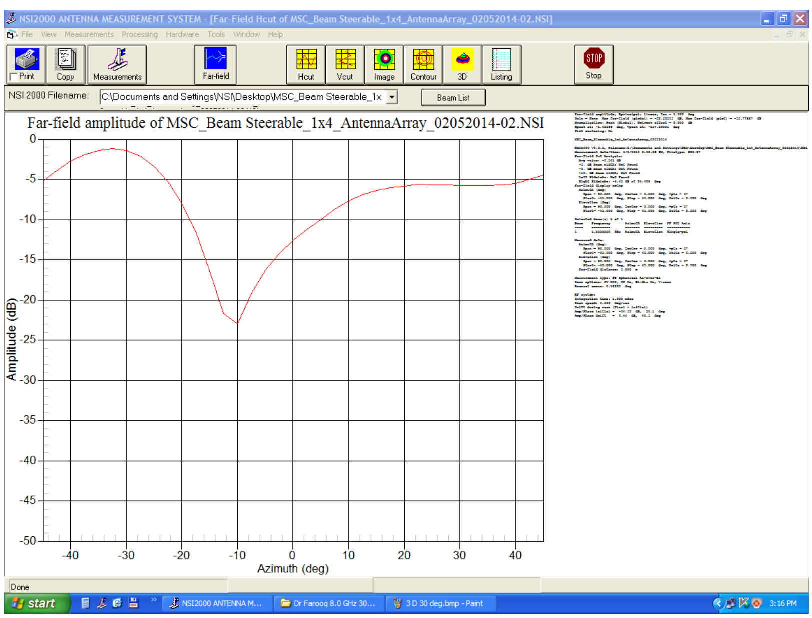


Fig.4.13a H Cut for -30^0 Phase Shift

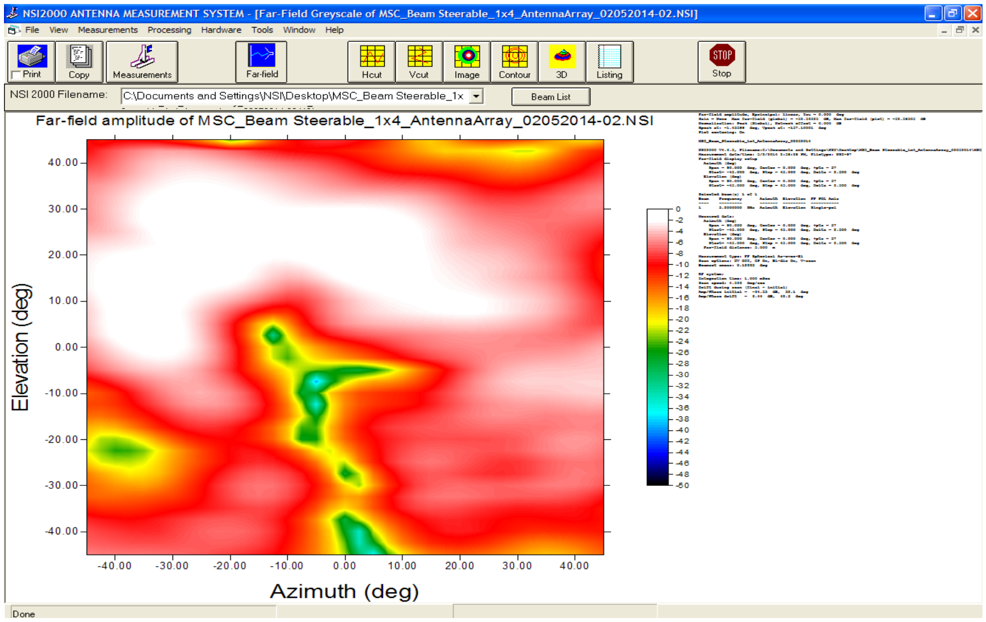


Fig.4.13b 2D Radiation Pattern Showing -30^0 Phase Shift

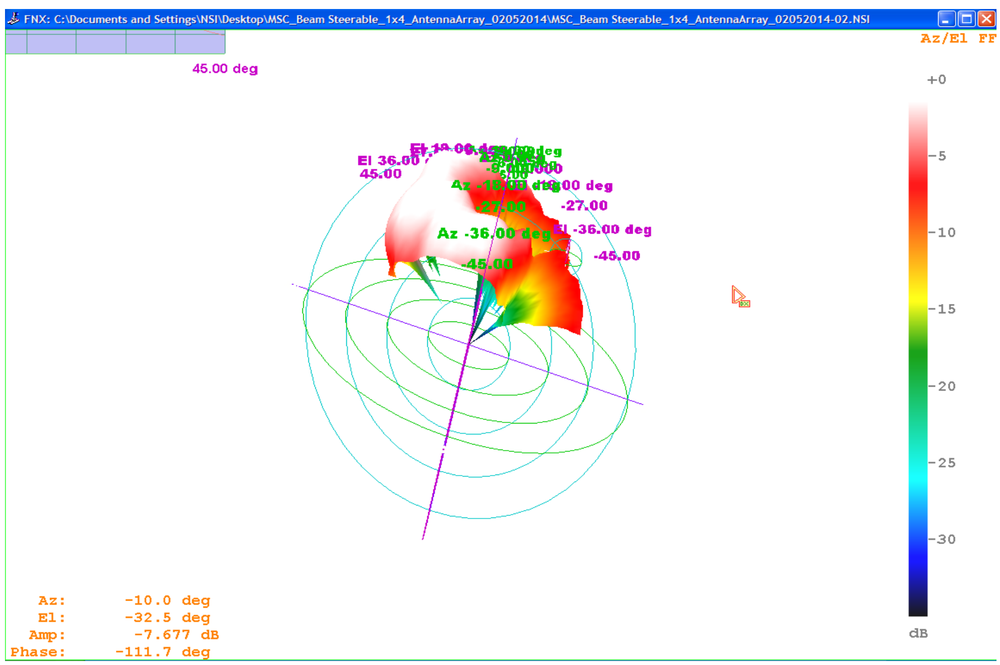


Fig. 4.13c 3D Radiation Pattern Showing -30^0 Phase Shift

Fig.4.13 Anechoic Chamber Results for -30^o Phase Shift

Fig. 4.13a and Fig. 4.13b shows the 2D radiation pattern for -30^0 phase shifting while Fig.4.13c shows the 3D radiation pattern in which white color shows the direction of main lobe which in this case is -30^0**.**

Chapter 5

RECOMMENDATIONS FOR FUTURE WORK

This project will be helpful in designing an Active Phased Array RADAR. RF front end has been successfully designed which can be used in any RF applications operating at 3.2GHz. Now only DSP part is needed to be designed after which it could be used in the satellite communication or imaging using SAR. This project can also be used to design the transceiver modules having integrated the phase shifters, circulators and amplifiers [6].

The project has been designed for beam shifting in only four discrete directions, that is, -30^0,-15^0,15^0,30^0. This project can be extended to many more beam shifting angles. Moreover, in this project linear array has been designed but this project can be extended to planar arrangement of microstrip arrays. DC biasing circuit for the biasing of diodes and amplifiers is done with the help of manual switches which can be controlled automatically by using microcontroller.

Chapter 6

CONCLUSION

6.1 Objectives Achieved

In HFSS, the patch antenna along with t-junction (feeding network) was designed at 3.2 GHz. The t-junction was matched to the patch antenna using quarter wave transformer. Radiation pattern, E field, VSWR and S-parameters were generated afterwards. Referring to Fig. 4.5a, satisfactory results have been achieved with S11= -24.9628 as shown in the result and analysis portion of the report.

In ADS, the feeding network was simulated and the S-parameters etc. were generated to verify and check the accuracy of design. The switching network consisting of PIN diodes was also designed on ADS and the results of simulations were generated to verify the accuracy. RF choke inductors (100 nH) were being used to isolate the RF energy and DC supply. Further protection was achieved by using shunt capacitors (10μF) at all the biasing points. Satisfactory results have been achieved.

Antenna along with the feeding network design was fabricated by NRTC while tested at RIMMS laboratory, NUST HQ. The VNA results and radiation pattern of anechoic chamber have been shown in the result and analysis portion of the report.

The final design was fabricated containing the patch antenna array, switching circuit and the feeding network on a single PCB, so that losses were minimized. Chip inductors and capacitors were used. These were manufactured by a technology known as Surface-mount technology (SMT). SMT is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of PCB. A device made through SMT is called as SMD (Surface Mount Device). Surface mount devices are smaller than their counterparts. NXP BAP50-03 PIN diodes are used for switching purpose to guide the beam in the required direction to get the beam shifted as desired. Just before each patch, PHA-1+ power amplifiers are used to provide active gain to the incoming signal which makes our design unique from passive phase shifters. The biasing voltages for diodes and amplifiers (MMIC) are provided by the PCB, designed to provide required amount of voltage and current. Etching is done using $FeCl_4$ and switches and resistors are mounted. DC wires are used to connect the switches to the biasing points on the APAA. Rechargeable batteries are used as DC power sources.

6.2 Achievements

The APAA has been tested for phase shifting at the Anechoic Chamber (RIMMS, NUST). The antenna was biased for -30^0 beam shift. The radiation pattern was taken and the results show that the beam was successfully shifted to -30^0, as was designed and thus verified the simulation results. The radiation pattern for -30^0 beam shift is shown in part 4.6 of chapter 4. The antenna with feeding network has been tested for S-parameter and Radiation pattern. Its radiation pattern show that the side lobe level is less than -10 dB, so spurious radiations are minimized and the power is directed more towards the desired direction.

6.3 Limitations

Syndicate tried its level best to procure T/R modules at S-band. However, the best quote received so far shows a single T/R module would cost ~ \$5000 and four of them were needed in the project so the total cost becomes ~\$20000. In this backdrop, procurement of such a costly component (that too minimum of 4 of these in numbers) is extremely difficult at UG FYP level. Alternatively, another approach is adopted which utilizes active components to fulfill our project goal of active phased array antenna using MMIC amplifiers and switched line PIN diode phase shifters. So as an alternative the receiving part of T/R module is designed, simulated and fabricated in the current stage of the project.

6.4 Applications

Following are some of the application areas of active phased array antennas.

Analogy with Synthetic aperture radar (SAR)

Naval Warships

Weather research

Radio-frequency identification (RFID) [7]

Cellular Systems

Smart Antennas

Synthetic Aperture Radar [8]

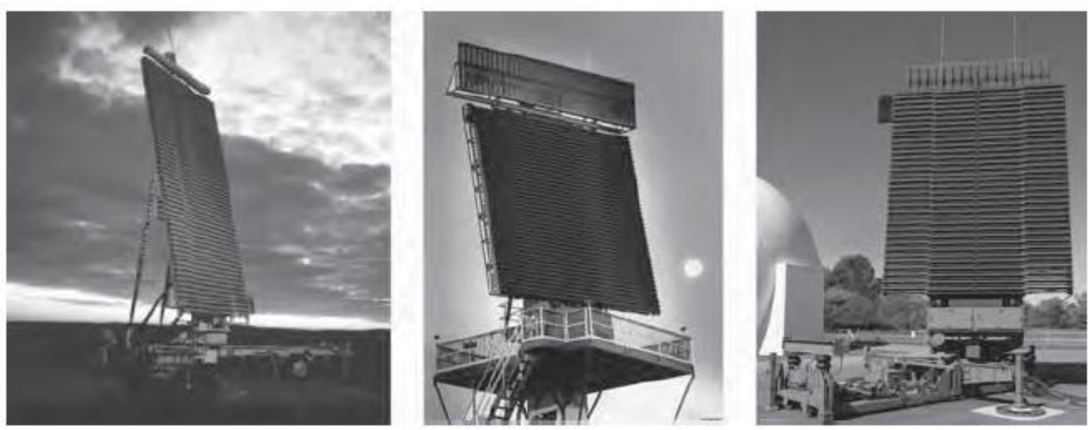


Fig.6.1 Large APAAs which are Developed as a Result of Combing the Output of a Large number Of Small T/R Modules Behind Each Array Element.

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[1] Balanis, Constantine A.Antenna Theory: Analysis and Design. Hoboken, NJ: John Wiley, 2005.

[2] Microwave Engineering by Pozar 3rd Edition.

[3] M. Maqsood, S. Gao, T. Brown, M. Unwin, R. de vos Van Steenwijk, J. D. Xu and C. I. Underwood, "Low-Cost Dual-Band Circularly Polarized Switched-Beam Array for Global Navigation Satellite System".

[4] http://www.microwaves101.com/encyclopedia/.cfm

[5] Balanis, Constantine A. Antenna Theory: Analysis and Design. Hoboken, NJ: John Wiley, 2005.

[6] Microwave Engineering by Pozar 4th Edition.

[7] Antenna Arrays by Randy L. Haupt.

[8] John D. Kraus and Ronald J. Marhefka, "Antennas: For All Applications", 3rd Ed. McGraw Hill

APPENDIX

Appendix A

Demonstration Outline/User Guide

Fig.A1 APAA

The designed APAA has been fabricated by a private company in Islamabad using LPKF machine. The components although being very small (SMD) are mounted on the board by syndicate itself. The biasing voltages for diodes and amplifiers (MMIC) are provided by the PCB designed to provide required amount of voltage and current. Etching is done using $FeCl_4$ and switches and resistors are mounted. DC wires are used to connect the switches to the biasing points on the APAA. Rechargeable batteries are used as DC power sources.

Fig.A2 Biasing switches

Following switch configurations are needed for the beam shift in desired direction

Table-D

states	B1	B2	B3	B4	B5	B1’	B2’	B3’	B4’	B5’
-30^0	+ve	+ve	+ve	-ve	+ve	-ve	-ve	-ve	+ve	-ve
-15^0	+ve	-ve	-ve	-ve	+ve	-ve	+ve	+ve	+ve	-ve
15^0	-ve	-ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	-ve
30^0	-ve	-ve	+ve	-ve	-ve	+ve	+ve	-ve	+ve	+ve

Radiation Pattern has been tested for -30^0 so respective switches, as shown in above table were switched ON and OFF by giving +4V and -4V with 40mA current.