RADIATION PATTERN CHARACTERISATION OF GMRT FEEDS

Submitted in Partial Fulfillment of the Requirements for the Degree of

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In
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by

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Jan-April 2012

BONAFIDE CERTIFICATE

This is to certify that this project report entitled "**RADIATION PATTERN CHARACTERISATION OF GMRT FEEDS**" has been submitted to **Indian Institute of Space Science and Technology, Thiruvananthapuram**, is a bonafide record of work done by **VIVEK DHOLPURIA and DEVENDRA SINGH"** under my supervision from **"January 9, 2012 "** to **"April 28, 2012"**

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ABSTRACT

Our project which titles "RADIATION PATTERN CHARACTERISATION OF GMRT FEEDS" aims to efficiently and effortlessly test an antenna i.e. get radiation pattern and various other properties of test antenna. Thus this project aims to characterize radio frequency receivers of GMRT (RF feeds) for their various properties quantifying their utility.

As very accurate Scanning and measurements results in more reliable outcomes and at the same time saves a lot of time and effort. This project work provides computerized characterization of feed which in comparison to earlier manually gathering of data (power and angle information) to get a radiation pattern is very much accurate. So basically our work has automatized Test-Range facility at NCRA which has an important contribution to Test-Range facility at NCRA, Pune

Project comprises of reception of transmitted signal by test antenna at test-range facility at NCRA, Pune. Data acquisition is done using program which is written in Lab View, data processing in Matlab i.e. plotting angle versus received power level which provide us the radiation pattern of test antenna and other information extraction like Taper, Phase center, symmetry etc. in Microsoft Excel.

Radiation Pattern in E and H plane for L-band, Conical Dipole and Modified Kildal feed are obtained and are included in the report. Cross-Plane patterns of Conical Dipole and Modified Kildal feed are also acquired Phase center measurements for Conical Dipole feed. Taper and Symmetry plots for all these feeds tells about their usability.

Finally project ends by concluding the utilization of the tested feeds.

Table of Contents

BONAFIDE CERTIFICATE **I**
DELARATION BY AUTHORS **II**
ACKNOWLEDGEMENT **III**
ABSTRACT **IV**

List of Figures 7

List of Tables 10

List of Symbols, Abbreviations and Nomenclature 11

1. INTRODUCTION 12

1.1 **OUR WORK** 13

1.2 **GMRT** 13

1.3 **BACKGROUND** 15

1.3.1 Radiation Pattern 15

1.3.2 E and H Planes 15

1.3.3 Polarization: 16

1.3.4 Taper 17

1.3.5 Phase center 17

1.3.6 Symmetry 17

1.3.7 Smoothing spline 17

1.3.8 VSWR 17

1.3.9 Return loss 18

1.3.10 Directivity 18

1.3.11 **Lab-View** 18

1.3.12 **Antenna theory:** 18

Modified Kildal feed 21

Corrugated horns (L-Band feed) 23

Conical Dipole Antenna 24
Log Periodic antenna 24
2. APPROACH USED 26
3. RESULTS AND DISCUSSIONS 34
3.1 Brief Results: 34
3.2 Radiation Pattern of L band feed 35
3.2.1 Taper Measurements for L-band feed 39
3.3 Radiation Pattern of Conical Dipole Feed 40
3.3.1 Co-Polar Pattern of Conical Dipole antenna 40
3.3.2 Cross Polar Pattern of Conical Dipole feed: 44
3.3.3 Taper Measurement for Conical Dipole feed 48
3.3.4 Phase Center Measurement for Conical Dipole feed 49
3.4 Radiation Pattern of Modified Kildal feed 50
3.4.1 Co-Polar Pattern of Modified Kildal feed 50
3.4.2 Taper measurements for Modified Kildal feed 54
3.4.3 Cross Polar Pattern of Modified Kildal feed 55
3.5 Comparison of Kildal and Conical Dipole feed 56
4. CONCLUSIONS AND RECOMMENDATIONS 57
APPENDIX-I 58
APPENDIX-II 59
BIBLIOGRAPHY 60

List of Figures

Figure 1-1 General Graph of radiation pattern 15
Figure 1-2 Modified Kildal feed 22
Figure 1-3 VSWR vs. frequency for Kildal feed 22
Figure 1-4 VSWR of Corrugated Horn vs. frequency 23
Figure 1-5 Dipole antenna 24
Figure 1-6 Log Periodic antenna 24
Figure 2-1 Picture of Set-up used to get radiation pattern 28
Figure 2-2 General Block Diagram of Test Range 28
Figure 2-3 Front Panel of Lab-View Program 29
Figure 2-4 Block Diagram of Lab-View Program 29
Figure 2-5 path difference 32
Figure 3-1 Taper plots in brief 34
Figure 3-2 Symmetry Plots in Brief 34
Figure 3-3 Radiation Pattern of L-band feed @ 1GHz 35
Figure 3-4 Radiation Pattern of L-band feed @ 1.06GHz 36
Figure 3-5 Radiation Pattern of L-band feed @ 1.17GHz 36
Figure 3-6 Radiation Pattern of L-band feed @ 1.20GHz 37
Figure 3-7 Radiation Pattern of L-band feed @ 1.28GHz 37
Figure 3-8 Radiation Pattern of L-band feed @ 1.39GHz 38
Figure 3-9 Radiation Pattern of L-band feed @ 1.4GHz 38
Figure 3-10 Taper plots for L-band feed (x-axis: frequency in MHz, y-axis: Taper in dB) 39
Figure 3-11 Radiation Pattern of Conical Dipole feed @ 250MHz 40
Figure 3-12 Radiation Pattern of Conical Dipole feed @ 300MHz 40
Figure 3-13 Radiation Pattern of Conical Dipole feed @ 327MHz 41
Figure 3-14 Radiation Pattern of Conical Dipole feed @ 360MHz 41
Figure 3-15 Radiation Pattern of Conical Dipole feed @ 400MHz 42
Figure 3-16 Radiation Pattern of Conical Dipole feed @ 450MHz 42
Figure 3-17 Radiation Pattern of Conical Dipole feed @ 500MHz 43
Figure 3-18 Radiation Pattern of Conical Dipole feed @ 525MHz 43
Figure 3-19 Cross Plane Patterns of Conical Dipole feed 44
Figure 3-20 Cross Plane Pattern of Conical Dipole feed @ 250MHz 44

Figure 3-21 Cross Plane Pattern of Conical Dipole feed @ 300MHz 45
Figure 3-22 Cross Plane Pattern of Conical Dipole feed @ 327MHz 45
Figure 3-23 Cross Plane Pattern of Conical Dipole feed @ 360MHz 46
Figure 3-24 Cross Plane Pattern of Conical Dipole feed @ 400MHz 46
Figure 3-25 Cross Plane Pattern of Conical Dipole feed @ 450MHz 47
Figure 3-26 Cross Plane Pattern of Conical Dipole feed @ 500MHz 47
Figure 3-27 Cross Plane Pattern of Conical Dipole feed @ 525MHz 48
Figure 3-28 Taper Plots for Conical Dipole feed (x-axis: frequency in MHz, y-axis: Taper in dB) .. 49
Figure 3-29 Radiation Pattern of Modified Kildal feed @ 250MHz 50
Figure 3-30 Radiation Pattern of Modified Kildal feed @ 300MHz 51
Figure 3-31 Radiation Pattern of Modified Kildal feed @ 327MHz 51
Figure 3-32 Radiation Pattern of Modified Kildal feed @360 52
Figure 3-33 Radiation Pattern of Modified Kildal feed @ 400MHz 52
Figure 3-34 Radiation Pattern of Modified Kildal feed @ 450MHz 53
Figure 3-35 Radiation Pattern of Modified Kildal feed @ 250MHz 53
Figure 3-36 Radiation Pattern of Modified Kildal feed @ 525MHz 54
Figure 3-37 Taper plots for Modified Kildal feed (x-axis: frequency in MHz, y-axis: Taper in dB) 55
Figure 3-38 Cross Plane Patterns of Modified Kildal Feed 55
Figure 3-39 Cross –Polar comparison of Modified Kildal and Conical Dipole feed 56
Figure 3-40 Comparison of Kildal and Conical Dipole @ 327 MHz 56

List of Tables

Table 3-1 Taper Readings for L-band feed 39
Table 3-2 Taper Readings for Coning Dipole feed 48
Table 3-3 Phase Center Readings for Conical Dipole feed (E-Plane) 49
Table 3-4 Phase Center Readings for Conical Dipole feed (H-Plane).................................... 50
Table 3-5 Taper Readings for Modified Kildal feed... 54

List of Symbols, Abbreviations and Nomenclature

TIFR	Tata Institute of Fundamental Research
GMRT	Giant Metrewave Radio Telescope
NCRA	National Centre for Radio Astrophysics
LHCP	Left Hand Circularly Polarized
RHCP	Right Hand Circularly Polarized
BFR	Beam Forming Ring
VSWR	Voltage Standing Wave Ratio
λ	Operating Wavelength
Δ	Path difference
ψ	Phase difference
GPIB	General Purpose Interface Bus
USB	Universal Serial Bus
DAQ	Data acquisition

1. INTRODUCTION

Testing and Characterizing is a very important and integral part in every department of every industry and so as in the case of GMRT, TIFR. GMRT consists of 30 fully steerable gigantic parabolic dishes of 45m diameter which makes it world's largest array of radio telescopes at meter wavelengths, thus testing the feed (which is going to be mounted at telescope) becomes very crucial.

Our work in this project is to characterize radio frequency receivers of GMRT (RF feeds) for their various properties quantifying their utility. This project work provides computerized characterization of feed which in comparison to earlier manually gathering of data (power and angle information) to get a radiation pattern is very much accurate, thus supports the significance of our work.

After an antenna is designed in software and is manufactured in the workshop, to ensure its performance is similar to that at ideal condition, testing an antenna is very important step, especially when it is going to be mass manufactured for GMRT observatory. Also this work has automatized the already existing Test-Range facility at NCRA which makes this process quick and provide more accurate results.

Chapter 1 covers basic introduction about our work, GMRT and basic concepts about the topic. Chapter 2 includes the approach used by us to successfully carry out the work and describes the procedure and methodology used by us, which include Lab-View program for data acquisition, Matlab program for data utilization to get the results. Chapter 3 includes results and discussions obtained during project. Chapter 4 covers Conclusions and Recommendations as outcome of the project. Finally report ends with Appendix and Bibliography.

1.1 OUR WORK

Characterization of feed includes plotting the radiation pattern of the feed i.e. power level in azimuth and elevation. We have done it for only azimuth angles as elevation rotation is not possible at current mounting. Test feed receives signal transmitted by Log Periodic antenna (transmitter antenna). Received signal is amplified and fed to Spectrum Analyzer from which signal enters the computer using GPIB-USB device. From this signal power level at concerned frequency is extracted using Lab-View program running in the computer and angle information is fed to computer from antenna platform from DAQ device.

1.2 GMRT

Giant Metrewave Radio Telescope (GMRT), is located at a site about 80 km north of Pune and consists of 30 fully steerable gigantic parabolic dishes of 45m diameter each spread over distances of upto 25 km. GMRT is one of the most challenging experimental programs in basic sciences undertaken by Indian scientists and engineers.

NCRA has set up a unique facility for radio astronomical research using the metrewavelengths range of the radio spectrum, known as the Giant Metrewave Radio Telescope (GMRT), it is located at a site about 80 km north of Pune. GMRT consists of 30 fully steerable gigantic parabolic dishes of 45m diameter each spread over distances of upto 25 km. GMRT is one of the most challenging experimental programs in basic sciences undertaken by Indian scientists and engineers.

The site : The site for GMRT, about 10 km east of Narayangaon town on the Pune-Nasik highway, was selected after an extensive search in many parts of India, considering several important criteria such as low man-made radio noise, availability of good communication, vicinity of industrial, educational and other infrastructure and, a geographical latitude sufficiently north of the geomagnetic equator in order to have a reasonably quiet ionosphere and yet be able to observe a good part of the southern sky as well.

Antenna configuration: The number and configuration of the dishes was optimized to meet the principal astrophysical objectives which require sensitivity at high angular resolution as well as ability to image radio emission from diffuse extended regions. Fourteen of the thirty dishes are located more or less randomly in a compact central array in a region of about 1 sq. km. The remaining sixteen dishes are spread out along the 3 arms of an approximately `Y'-shaped configuration over a much larger region, with the longest interferometric baseline of about 25 km.

The multiplication or correlation of radio signals enable radio images of celestial objects to be synthesized with a resolution equivalent to that obtainable with a single gigantic dish of 25 kilometer in diameter. The array operates in six frequency bands centered on around 50, 153, 233, 325, 610 and 1420 MHz. This configuration works because of the long wavelengths (21 cm and longer) at which the telescope operates. Each antenna has four different receivers mounted at the focus. Each individual receiver assembly can rotate so that the user can select the frequency at which to observe.

The highest angular resolution achievable will range from about 60 arcsec at the lowest frequencies to about 2 arcsec at 1.4 GHz.

The design breakthrough: GMRT is an indigenous project. The construction of 30 large dishes at a relatively small cost has been possible due to an important technological breakthrough achieved by Indian Scientists and Engineers in the design of light-weight, low-cost dishes. The design is based on what is being called the `SMART' concept - for Stretch Mesh Attached to Rope Trusses.

The dish has been made light-weight and of low solidity by replacing the conventional back-up structure by a series of rope trusses (made of thin stainless steel wire ropes) stretched between 16 parabolic frames made of tubular steel.

Electronic Frontend and Backend: Apart from the novel low-cost design of the parabolic dishes, the instrument has state-of-the-art electronics systems developed indigenously.

1.3 <u>BACKGROUND</u>

1.3.1 Radiation Pattern

When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern as shown in fig. 1-1. The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a fixed or constant distance. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. The radiation pattern of the antenna is of principle concern when engineering a communications system.

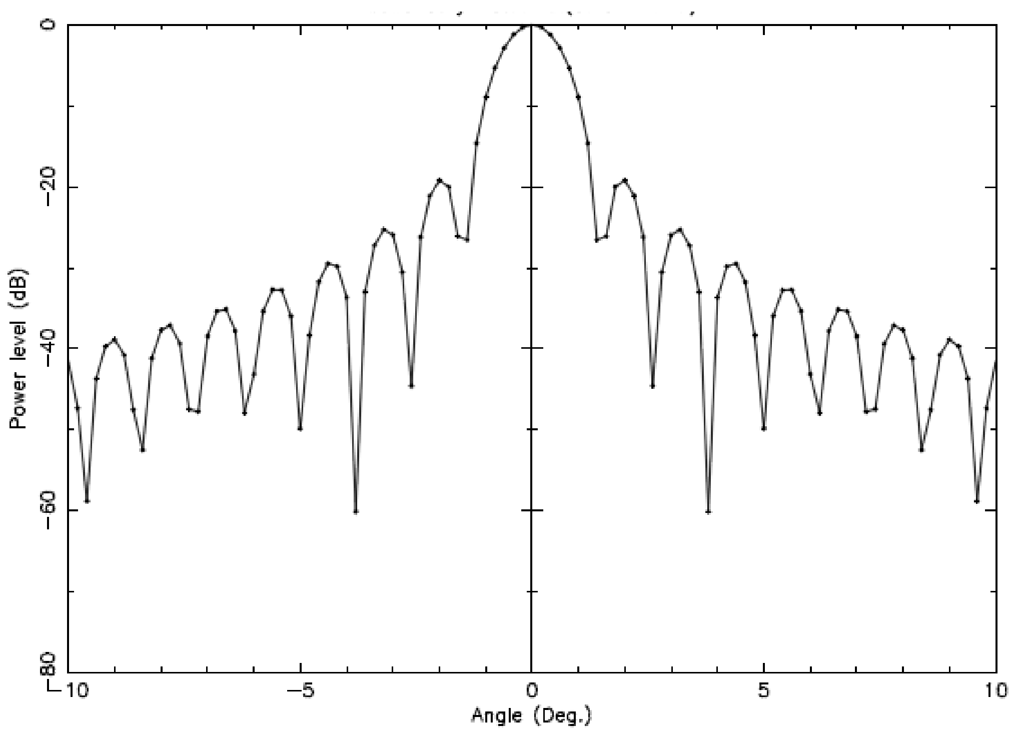


Figure Error! No text of specified style in document.**-1 General Graph of radiation pattern**

1.3.2 E and H Planes

Many antennas have two planes of symmetry. If such antennas are excited for polarization in such wave E-field on axis lies in one of symmetry planes (for e.g. say y direction) then E field lie in one y-z plane (z being direction of propagation) for all azimuth angles in 90º elevation plane.

Therefore this far field function in y-z plane is called E-plane pattern and this plane is E-plane. Far field function in x-z plane is therefore called H-plane and this plane is called H-plane.

1.3.3 Polarization:

Polarization is defined as the orientation of the field vector (magnetic or electric field vector) of an electromagnetic wave; Polarization is in general described by an ellipse. The initial polarization of a radio wave is determined by the antenna that launches the waves into space. The environment through which the radio wave passes on its way from the transmit antenna to the receive antenna may cause a change in polarization. Two often used special cases of elliptical polarization are linear polarization and circular polarization.

- With linear polarization the field vector stays in the same plane. If the field vector stays vertical or horizontal with respect to the ground then it will be called as vertically or horizontally polarized wave, respectively.

- In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. The rotation may be right-hand or left-hand.

Co-polarization: Co-polarization is the polarization in same plane to the polarization being discussed. For instance, if the fields from an antenna are meant to be horizontally polarized, the co-polarization in this case is also horizontally polarization. If the polarization is Left Hand Circularly Polarized (LHCP), the co-polarization is also Left Hand Circularly Polarized (LHCP).

Cross polarization: Cross polarization is the polarization orthogonal to the polarization being discussed. For instance, if the fields from an antenna are meant to be horizontally polarized, the cross-polarization in this case is vertical polarization. If the polarization is Right Hand Circularly Polarized (RHCP), the cross-polarization is Left Hand Circularly Polarized (LHCP).

1.3.4 Taper

The feed taper is defined as the amplitude of the feed radiation pattern at the rim of the reflector relative to the maximum value (assumed to be along the parabola axis).

1.3.5 Phase center

All horns and feeds have a phase center. This is the theoretical point along the axis of the feed which is the center of curvature of the phase fronts of the emerging spherical waves.

1.3.6 Symmetry

It tells about similarity between left and right halves pattern. It can be calculated as difference between left and right taper.

1.3.7 Smoothing spline

The smoothing spline is a mathematical fit used for smoothing (fitting a smooth curve to a set of noisy observations) using a spline function. Spline function is a smooth polynomial function that is piecewise-defined, and possesses a high degree of smoothness at the places where the polynomial pieces connect.

1.3.8 VSWR

VSWR stands for Voltage Standing Wave Ratio, and is also referred to as Standing Wave Ratio (SWR). Voltage Standing wave ratio (SWR) is the ratio of the amplitude of a partial standing wave at an antinode (maximum) to the amplitude at an adjacent node (minimum), in an electrical transmission line.

1.3.9 Return loss

Return loss is the loss of signal power resulting from the reflection caused at a discontinuity in transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB);

$$\boldsymbol{RL(dB) = 10log_{10}\frac{Pi}{Pr}}$$ **Equation** Error! No text of specified style in document.**-1**

Where RL (dB) is the return loss in dB, P_i is the incident power and P_r is the reflected power.

1.3.10 Directivity

The radiated power in the direction of the main lobe relative to what would be radiated by an isotropic antenna with the same input power is termed as directivity. A related quantity called the Gain also takes into account any electrical losses of the antenna. For reflector antennas, one can also define an aperture efficiency which is the ratio of the effective collecting area of the telescope to its geometric area.

1.3.11 Lab-View

Laboratory Virtual Instrumentation is referred as Lab-View. It is engineering Workbench which is majorly used for Data Acquisition, Instrument Control, and Industrial Automation etc. It has two working windows one is called front panel which can be used to change variables and to see output and second is block diagram window which is used to write the main program. Different functional nodes are connected by wires, these wires propagate variables and node execute as soon as all its input variables are available.

Data acquisition: acquiring signals from real world phenomena, digitizing signals, analyzing, presenting and saving data.

1.3.12 Antenna theory:

Antenna is a device that transmits and/or receives electromagnetic waves. Electromagnetic waves are often referred to as radio waves. It may be defined as the structure associated with the region of transmission between a guided wave and free space wave. Ideally an antenna demonstrates a property known as reciprocity, i.e. an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired.

Types of antennas

- Wire antennas:

The random wire antenna is simply a very long (at least one quarter wavelength) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available. With different arrangement, the basic antennas are Short Dipole Antenna, Dipole Antenna, Half-Wave Dipole Broadband Dipoles, Monopole Antenna, Folded Dipole Antenna and Small Loop Antenna.

- Microstrip Antennas:

The microstrip antenna, which is also commonly referred to as the patch antenna consists mainly of a square conductor mounted over a ground plane. A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Because such antennas have a very low profile, are mechanically rugged and can be shaped to conform to the curving skin of a vehicle, they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices.

- Reflector Antennas

Reflector antennas consist of an active device located in the front of antenna reflector. An antenna reflector is a device that reflects electromagnetic waves.it is a passive element slightly longer than and located behind a radiating dipole element that absorbs and re-radiates the signal in a directional way. The most common reflector types are:-

- *Corner reflector* reflects the incoming signal back to the direction it came from.
- *Parabolic reflector* focuses a beam signal into one point, or directs a radiating signal into a beam.
- *Flat reflector* just reflects the signal like a mirror and is often used as a passive repeater.

- Travelling Wave Antennas

In a travelling wave antenna, current travels along the antenna and the phase varies continuously. Some of the travelling wave antennas are:-

- *Helical antenna* (helix) is a travelling wave antenna in the shape of a corkscrew that produces radiation along the axis of the helix antenna. These helix antennas are referred to as axial-mode helical antennas. The benefits of this helix antenna are it has a wide bandwidth, is easily constructed, has real input impedance, and can produce circularly polarized fields.
- *The Yagi-Uda antenna or Yagi Antenna* is one of the most brilliant antenna designs. It is simple to construct and has a high gain. The Yagi antenna consists of a single 'feed' or 'driven' element, typically a dipole or a folded dipole antenna. This is the only member of the above structure that is actually excited (by a source voltage or current applied). The rest of the elements are parasitic - they reflect or help to transmit the energy in a particular direction.

- Slot antennas

Slot antennas are used typically at frequencies between 300 MHz and 24 GHz. They are designed by cutting out surface they are to be mounted on, and have radiation patterns that are roughly omnidirectional (similar to a linear wire antenna). The polarization of the slot antenna is linear. The slot size, shape and its cavity offer design variables that can be used to tune performance.

- Horn antenna

Horn Antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz. They are used as feeders (called feed horns) for larger antenna structures such as parabolic antennas

Types of antenna used in project:-

Modified Kildal feed

It is a Dipole-Disk Antenna with Beam-Forming Ring and sleeves: - Generally a dipole has a broader H pattern than its E pattern (The E pattern being in the plane containing the dipole). For good cross– polarization properties it was essential to have matched E and H plane patterns. An elegant method for achieving this pattern matching was given by P.S.Kildal, and involves placing a beam forming ring (BFR) above the dipole. The conducting ring is placed above the dipole in a plane parallel to the reflector and is supported by dielectric rods. The beam forming ring compresses the H-plane pattern while it has no significant effect on the E-plane.

The parameters of the antenna are:

- Reflector diameter: 2.2λ
- Height of dipole above reflector: 0.26λ
- BFR diameter: 1.22λ
- BFR height above reflector: 0.51λ

Figure Error! No text of specified style in document.**-2 Modified Kildal feed**

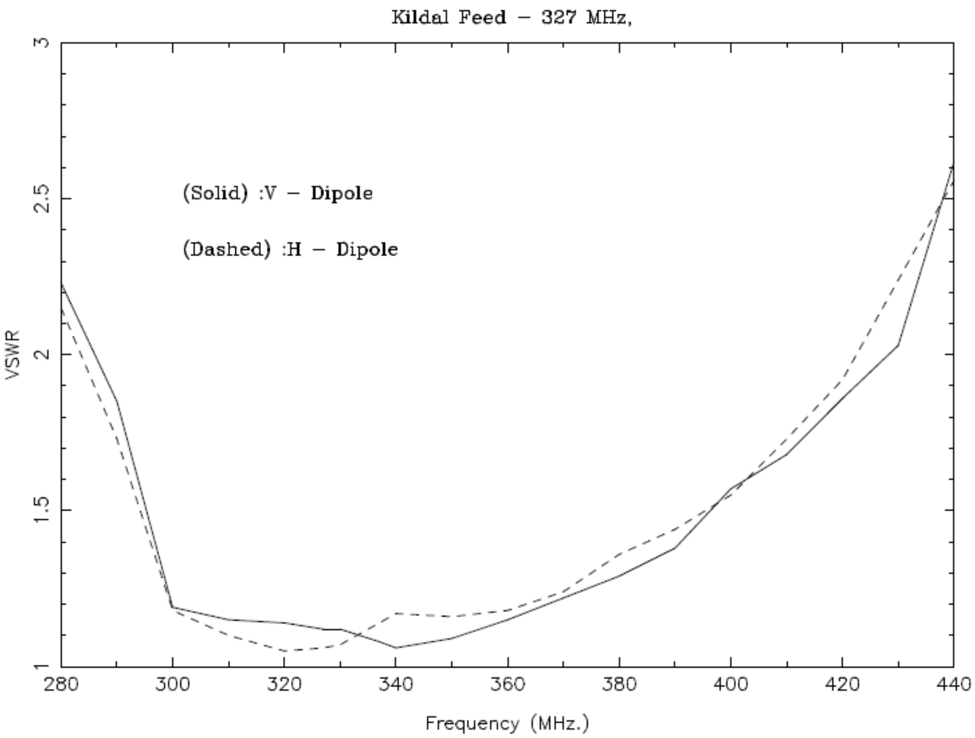


Figure Error! No text of specified style in document.**-3 VSWR vs. frequency for Kildal feed**

The figure above show bandwidth (VSWR<2) = 250-430 MHz i.e.~200 MHz

Corrugated horns (L-Band feed)

This feed was designed and constructed by the Millimeter Wave Laboratory of the Raman Research Institute. It is of the corrugated horn type - known for its high aperture efficiency and very low cross-polarization levels. In any horn, the antenna pattern is severely affected by the diffraction from the edges which can lead to undesirable radiation not only in the back lobes but also in the main lobe. By making grooves on the walls of the horn, the spurious diffractions are eliminated. Such horns are called "corrugated horns".

This feed at 1420 MHz has fins instead of grooves, since the whole assembly is made out of brass sheets. The flare–angle of the horn is 120°. The dimensions of the feed are:

- Aperture diameter: 3.65 λ
- Horn length: 4.48 λ

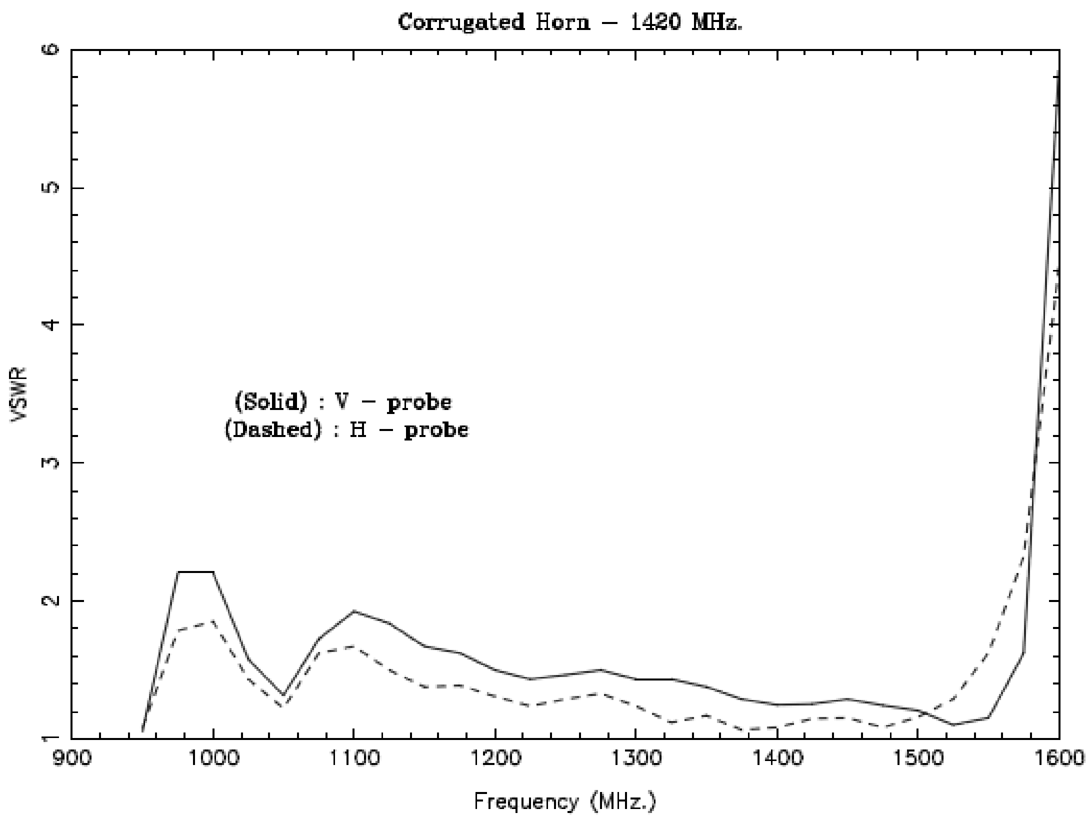


Figure Error! No text of specified style in document.**-4 VSWR of Corrugated Horn vs. frequency**

The figure 1-4 show bandwidth (VSWR<2) = 1000-1580 MHz i.e.~600 MHz. The entire band is divided into 4 sub bands, each 140 MHz wide and centered on 1390, 1280, 1170 and 1060 MHz's. There is also a bypass mode in which the entire bandwidth is available.

Conical Dipole Antenna

It is basically a Dipole antenna with a conical reflector. It is having a good bandwidth of 250MHz. Due to the conical reflector converging property it has larger bandwidth and average polarization property.

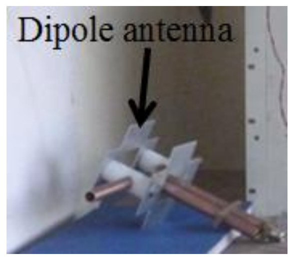


Figure Error! No text of specified style in document.**-5 Dipole antenna**

Log Periodic antenna

A log-periodic antenna is a broadband, multi-element, directional, narrow-beam antenna that has impedance and radiation characteristics that are regularly repetitive as a logarithmic function of the excitation frequency. The individual components are often dipoles, as in a log-periodic dipole array (LPDA). The log periodic antenna was invented by Dwight E. Isbell, Raymond DuHamel and variants by Paul Mayes. The lengths and spacings of the elements of a log-periodic antenna increase logarithmically from one end to the other.

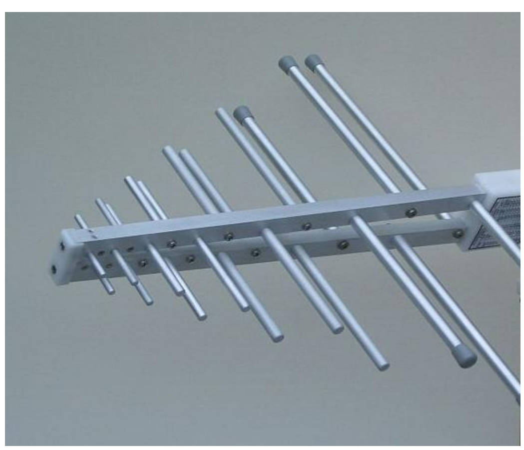


Figure Error! No text of specified style in document.**-6 Log Periodic antenna**

This antenna design is used where a wide range of frequencies is needed while still having moderate gain and directionality. It is sometimes used for a (VHF/UHF) television antenna. Due its large bandwidth and directionality it is used as transmitter antenna in testing.

2. APPROACH USED

The core of the project was in writing a program in Lab-View for data acquisition and to write Matlab code for data utilization for obtaining results i.e. to get radiation pattern in E and H plane and to calculate phase center of the feed.

The existing Test-Range facility at NCRA, Pune is used for measurements of radiation pattern of test antenna. Test antenna receives the signal transmitted by transmitter antenna which is a Log-Periodic antenna in this case.

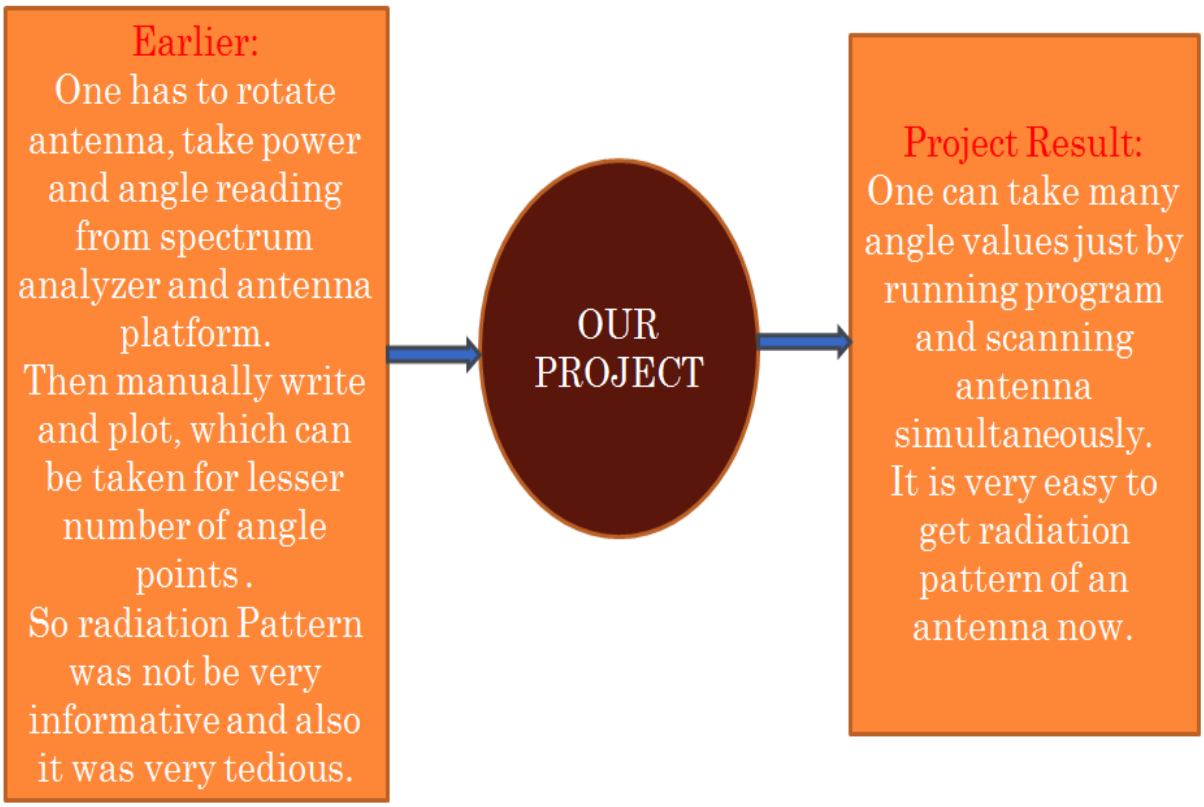
Set–up information:

- Height of Transmitter antenna (h_t) = 15m
- Height of Receiver antenna (h_r) = 15m
- Distance between antennas = 134.25m
- Spectrum Analyzer: hp8591
- Antenna Platform
- National Instruments encoder, DAQ (angle information is recorded as voltage)
- National Instruments GPIB-USB interface
- Transmitter antenna: Log Periodic

While signal is transmitted the receiving antenna makes a full scan (i.e. from -180º to +180º) with the help of switch-controlled mechanical steering system and angle information is taken from it using a detector. Received signal is send to spectrum analyzer from which power information can be recorded. Simultaneously these angle and power information are saved into a text file using the Lab-View program which can be further used to get required plot.

In brief project can be summarized as below, i.e. using the new Test-Range at NCRA, measure the following:

- E & H plane patterns of the Conical Dipole feed for frequency range of 280 - 520 MHz, in steps of 20 MHz interval.
- Cross-polar patterns for the feed in the same frequency range.
- Measurement and estimation of the Phase center of the feed over the specified frequency range.
- Same things done for other feeds.



Set up Used:

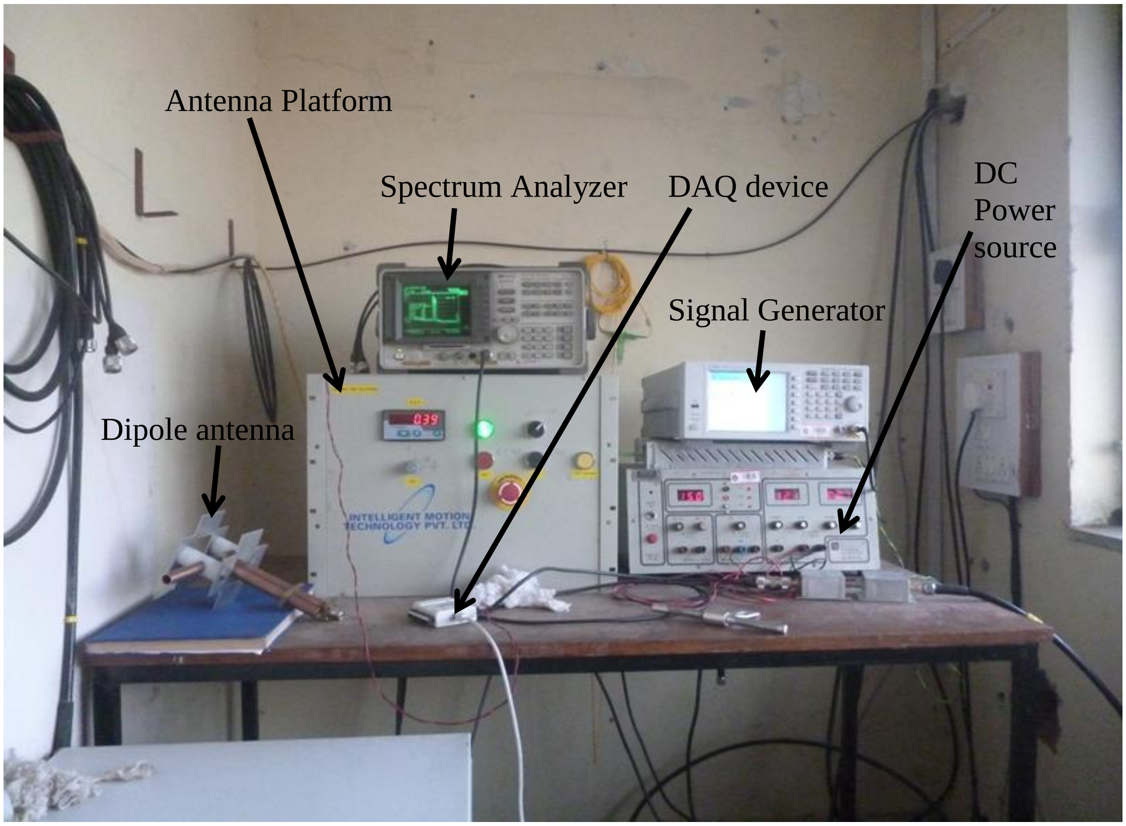


Figure 2-7 Picture of Set-up used to get radiation pattern

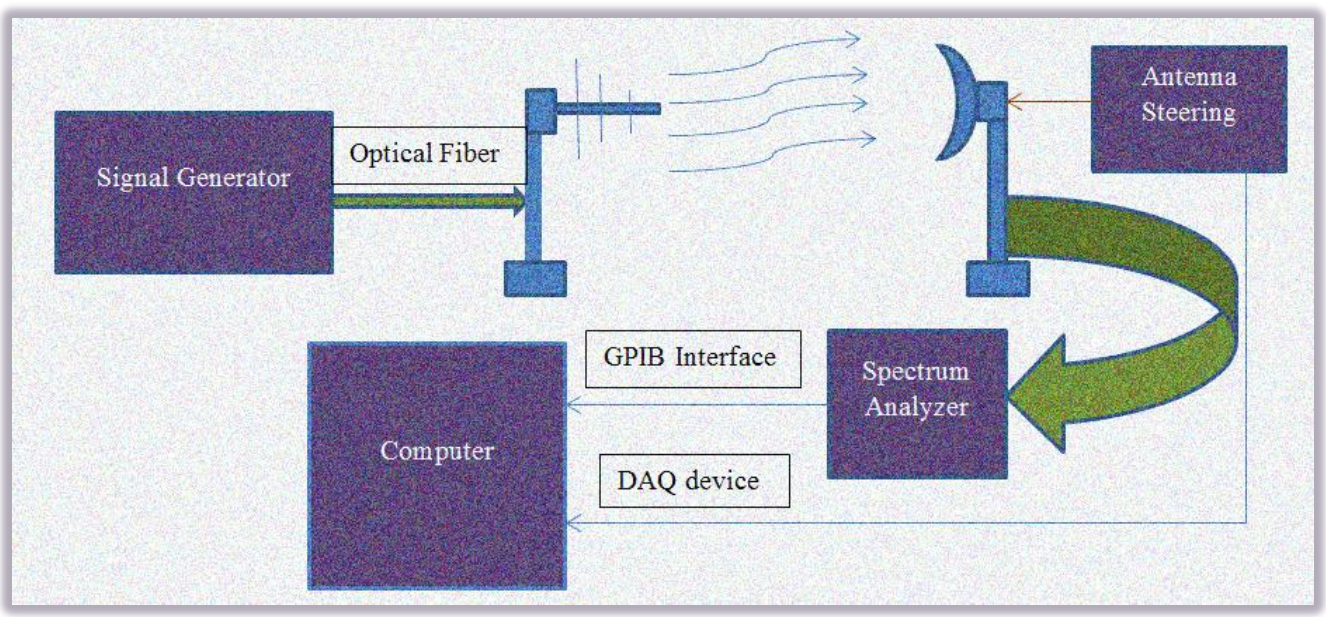


Figure 2-8 General Block Diagram of Test Range

2.1 Lab-View Program:

Program for data acquisition is written in Lab-View

- Power information is taken from Spectrum Analyzer using GPIB interface.
- Angle information as voltage is recorded using National Instruments encoder DAQ.

Both these power and angle information are saved in a text file while program runs in a computer.

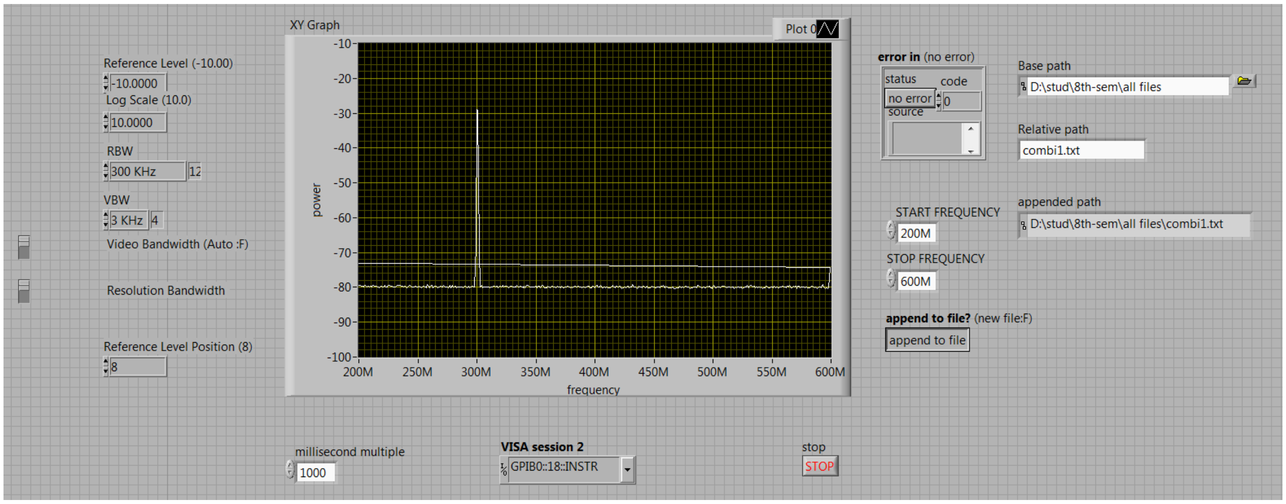


Figure 2-9 Front Panel of Lab-View Program

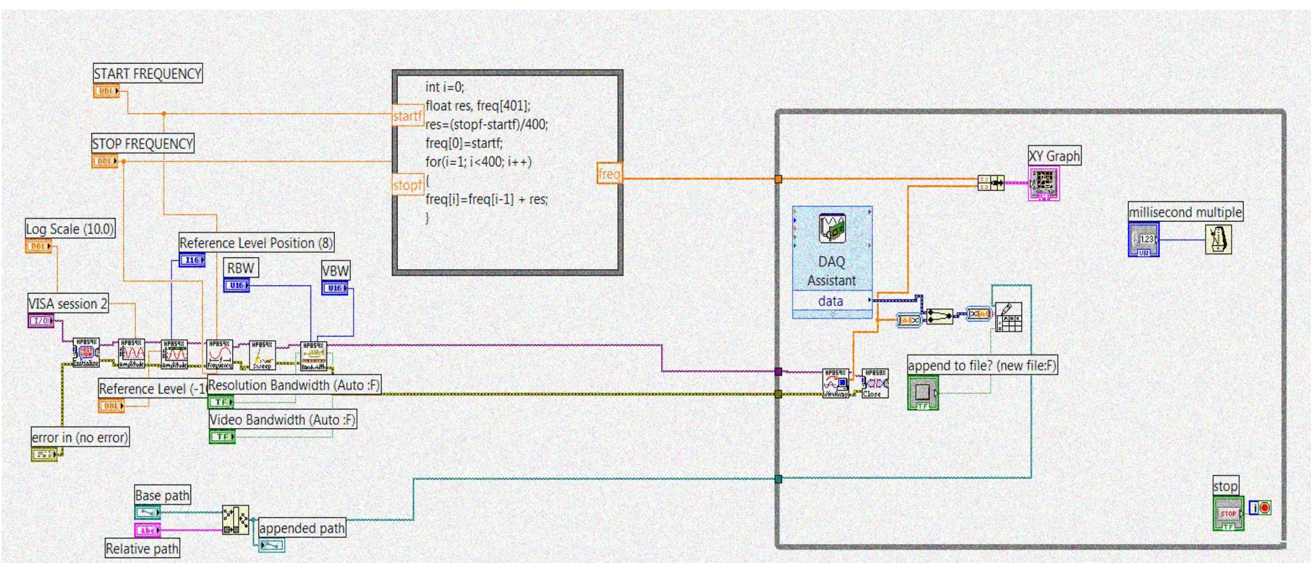


Figure 2-10 Block Diagram of Lab-View Program

Description of block sets used in Lab-View program:

a) Initialization/Configure blocks: These block sets are used to initialize various properties of Spectrum Analyzer.

- Initialize: This block set scans the instrument and store which instruments is it, i.e. basic information about the Spectrum Analyzer.
- Amplitude: This block set provide information about amplitude axis (i.e. Y-axis), it has been manually set to the Log Scale.
- Amplitude Level: This block set is used to set reference level for amplitude axis which is manually set to 8^{th} level from above.
- Frequency: It is used to set range of frequencies to be scanned, by mentioning start and stop frequencies which can be modified any time through front panel.
- Sweep: This block set tells that how often instrument to be scanned and information to be updated.
- Bandwidth: It is used to set resolution bandwidth and video bandwidth manually from front panel. Resolution bandwidth is set to be 300 KHz and video bandwidth is set to be 3 KHz.

b) Data Acquisition Blocks: These blocks are used to acquire real-time data from Spectrum Analyzer and Antenna Platform.

- DAQ Assistant: This block is used to get angle data from the Antenna Platform.
- Wvfm to Array: It acquires power values from Spectrum Analyzer and converts the incoming waveform into array with each column representing different frequency.

c) Data Storing Blocks: These Block sets helps to store the acquired data in form of text file.

- Write to Spreadsheet: It is used to write 2D data one by one in rows to text file.

- Build Path: This block is used to make appended path from base and relative path which is given to above block as input.

2.2 Matlab Program

From the text file made by Lab-View program angle and power values are taken, processed and plotted in Matlab, program for which is also written. Description of this program (appendix-I) is given below:

1. File made by lab-view is read using “textread” command and information is stored in a array.
2. Array created above contain angle and power information row by row, from which these two information are saved in two different arrays.
3. Angle information we got is actually in voltage, so it is converted into angle using Conversion graph given by manufacturer.
4. Plot is made between Power and angle thus we get Radiation Pattern.

2.3 Curve Fitting:

Plotted curve by above program is fitted using curve fitting tool in Matlab. Smoothing spline curve fitting is used which provide smoothened Radiation Pattern.

2.4 Taper plot:

Left and right Taper (at -62.5 and +62.5 as parabolic dish make angle of 125 at focii) values from Radiation Pattern are saved and averaged in Microsoft Excel file and Taper plot has been made for all the three feeds.

2.5 **Symmetry Plots**:

It is plot of difference between left and right taper vs. frequency, which is also plotted in Microsoft Excel.

2.6 **Phase Center Measurement**:

The test antenna is rotated through an angle, ϴ from the line joining both antennas. Say phase center is at distance r from the axis of rotation, then from figure,

$$\text{Path difference, } \Delta = \boldsymbol{d1} - (\boldsymbol{d} - \boldsymbol{r}) \quad \text{Equation 2-2}$$

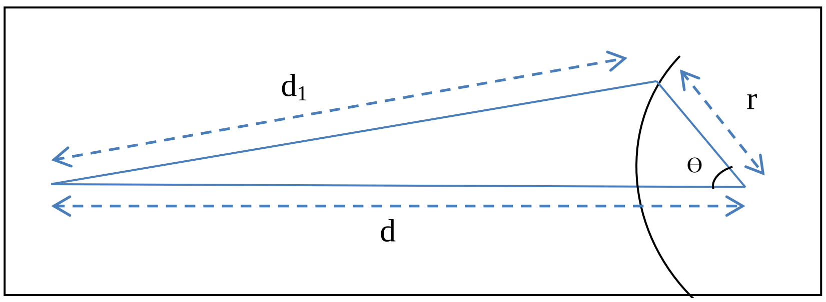


Figure 2-11 path difference

Using trigonometric relations we get:-

$$\boldsymbol{d_1}^2 = \boldsymbol{d}^2 + \boldsymbol{r}^2 \quad \text{Equation 2-3}$$

From eq. 2.1 and 2.2

$$\mathbf{r} = \frac{(\mathbf{2d}+\Delta)}{\mathbf{2}+\frac{\mathbf{2d}}{\Delta}(\mathbf{1}-\mathbf{cos}\Theta)} \quad \text{Equation 2-4}$$

Therefore

Now if measured phase difference is ψ, then path difference, Δ=ψ/360 and we can calculate phase of received signal with respect to that of transmitted signal by using Network Analyzer. Thus we can measure phase difference between two signals received at two different angles (Θ_1, Θ_2), say ψ_1,ψ_2.

Therefore path difference between them can be written as,$\Delta = \frac{\psi 1 - \psi 2}{360} \, . \boldsymbol{\lambda}$ Equation 2-5

From eq. 2-4 and 2-3 we can get phase center (r).

Steps taken to get phase center:

- Angle and Phase values are recorded at different angles.
- Phase difference between the (i) wave at zero azimuth and (ii) wave at some other angle, other angle is varied from -10 to 10 degree in steps of 2 degree.
- This phase difference is used to get Δ from eq. 2-4.
- From eq. 2-3 phase center can be calculate.
- So for a single frequency we get 10 values of phase center which is averaged to obtain single value.
- These above five steps are carried out for required frequencies; we have done it for 250,300,327,360,400,450,500,525 MHz for Conical Dipole antenna.

Angle and Phase values are recorded manually in text file which is accessed by Matlab program (Appendix-II). Matlab program is written using equation from 2-1 to 2-4. Distance between transmitter and receiver antennas, d = 134.256m.

3. RESULTS AND DISCUSSIONS

3.1 Brief Results:

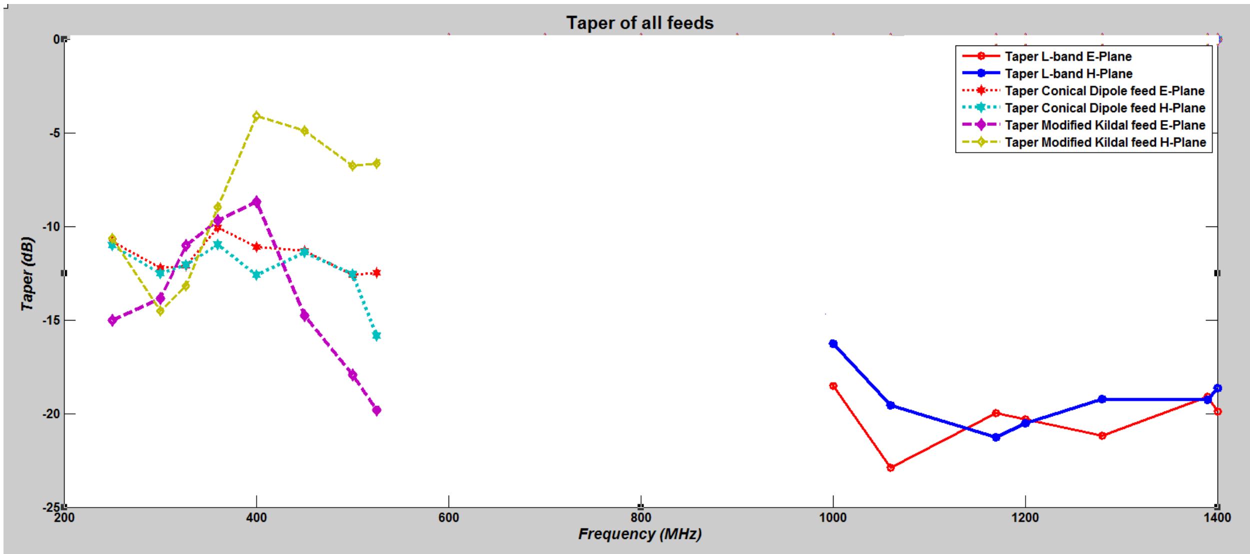


Figure 3-12 Taper plots in brief

Above figure shows Taper curves for L-band, Conical Dipole and Kildal feed. As seen from plots above since Taper values varies less for L-band and Conical Dipole, they are better than the Modified Kildal feed as Taper varies over almost 12dB in its case.

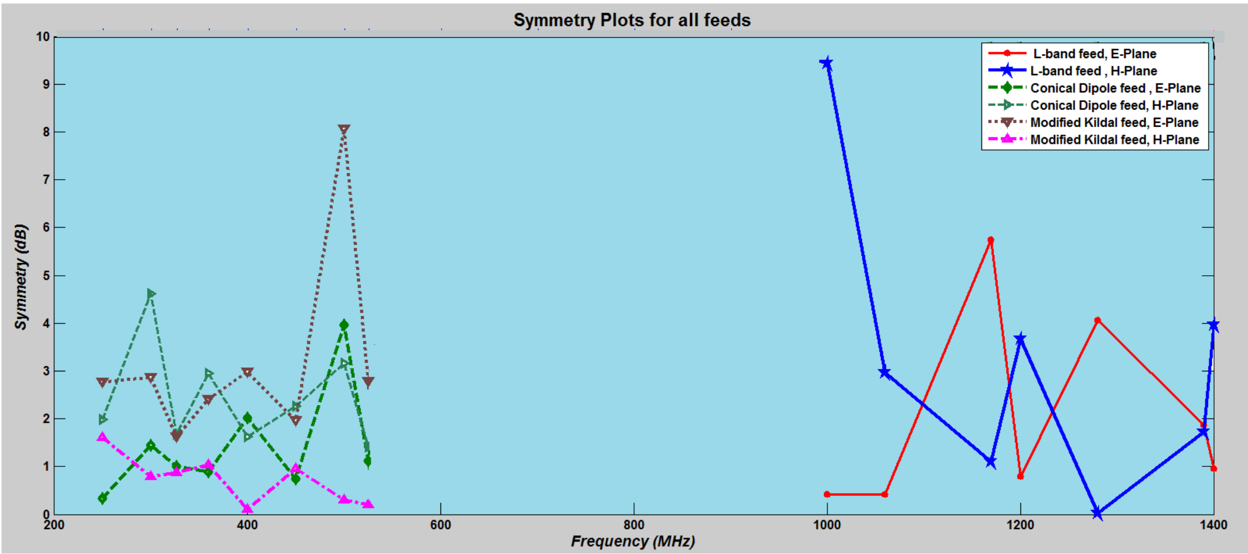


Figure 3-13 Symmetry Plots in Brief

From Symmetry plots we can say that conical Dipole is good as variation is in only 3dB, for Kildal feed variation is of 1.5 dB upto 450MHz but shoots at 525MHz, finally for L-band feed variation is of 4.5 dB which is highest of all.

3.2 Radiation Pattern of L band feed

Figure from 3-3 to 3-9 shows Co-Polar radiation pattern of L-band feed in E and H plane which covers frequency range of 1000 to 1400MHz.

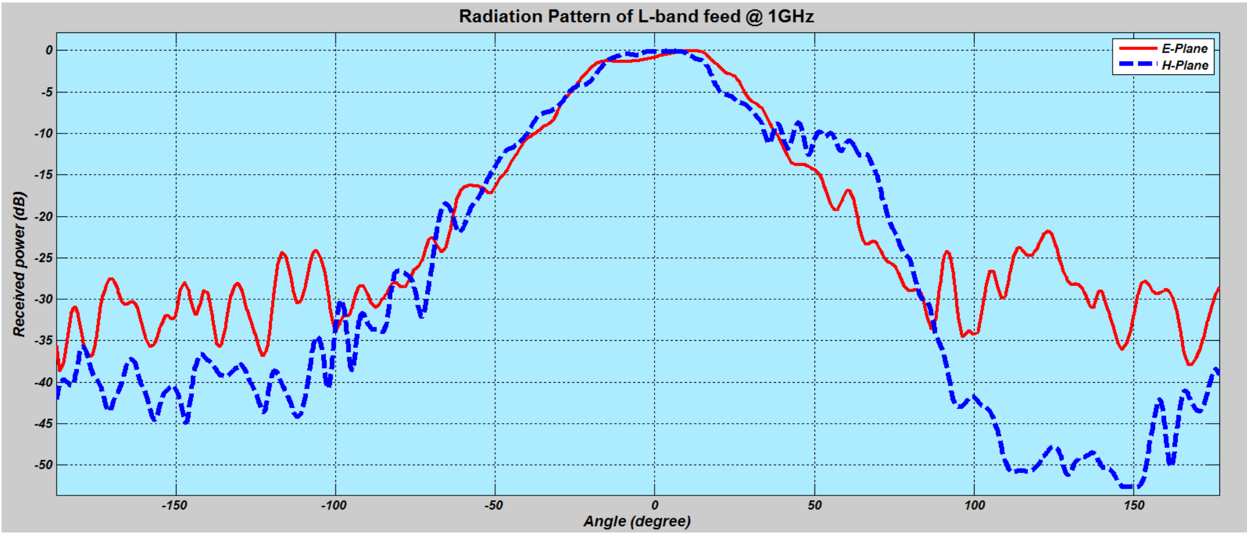


Figure 3-14 Radiation Pattern of L-band feed @ 1GHz

As seen from above figure, pattern is supposed to be diverted from actual pattern between 40 to 80 degrees because of interference caused by some other source.

As long as E and H plane patterns are almost matching it is supposed to work good at that frequency and it is observed from fig. 3-3 to 3-9 patterns are very good so it would perform well at all these frequencies as designed as center frequencies for it.

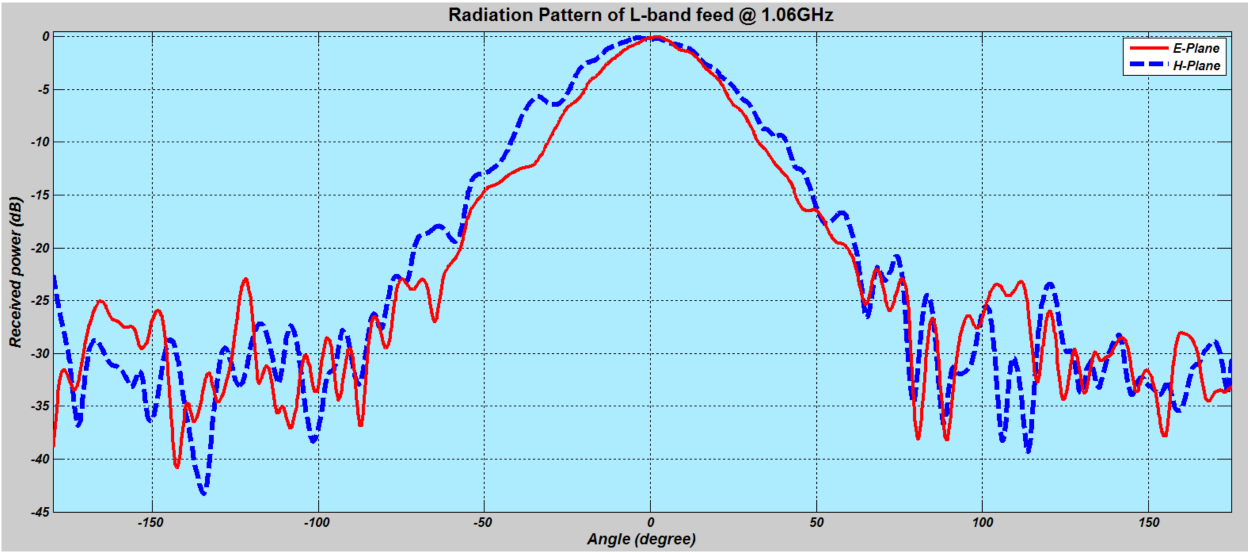


Figure 3-15 Radiation Pattern of L-band feed @ 1.06GHz

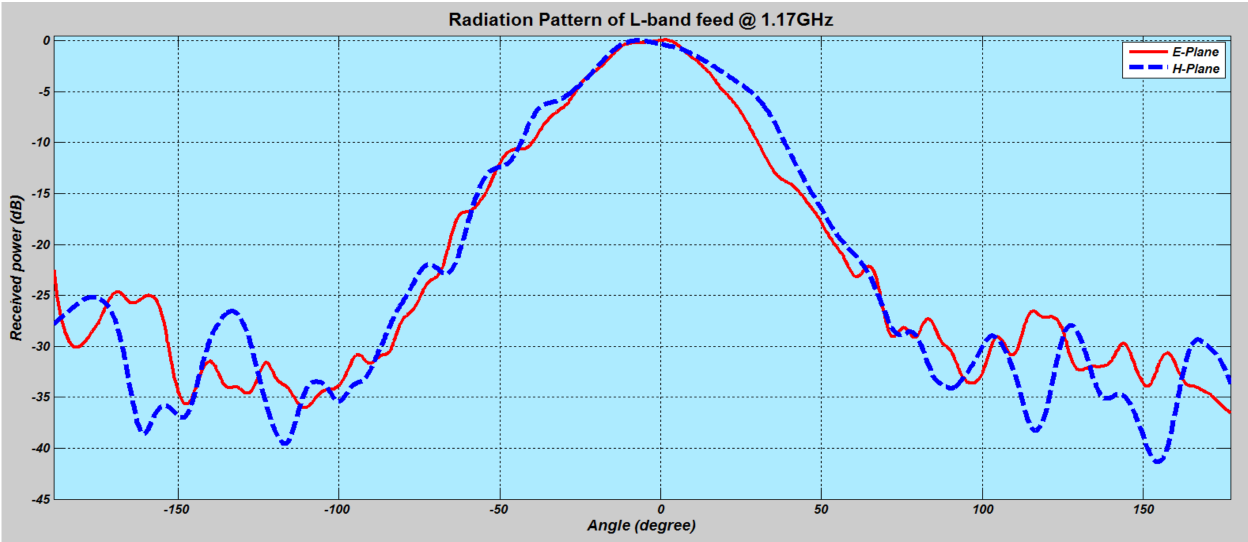


Figure 3-16 Radiation Pattern of L-band feed @ 1.17GHz

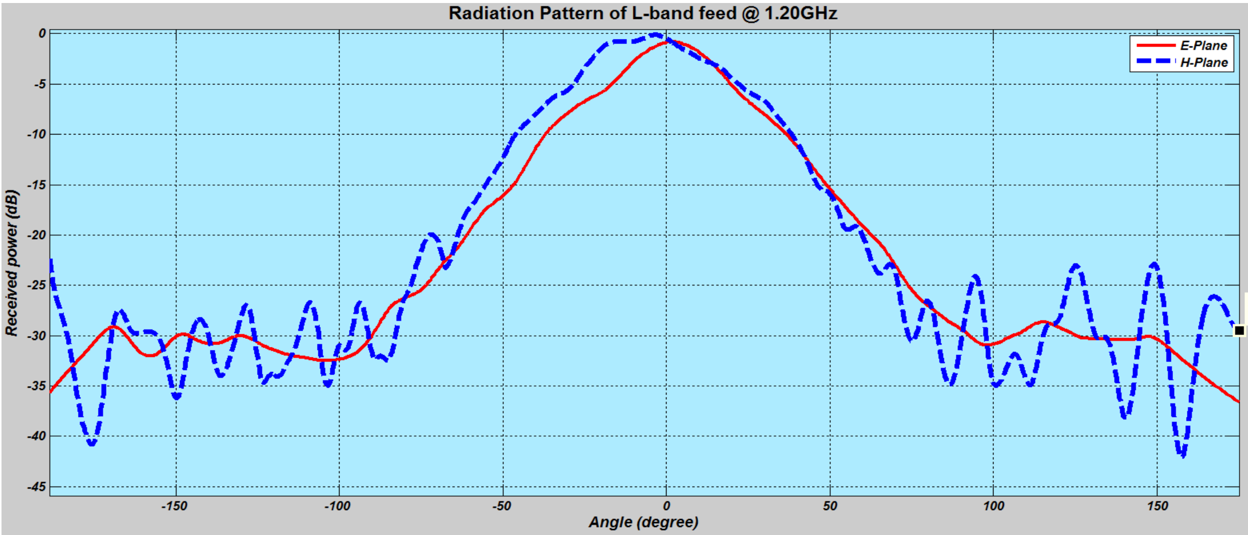


Figure 3-17 Radiation Pattern of L-band feed @ 1.20GHz

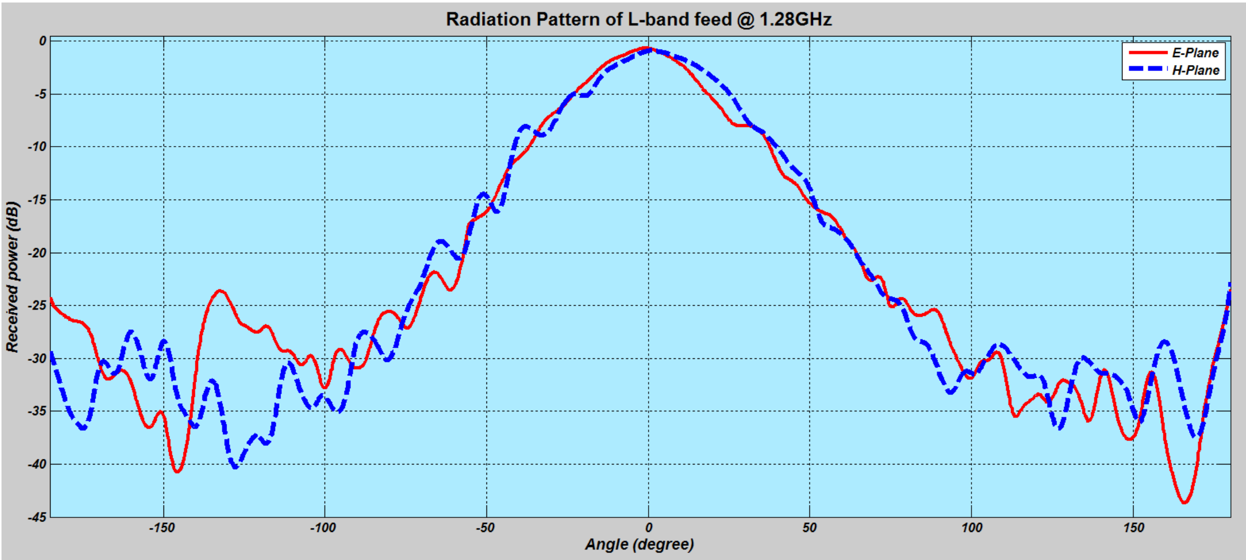


Figure 3-18 Radiation Pattern of L-band feed @ 1.28GHz

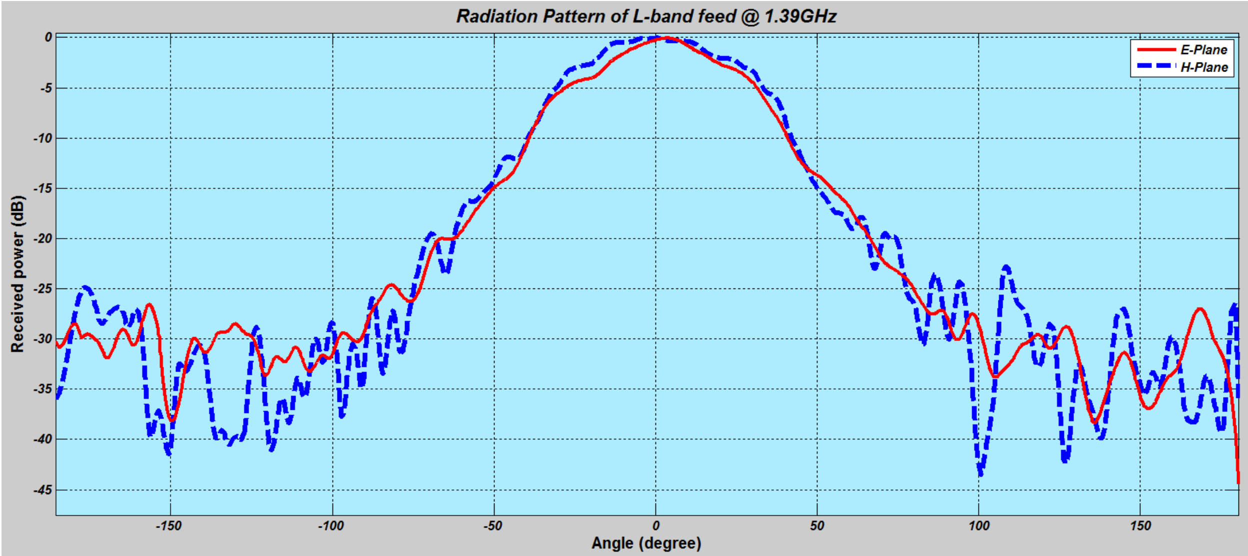


Figure 3-19 Radiation Pattern of L-band feed @ 1.39GHz

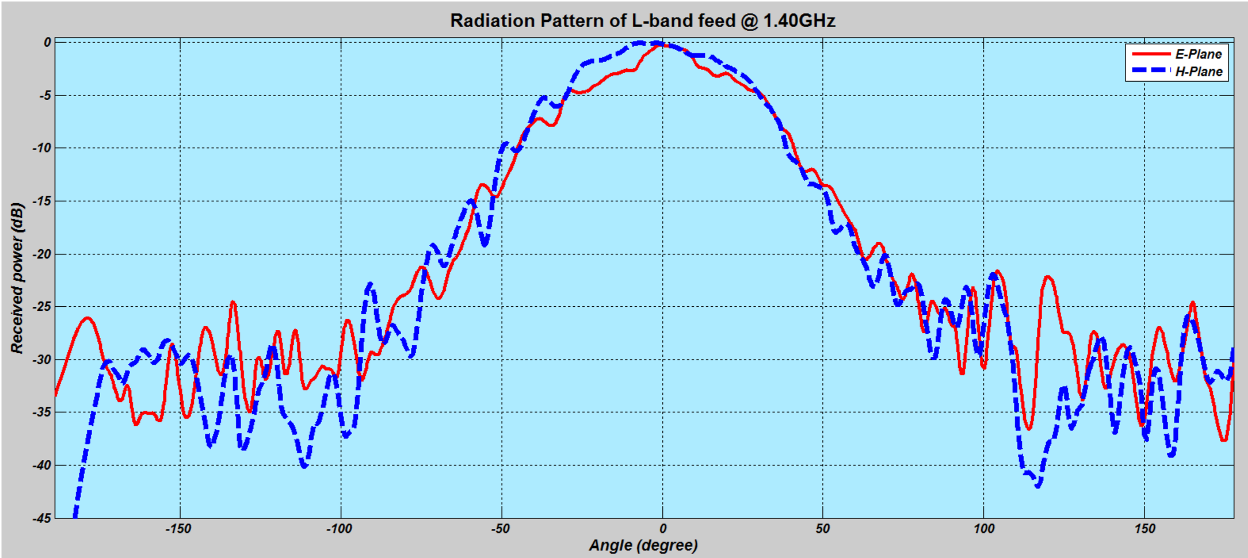


Figure 3-20 Radiation Pattern of L-band feed @ 1.4GHz

3.2.1 Taper Measurements for L-band feed

Form the radiation patterns obtained, results can be summarized and presented in form of Taper plots below.

Table 3-1 Taper Readings for L-band feed

Frequency (MHz)	E-Plane Taper L (-62.5)	E-Plane Taper R (62.5)	Average	H-Plane Taper-L(-62.5)	H-Plane Taper-R(62.5)	Average2
1000	-18.71	-18.3	-18.505	-21	-11.57	-16.285
1060	-23.11	-22.7	-22.905	-18.09	-21.06	-19.575
1170	-17.12	-22.86	-19.99	-20.71	-21.82	-21.265
1200	-20.71	-19.91	-20.31	-18.69	-22.36	-20.525
1280	-23.22	-19.16	-21.19	-19.21	-19.23	-19.22
1390	-20.04	-18.17	-19.105	-20.15	-18.42	-19.285
1400	-19.42	-20.37	-19.895	-16.65	-20.61	-18.63

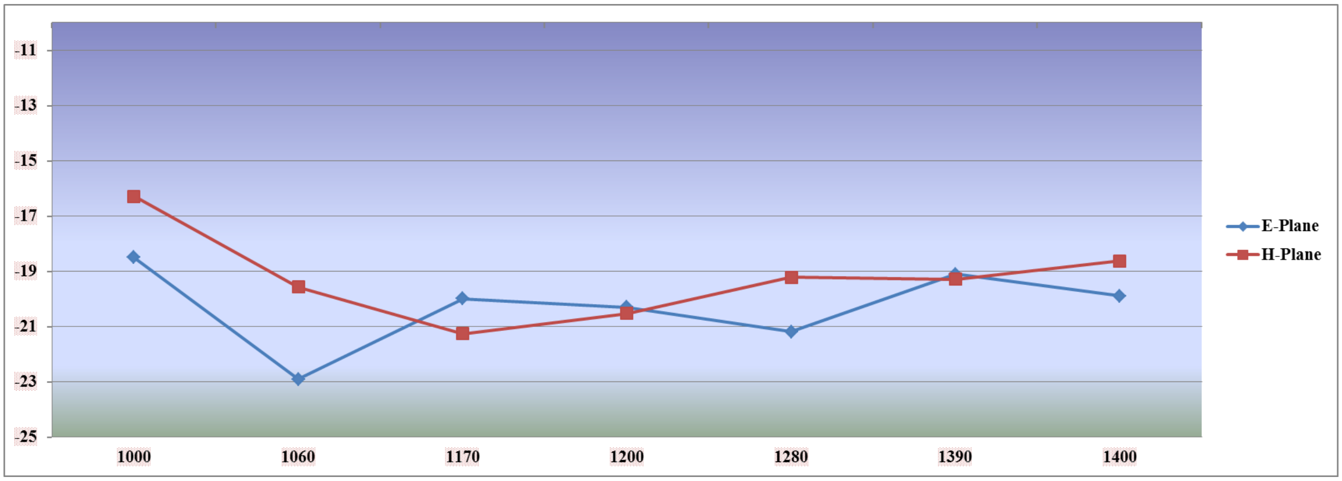


Figure 3-21 Taper plots for L-band feed **(x-axis: frequency in MHz, y-axis: Taper in dB)**

As observe from above figure Taper is well within 2dB range which is very good. (Note: at 1GHz Readings are shooting are supposed to be because of interference as seen Pattern in fig 3-3)

3.3Radiation Pattern of Conical Dipole Feed

3.3.1 Co-Polar Pattern of Conical Dipole antenna

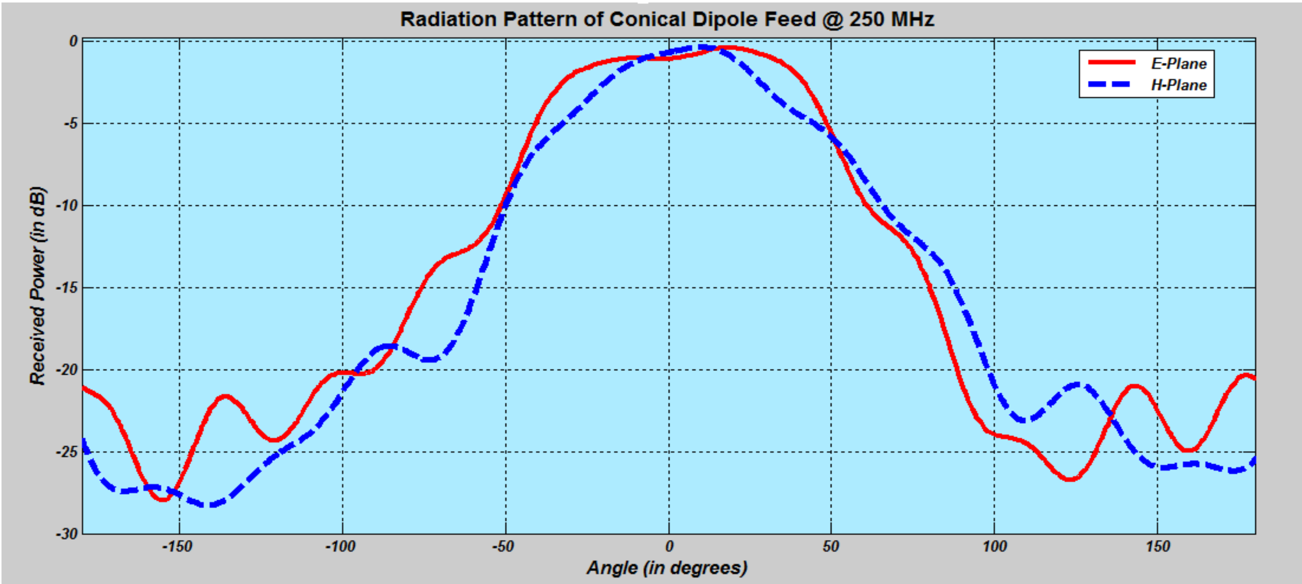


Figure 3-22 Radiation Pattern of Conical Dipole feed @ 250MHz

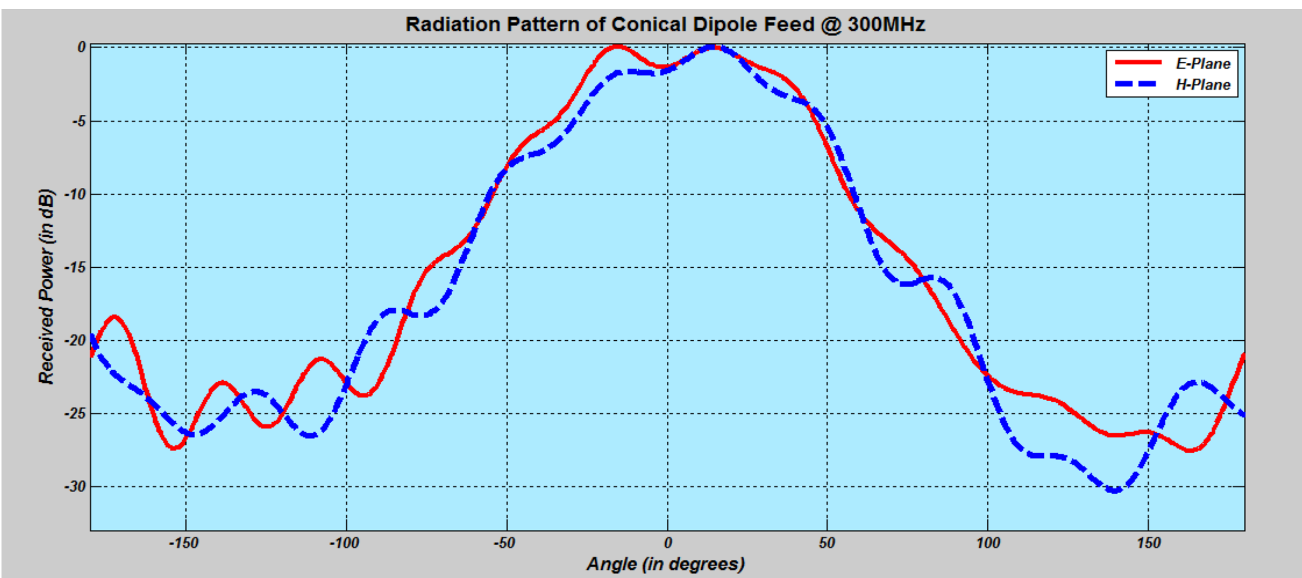


Figure 3-23 Radiation Pattern of Conical Dipole feed @ 300MHz

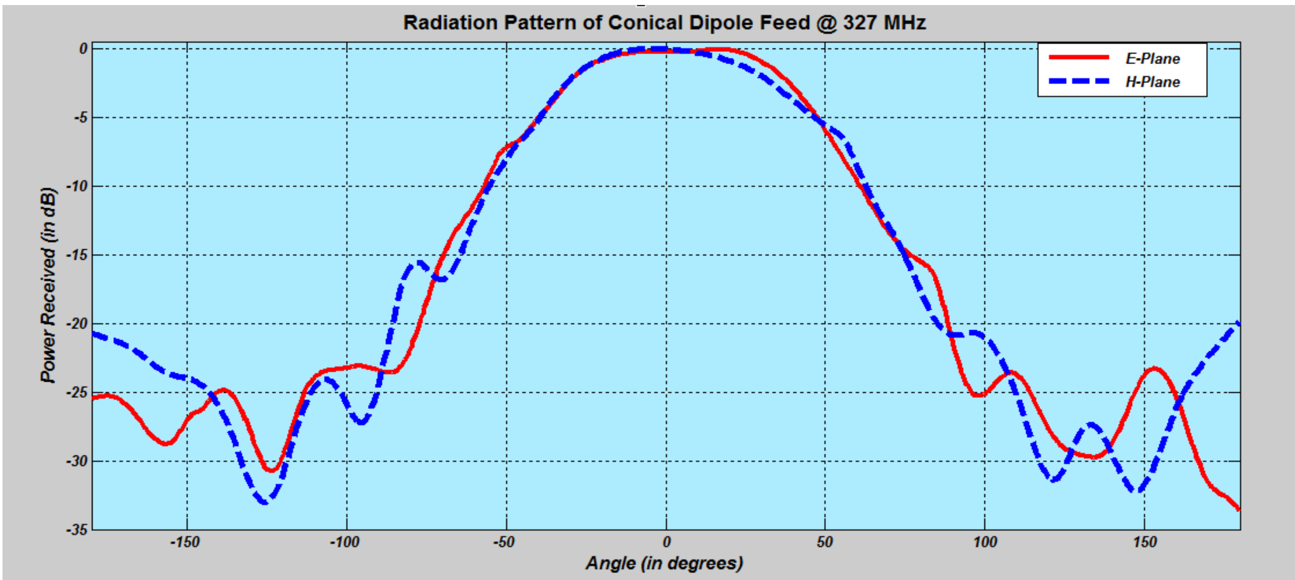


Figure Error! No text of specified style in document.**-24 Radiation Pattern of Conical Dipole feed @ 327MHz**

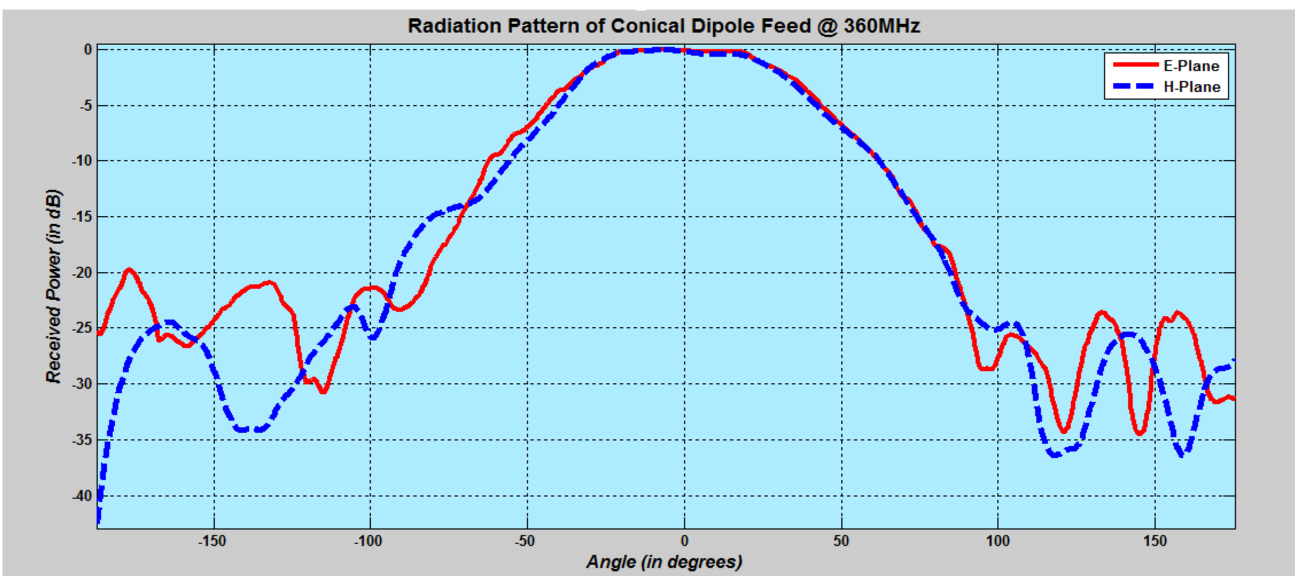


Figure 3-25 Radiation Pattern of Conical Dipole feed @ 360MHz

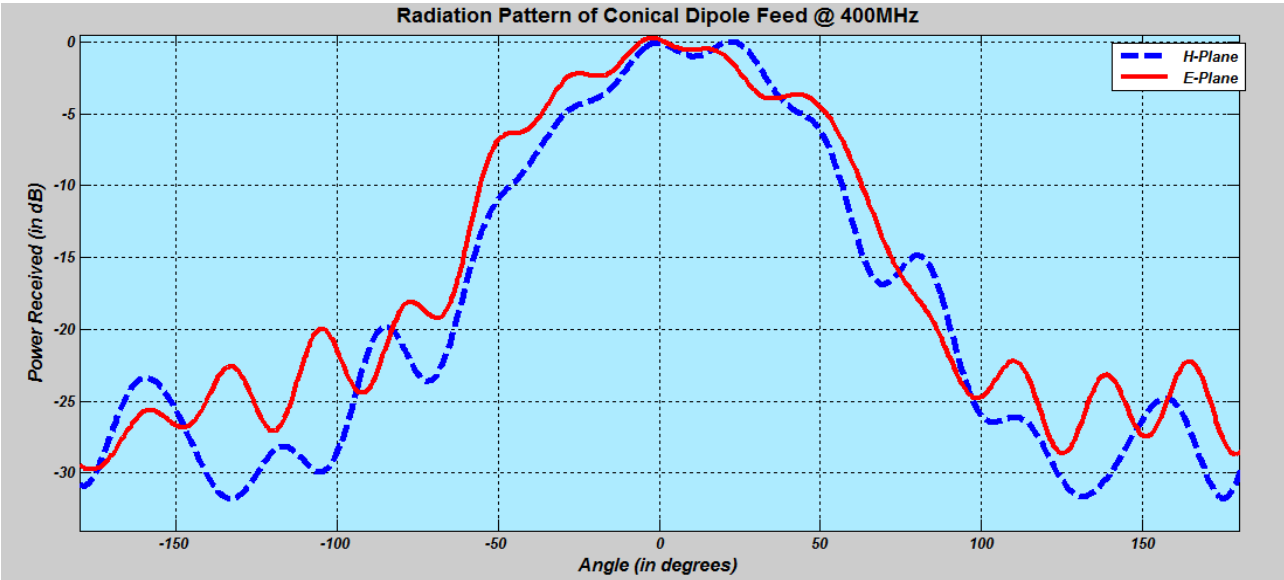


Figure 3-26 Radiation Pattern of Conical Dipole feed @ 400MHz

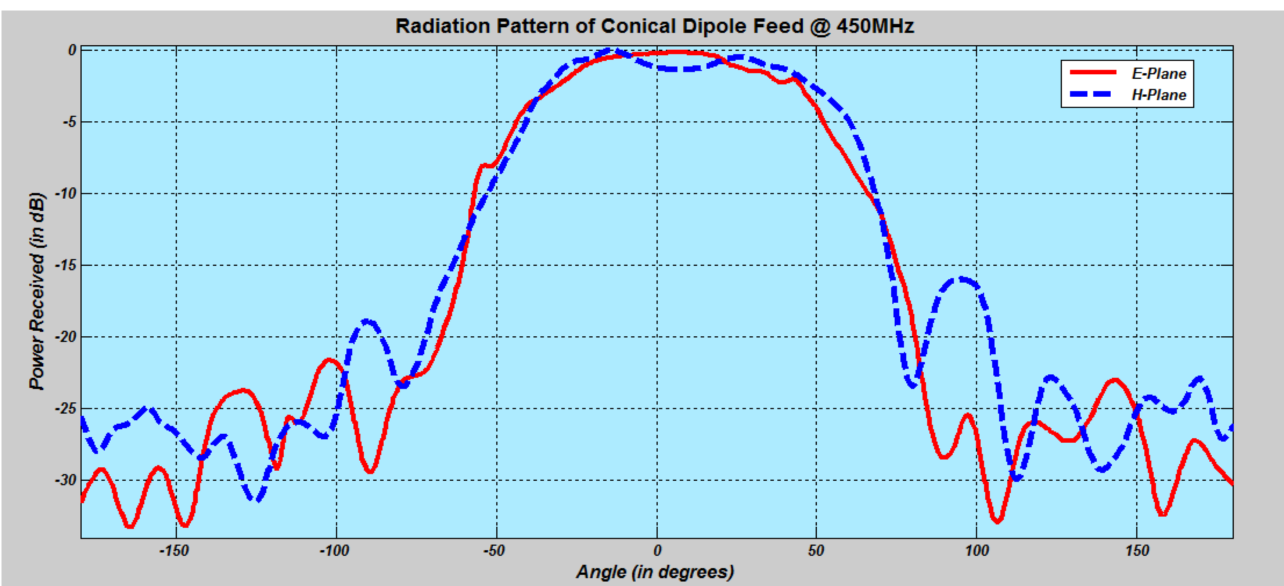


Figure 3-27 Radiation Pattern of Conical Dipole feed @ 450MHz

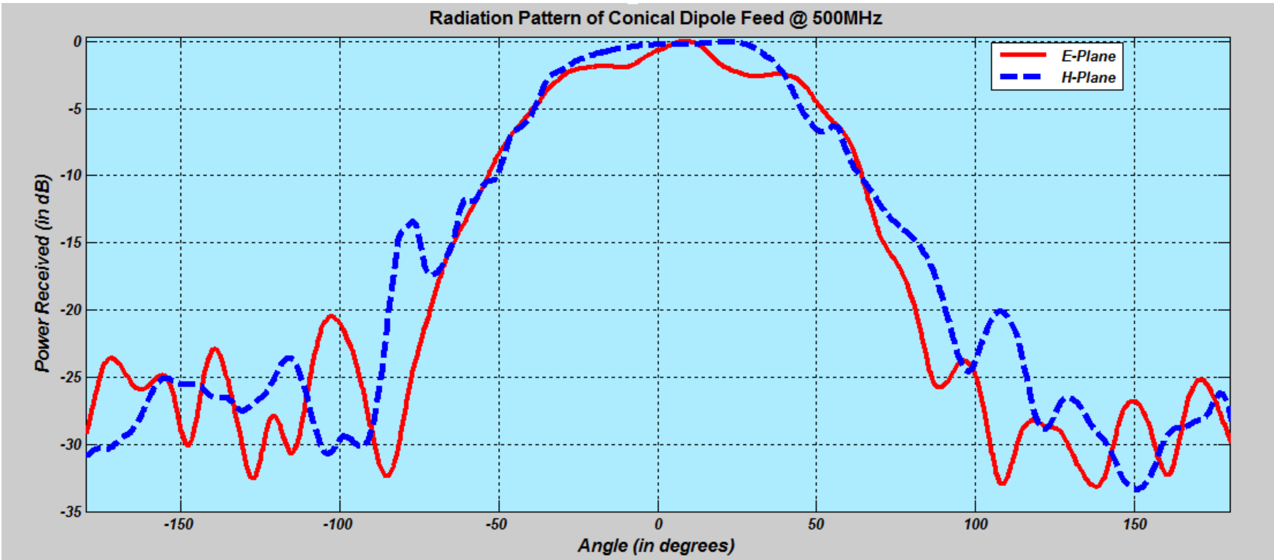


Figure 3-28 Radiation Pattern of Conical Dipole feed @ 500MHz

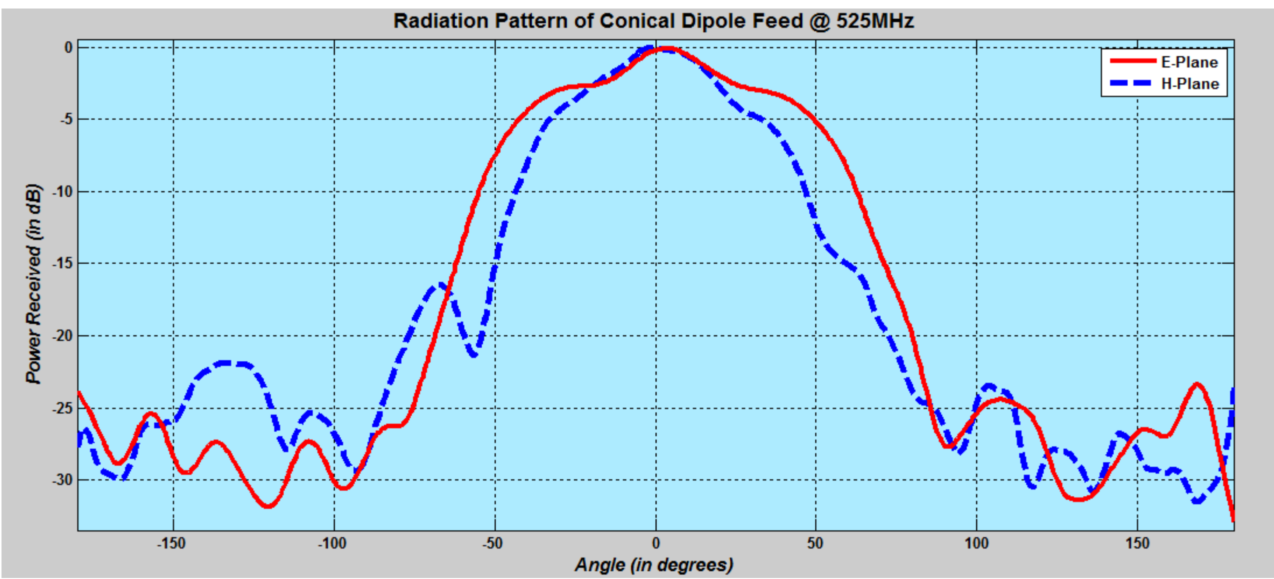


Figure 3-29 Radiation Pattern of Conical Dipole feed @ 525MHz

3.3.2 Cross Polar Pattern of Conical Dipole feed:

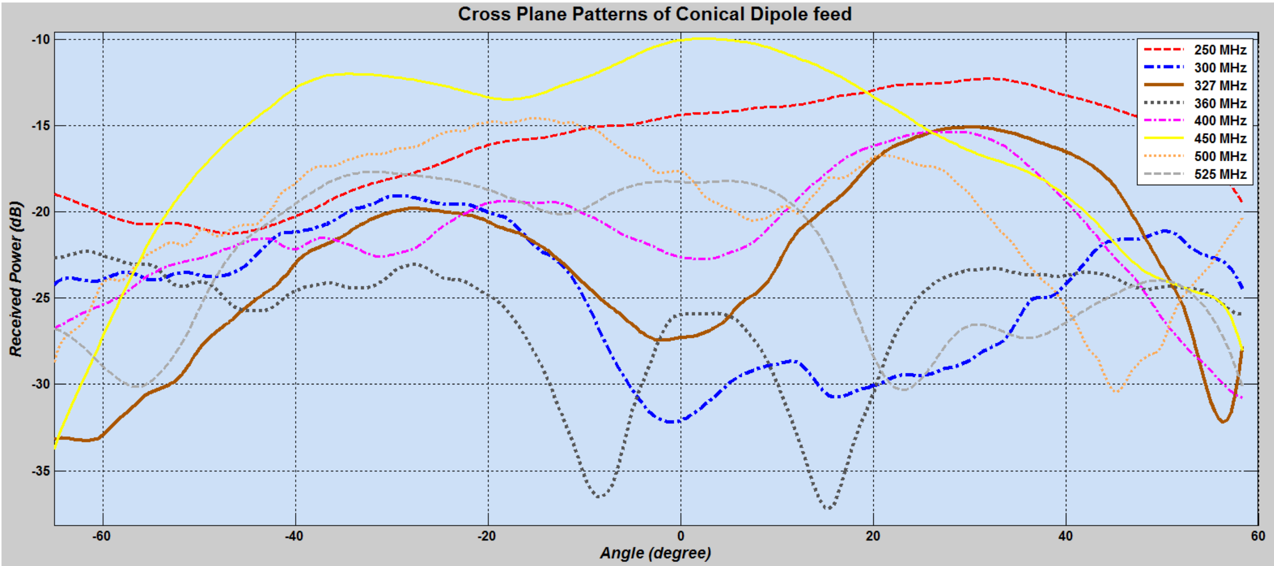


Figure 3-30 Cross Plane Patterns of Conical Dipole feed

From fig. 3-19 we can say that cross plane pattern are good at 300 and 327 MHz as good dip can be seen at zero azimuth.

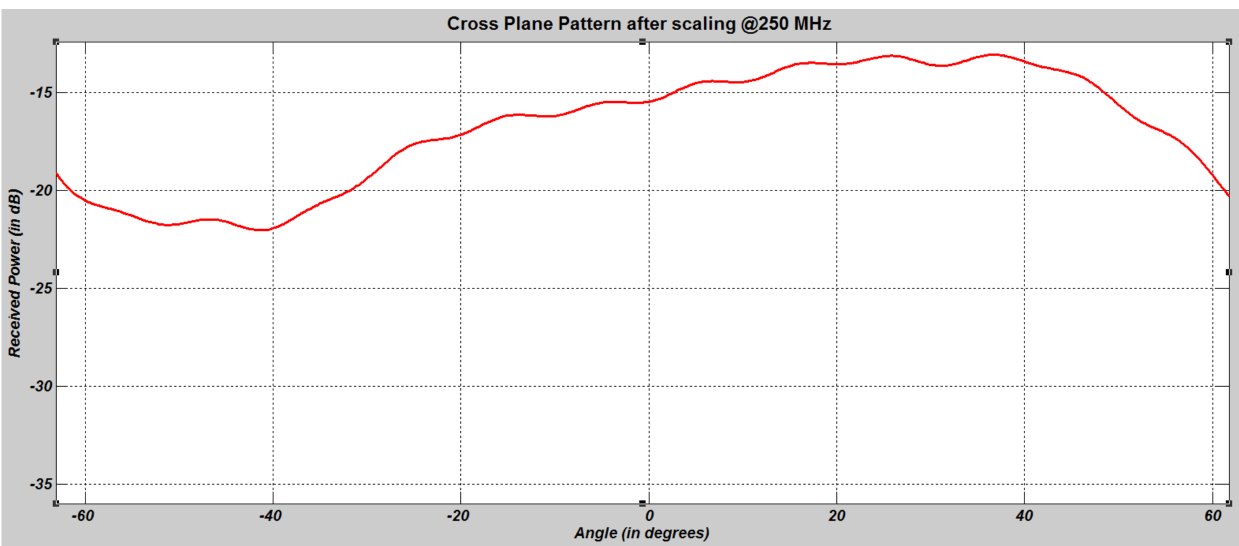


Figure 3-31 Cross Plane Pattern of Conical Dipole feed @ 250MHz

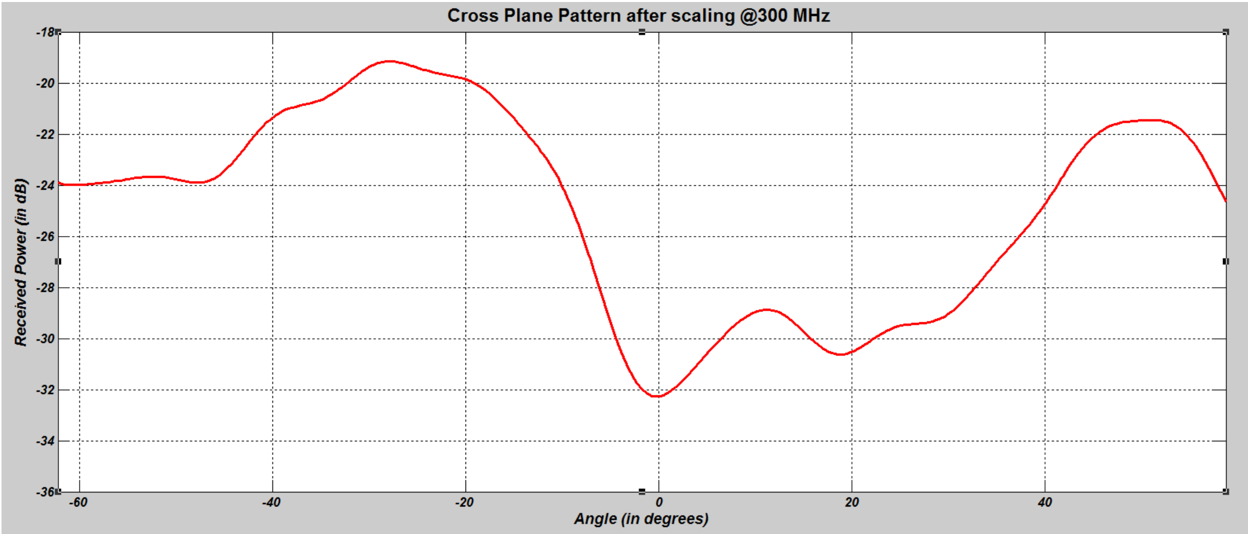


Figure 3-32 Cross Plane Pattern of Conical Dipole feed @ 300MHz

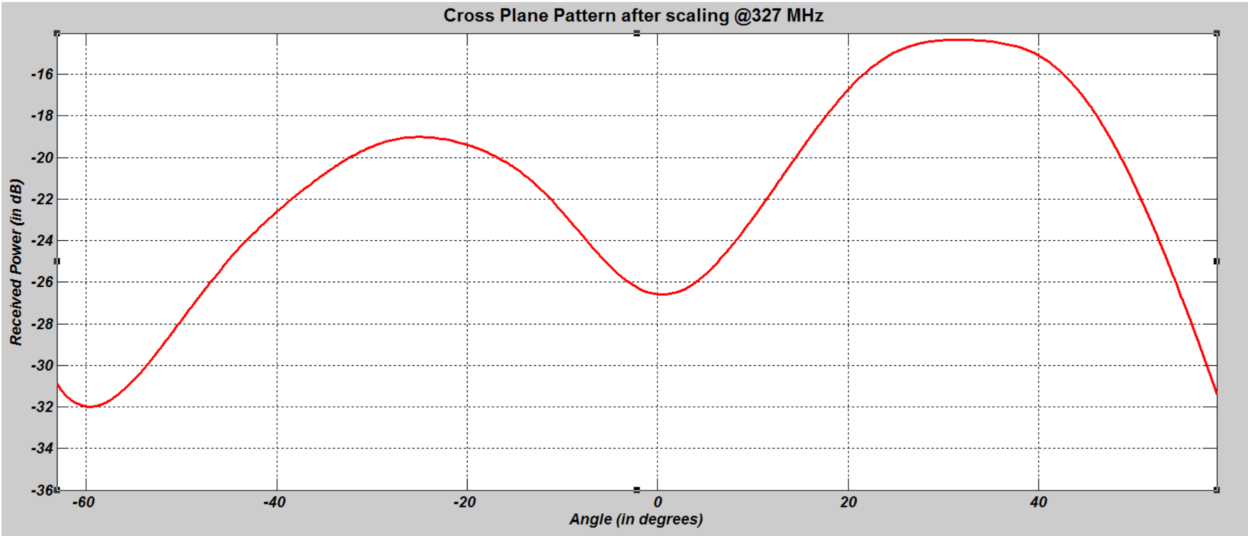


Figure 3-33 Cross Plane Pattern of Conical Dipole feed @ 327MHz

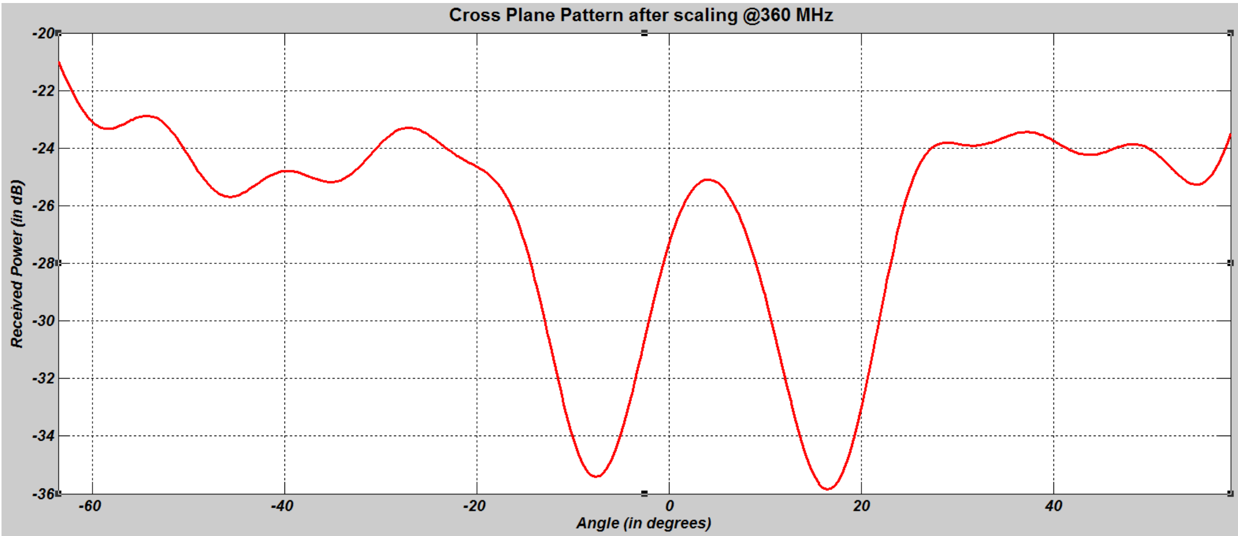


Figure 3-34 Cross Plane Pattern of Conical Dipole feed @ 360MHz

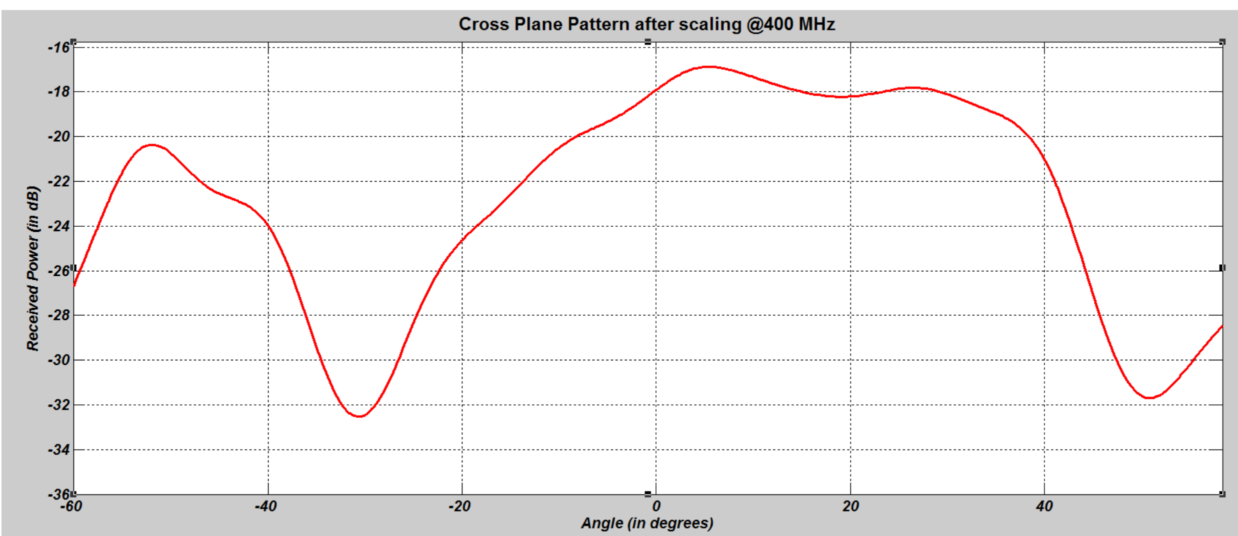


Figure 3-35 Cross Plane Pattern of Conical Dipole feed @ 400MHz

Figure 3-36 Cross Plane Pattern of Conical Dipole feed @ 450MHz

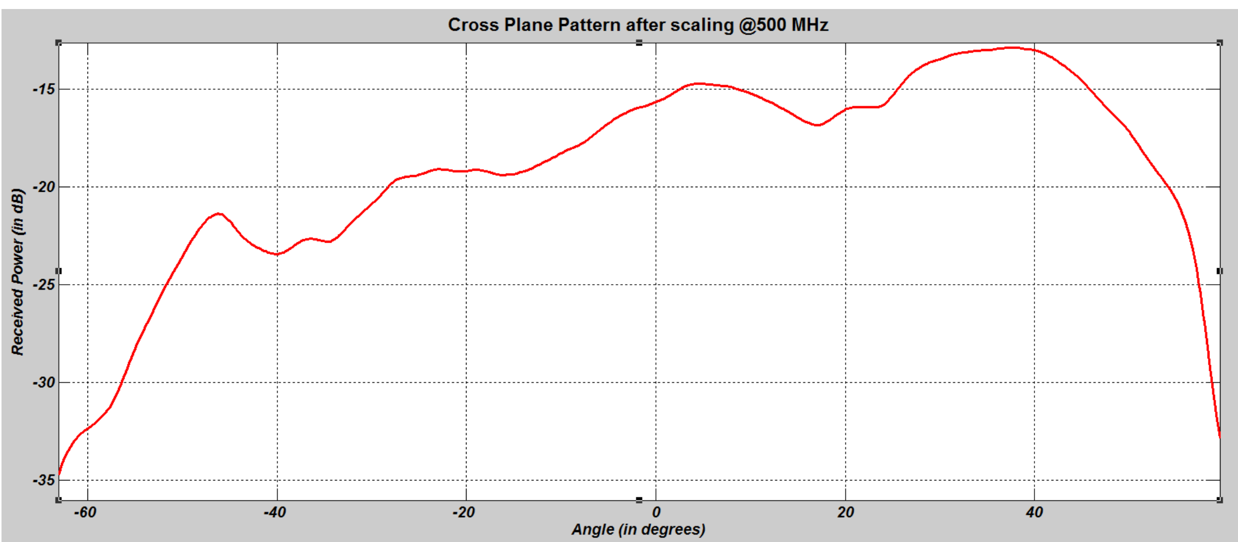


Figure 3-37 Cross Plane Pattern of Conical Dipole feed @ 500MHz

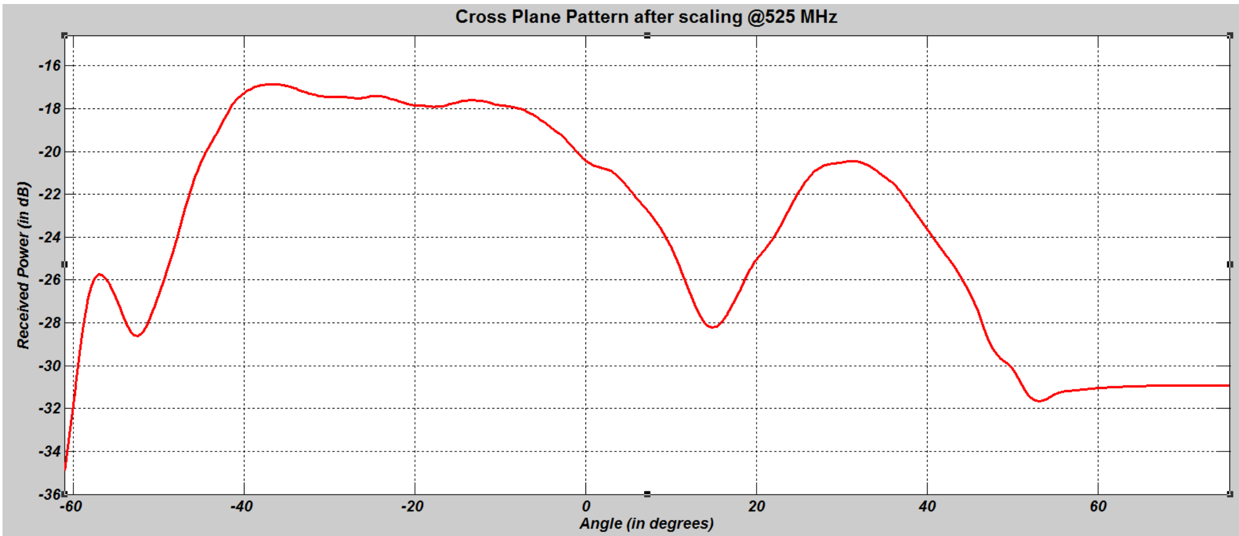


Figure 3-38 Cross Plane Pattern of Conical Dipole feed @ 525MHz

3.3.3 Taper Measurement for Conical Dipole feed

Table 3-2 Taper Readings for Coning Dipole feed

Frequency	E-Plane Taper L (-62.5)	E-Plane Taper R (62.5)	Average	H-Plane Taper-L (-62.5)	H-Plane Taper-R (62.5)	Average2
250	-10.99	-10.66	-10.825	-12.03	-10.05	-11.04
300	-11.5	-12.95	-12.225	-10.21	-14.83	-12.52
327	-11.6	-12.6	-12.1	-12.89	-11.22	-12.055
360	-9.612	-10.5	-10.056	-12.44	-9.49	-10.965
400	-12.1	-10.09	-11.095	-11.8	-13.42	-12.61
450	-11.7	-10.95	-11.325	-10.28	-12.54	-11.41
500	-10.64	-14.6	-12.62	-14.15	-10.99	-12.57
525	-13.04	-11.92	-12.48	-16.57	-15.15	-15.86

Table 3-2 contains Taper readings and as observe from figure 3-28 Taper varies only in range of 1.5 dB which is very good as it tells that feed have almost same response over the frequency range of 250 MHz.

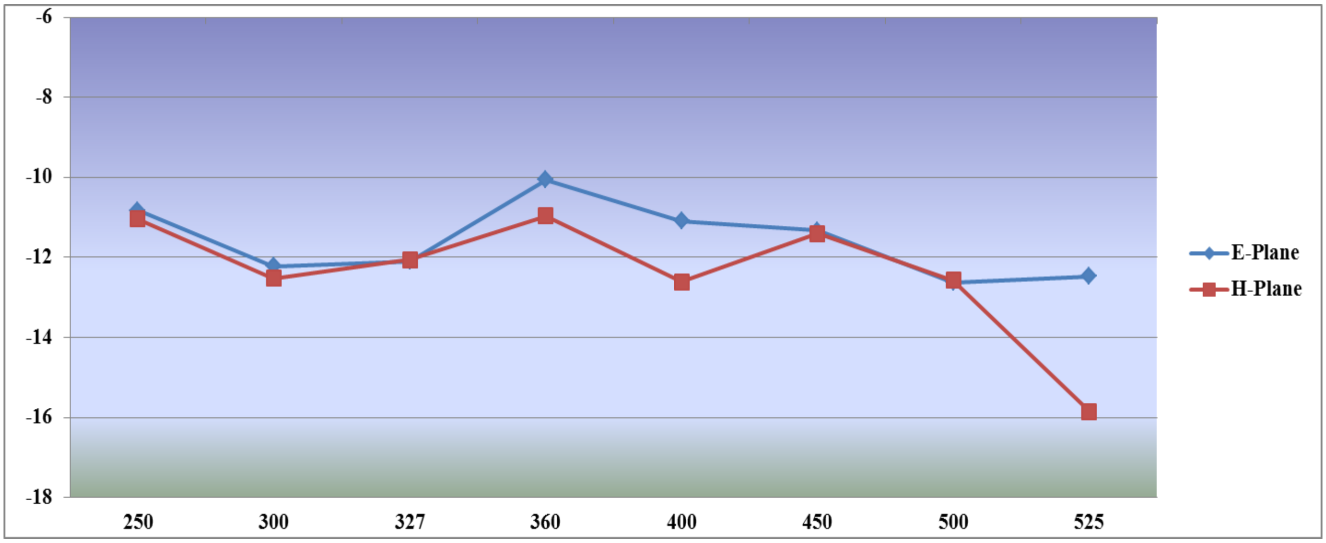


Figure 3-39 Taper Plots for Conical Dipole feed (x-axis: frequency in MHz, y-axis: Taper in dB)

3.3.4 Phase Center Measurement for Conical Dipole feed

The shaded values are ignored and considered as errors as variation is too much. Phase center for E-Plane = -1.4395 and for H-Plane = -0.42181. So from these Phase center is approximated to be at some point behind antenna. (NOTE: These results are doubtful because of phase measurement from such far distance and recommended to be repeated. Also Network Analyzer is less sensitive for measurement from this large distance, so may more sensitive instrument can be used)

Table 3-3 Phase Center Readings for Conical Dipole feed (E-Plane)

	Value of 'r'(in mm) over Approximated Angle(in degree) with respect to center										
f	-10	-8	-6	-4	-2	2	4	6	8	10	Avg.
327	-5.7	-7.66	-5843.3	-1.8	-0.9	0.5	1.5	43.8	2.6	1.4	-1.2575
250	0.4	0.4	19.6	0.5	0.5	-0.7	-1.6	-472.1	-4.7	-4.4	-1.2
300	-6.3	-7.9	1525.0	-2.7	-1.4	1.0	1.2	51.1	3.1	2.4	-1.325
360	2.0	3.6	59.0	1.5	1.3	-1.5	-2.9	442.0	-10.2	-7.8	-0.54
400	-8.6	-10.4	595.8	-2.9	-1.6	0.9	1.9	65.6	3.6	1.6	-0.728
450	1.6	2.9	63.3	2.4	1.5	-1.7	-2.7	-359.2	-8.9	-7.5	-1.55
500	-8.8	-9.9	191.2	-3.3	-2.4	1.2	1.2	39.8	3.1	2.0	-2.33
525	0.7	2.3	9.9	1.1	0.7	-1.0	-2.3	399.8	-8.9	-7.4	-1.85
550	-6.1	-7.3	-488.8	-1.6	-0.000	0.7	0.6	30.8	0.6	0.1	-2.175
Overall Average											-1.4395

Table 3-4 Phase Center Readings for Conical Dipole feed (H-Plane)

Frequency	Value of 'r'(in mm) for H-plane						Avg.
250	0.51	-3.65	-5.20	-3.96	-30.28	-7.55	-3.308
300	181.58	276.81	2.08	2.28	57.15	5.88	3.413
327	-1.53	-226.29	-0.40	-0.79	240.31	-1.84	-1.14
350	2.22	33.89	1.08	1.48	-1.55	-3.56	-0.06
400	-4.48	140.66	-0.97	-0.35	-1.08	-1.44	-1.664
450	1.72	118.87	1.34	4.44	-1.47	-3.80	0.59
500	-4.38	-8.39	-0.69	0.50	1.63	0.66	-1.778
550	0.22	2.90	0.29	-1.12	131.62	93.40	0.5725
	Overall Average						-0.42181

3.4 Radiation Pattern of Modified Kildal feed

3.4.1 Co-Polar Pattern of Modified Kildal feed

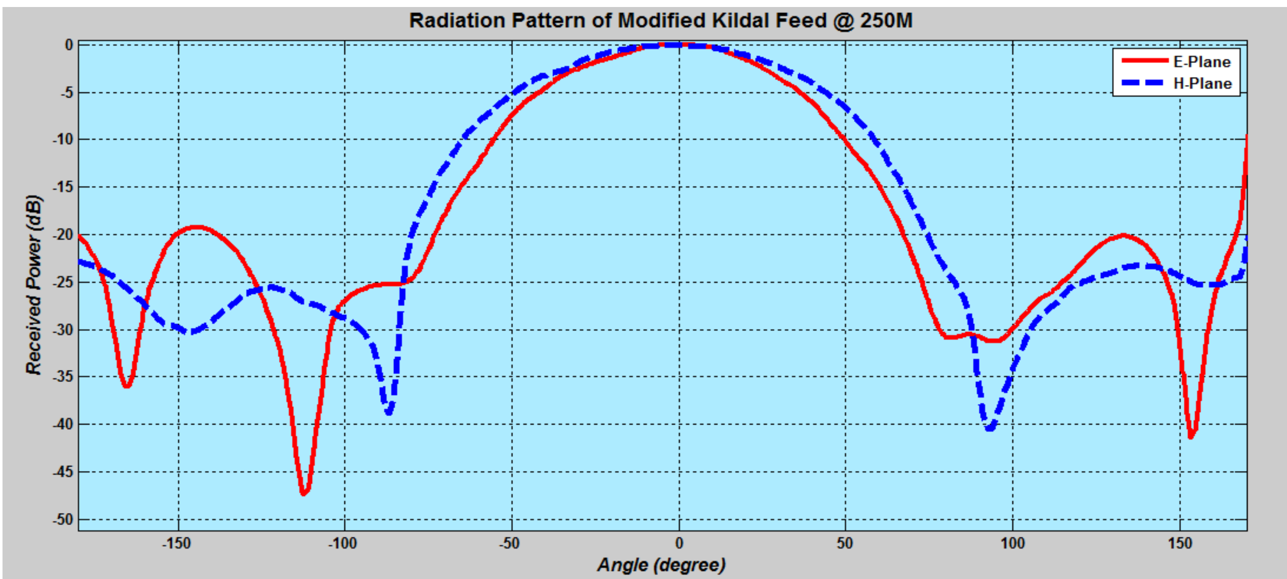


Figure 3-40 Radiation Pattern of Modified Kildal feed @ 250MHz

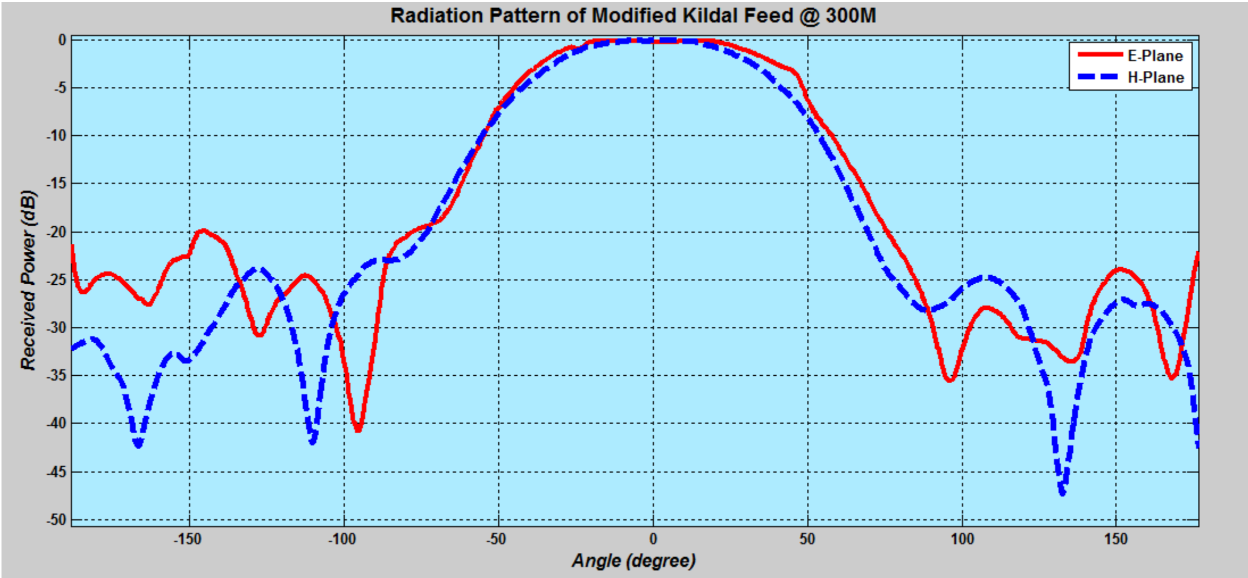


Figure 3-41 Radiation Pattern of Modified Kildal feed @ 300MHz

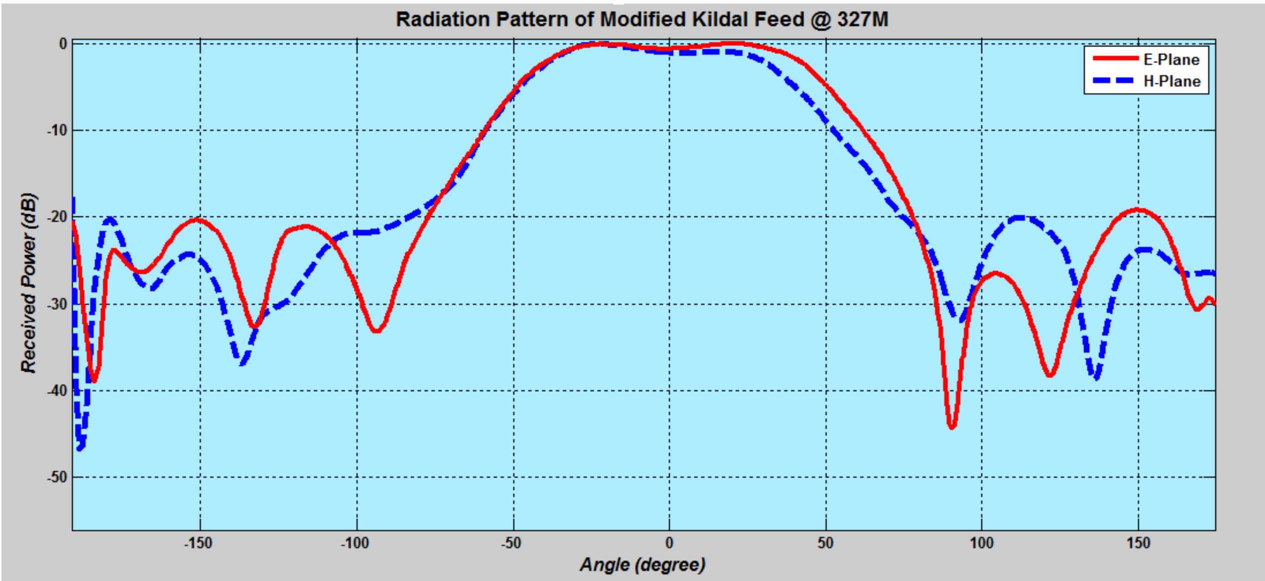


Figure 3-42 Radiation Pattern of Modified Kildal feed @ 327MHz

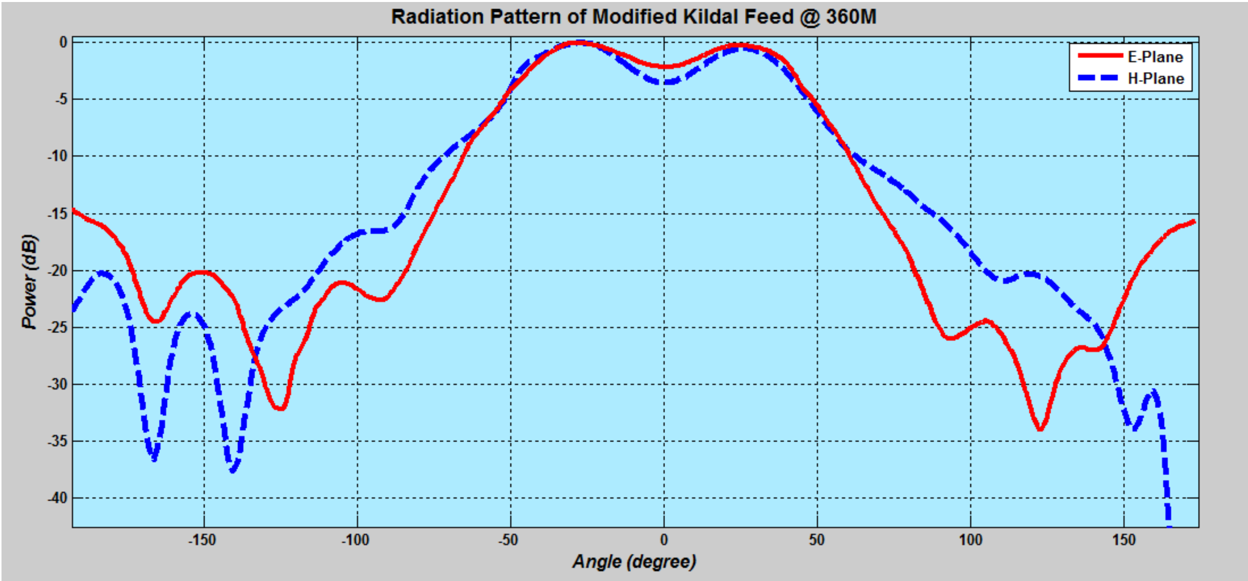


Figure 3-43 Radiation Pattern of Modified Kildal feed @360

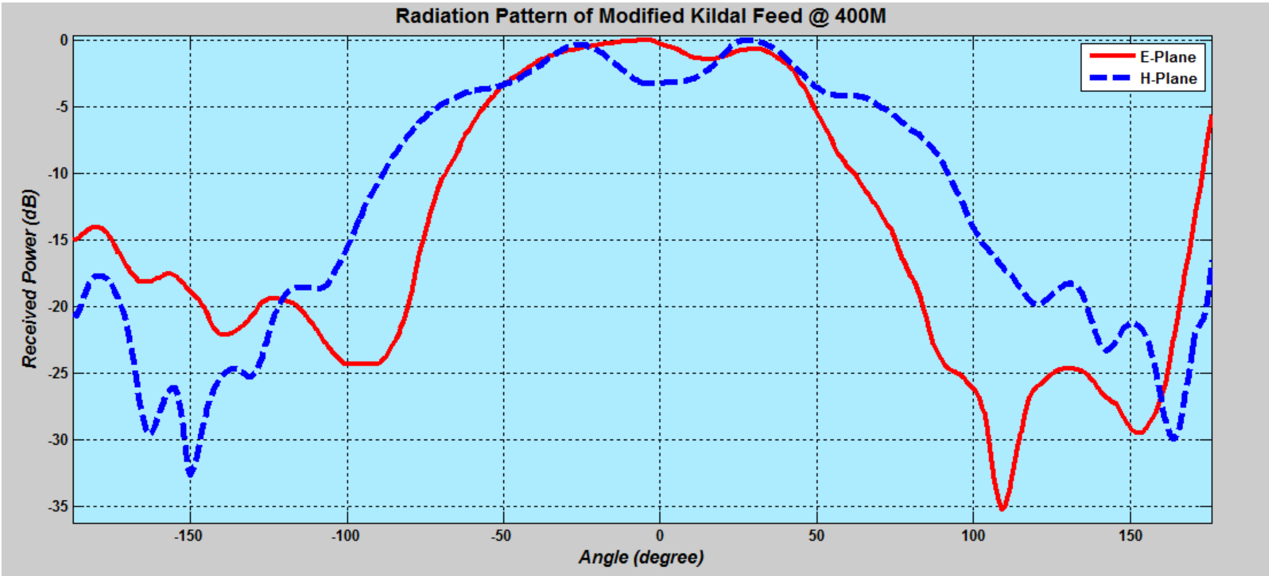


Figure 3-44 Radiation Pattern of Modified Kildal feed @ 400MHz

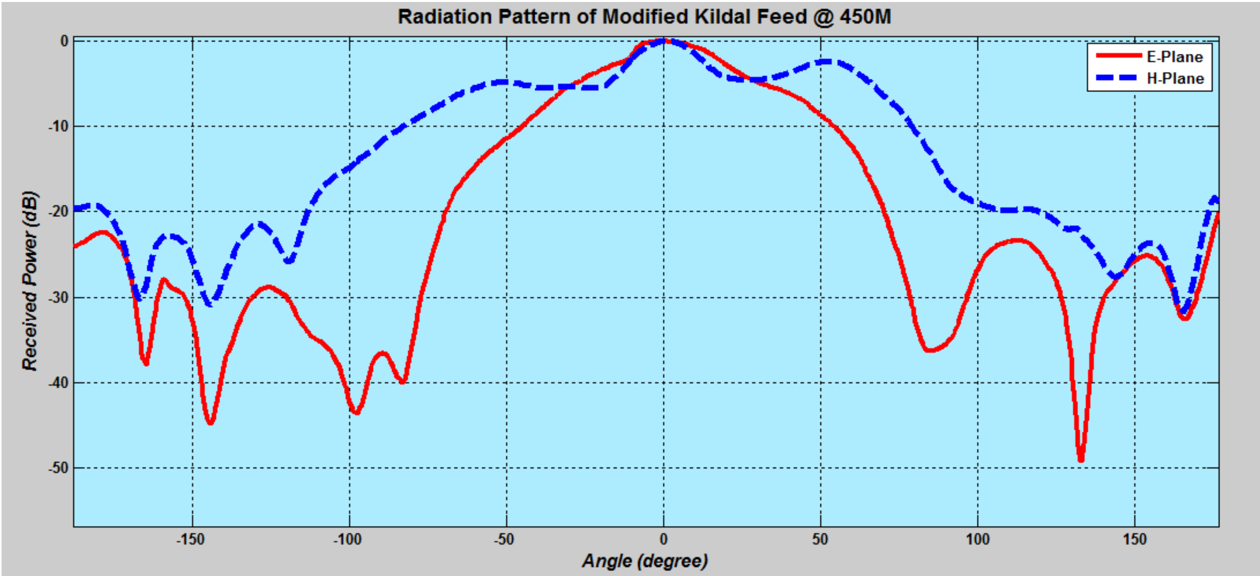


Figure 3-45 Radiation Pattern of Modified Kildal feed @ 450MHz

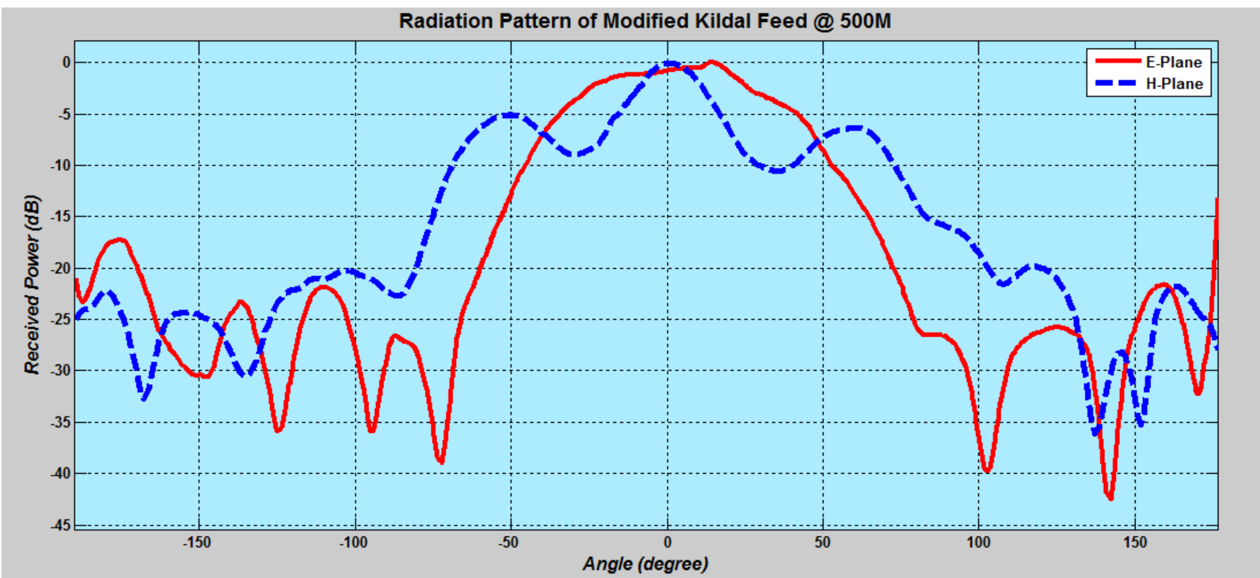


Figure 3-46 Radiation Pattern of Modified Kildal feed @ 250MHz

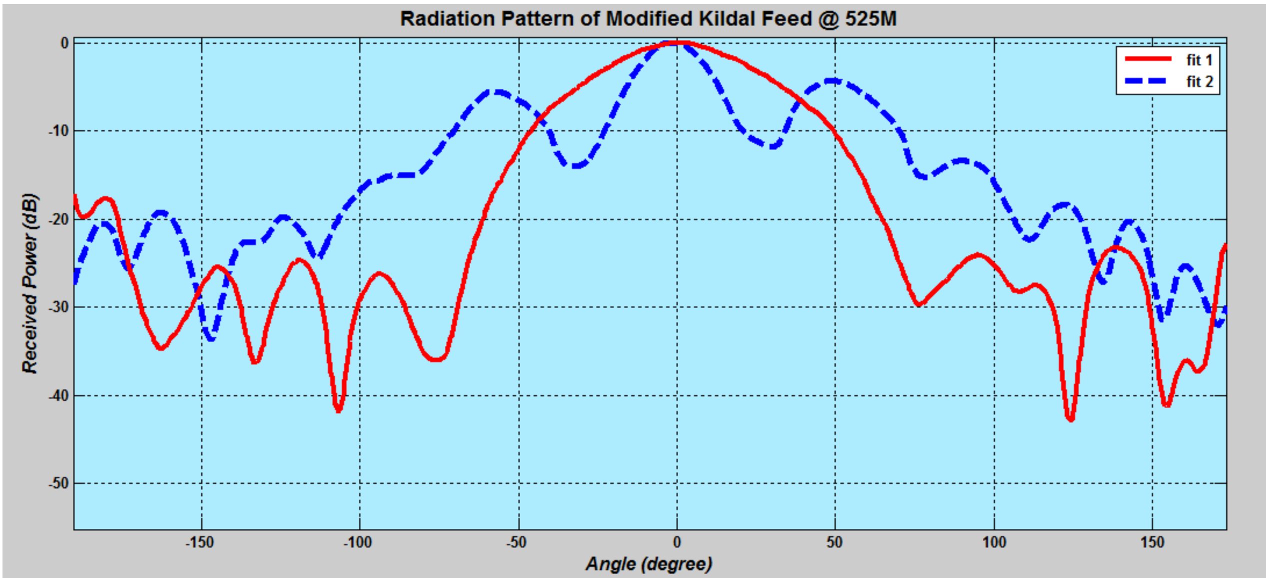


Figure 3-47 Radiation Pattern of Modified Kildal feed @ 525MHz

By looking at figure from 4-19 to 4-36 we can say Kildal feed works well in the region of 250-360MHz.

3.4.2 Taper measurements for Modified Kildal feed

Table 3-5 Taper Readings for Modified Kildal feed

Frequency (MHz)	E-Plane Taper L (-62.5)	E-Plane Taper R(62.5)	Average	H-Plane Taper- L	H-Plane Taper- R	Average2
250	-13.64	-16.41	-15.025	-9.024	-12.23	-10.627
300	-15.27	-12.41	-13.84	-13.72	-15.32	-14.52
327	-11.84	-10.22	-11.03	-12.31	-14.07	-13.19
360	-8.493	-10.91	-9.7015	-7.937	-10	-8.9685
400	-7.213	-10.2	-8.7065	-3.981	-4.191	-4.086
450	-15.76	-13.79	-14.775	-5.863	-3.963	-4.913
500	-21.99	-13.92	-17.955	-7.061	-6.449	-6.755
525	-21.22	-18.43	-19.825	-6.448	-6.845	-6.6465

Figure 3-48 Taper plots for Modified Kildal feed (x-axis: frequency in MHz, y-axis: Taper in dB)

From above fig. it is seen that Taper is varying almost 10 dB, which means beamwidth is decreasing till 400MHz and then it is increasing. But too much variation is not accepted.

3.4.3 Cross Polar Pattern of Modified Kildal feed

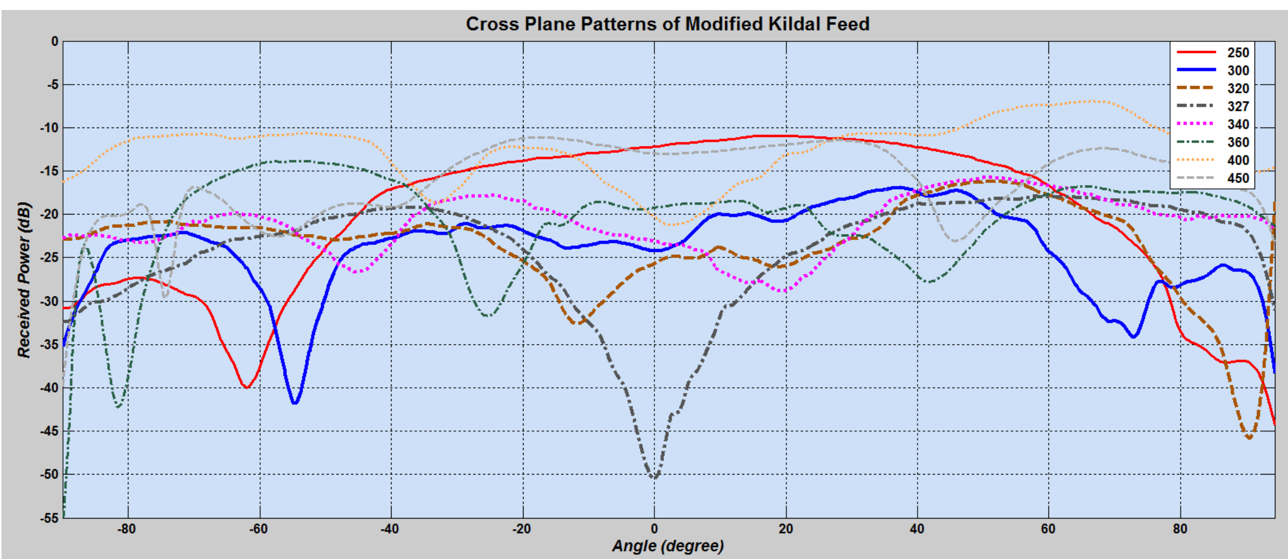


Figure 3-49 Cross Plane Patterns of Modified Kildal Feed

At 327MHz power level is -50dB which is very good.

3.5 Comparison of Kildal and Conical Dipole feed

- As seen in above figure at zero azimuth dip for Kildal feed is more, which means E and H planes are well isolated in it in comparison to conical dipole feed i.e. polarization properties of Kildal are very good at 327 MHz.

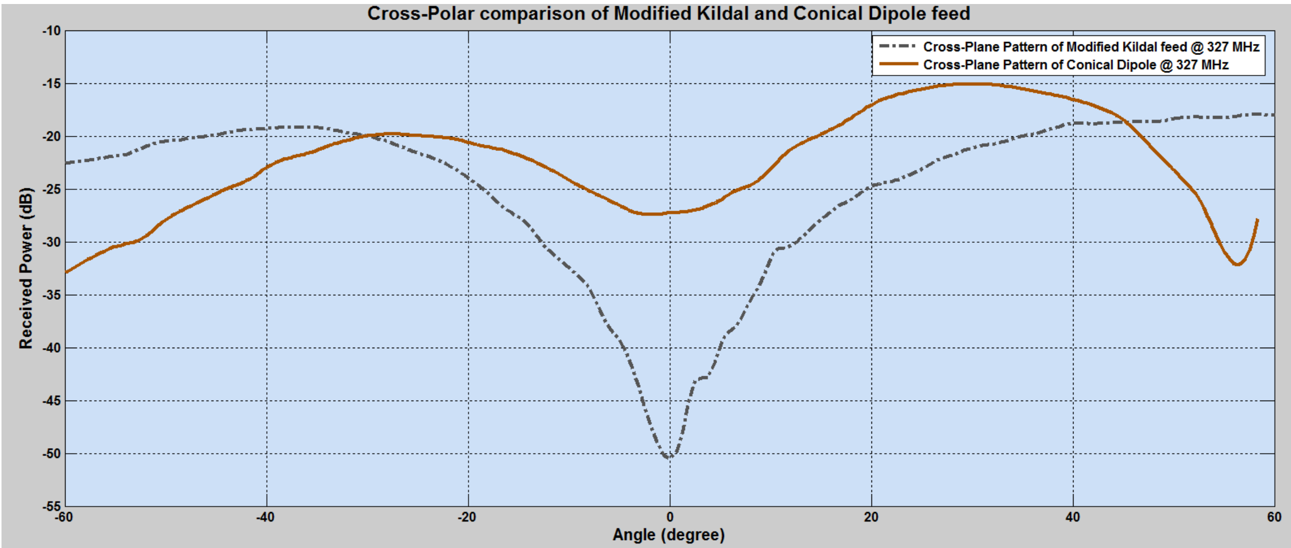


Figure 3-50 Cross –Polar comparison of Modified Kildal and Conical Dipole feed

- HPBW for Conical Dipole feed is nearly 73 degree. HPBW for Kildal feed is nearly 88 degree in E-Plane and 77 degree in H-Plane. Other than that pattern is good for both.

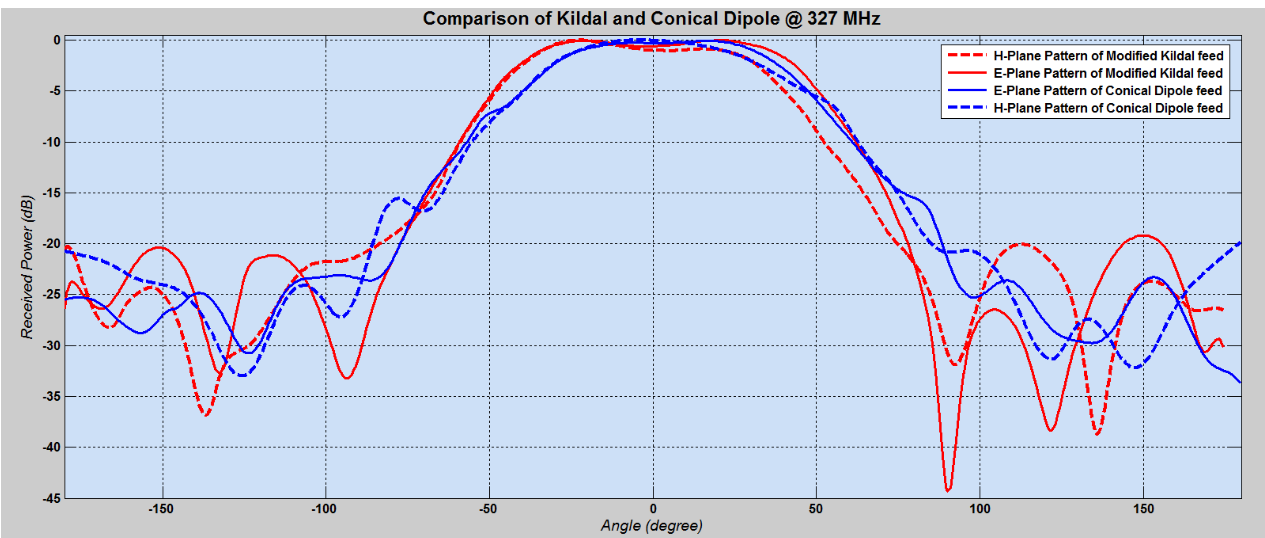


Figure 3-51 Comparison of Kildal and Conical Dipole @ 327 MHz

4. CONCLUSIONS AND RECOMMENDATIONS

- If additional bandwidth is major concern then it would be good to go for Conical Dipole as it has a large bandwidth of 250MHz and relatively poor polarization property.
- As Co-Polar pattern are very good and cross-polar pattern are also not bad for Conical Dipole feed, so it can be mounted at antennas in GMRT.
- If one has to observe polarized sources Modified Kildal feed would be a good choice, but less bandwidth limits its use.
- Although we got Phase center at some 1mm. below it, but still since there is so much ambiguities in readings this result is not supposed to be reliable. There is also question on reliability of the instrument (Network Analyzer), so we suggest it to be done again with some other instrument (more sensitive). Also it would be better to decrease distance between transmitter and receiver antenna for Phase measurement to get better results.
- On the basis of Co-Plane patterns, Taper and symmetry plots working of L-band feed is indubitable.
- With the lack of time phase center measurement couldn't be done for L-band and Kildal feed so it is recommended to do so for better results and complete characterization of these feeds.

APPENDIX-I

Matlab Program for getting Plot:

```
clear all;
[textdata] = textread('filename.txt');
A=size(textdata);
N=A(1);
power(N/2)=(0);
angle(N/2)=(0);
j=1;
for i=1:N/2
    power(j) = textdata(2*i,201);
    angle(j) = textdata(2*i-1,201);
    j=j+1;
end
for y=1:10
    for i=1:N/2
        if (i<N/2-2)
            if (abs((angle(i+1))-(angle(i)))>0.1 && abs((angle(i+1))-(angle(i)))<2 )
                angle(i+1)= (angle(i)+angle(i+2))/2;
            end
        end
    end
end
[angle_volt] = textread('angle_volt.txt','%n');
[angle_degree] = textread('angle_degree.txt','%n');
anglefit=polyfit(angle_volt,angle_degree,1);
angle_degree_cal=anglefit(1).*angle+anglefit(2);
for i=1:N/2
    if ( (angle_degree_cal(i) >180) && (angle_degree_cal(i) <=360) )
        angle_degree_cal(i) = angle_degree_cal(i) - 360 ;
    end
end
for x=1:10
    for i=1:N/2
        if (i<N/2-2)
            if (abs((angle_degree_cal(i+1))-(angle_degree_cal(i)))>0.5)
                angle_degree_cal(i+1)= (angle_degree_cal(i)+angle_degree_cal(i+2))/2;
            end
        end
    end
end
max(power)
angcorr=angle_degree_cal-6;
for i=1:N/2
    if ( (angcorr(i) >180) && (angcorr(i) <=360) )
        angcorr(i) = angcorr(i) - 360 ;
    end
end
pownor=power-max(power);
figure;
plot(angle_degree_cal,power);
figure;
plot(angcorr,pownor,'r');
```

APPENDIX-II

Matlab program for getting Phase center:

```
clear all;
k=1;
d=134250.6;
angle(8,7)=0;
phase(8,7)=0;
delta(8,7)=0;
theta(8,7)=0;
frequency(8)=0;
[phas]=textread('phase.txt');
[ang] = textread('angle.txt');
for i=1:8
    frequency(i)=(10^6)*ang(k);
    k=k+1;
    for j=1:7
        angle(i,j)=ang(k);
        if ( (angle(i,j) >180) && (angle(i,j) <=360) )
            angle(i,j) = angle(i,j)-360 ;
        end
        phase(i,j)=phas(k);
        k=k+1;
    end
end
for i=1:8
    for j=1:7
        delta(i,j)=((phase(i,4))-(phase(i,j)))*(3*10^11)/frequency(i);
        theta(i,j)=angle(i,4)-angle(i,j);
    end
end
r=(delta+2*d)./(2.*(1+(d./delta).*(1-cos(theta))));
```

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