# ANALYSIS AND EVALUATION OF EXISTING C-BAND FEED HORNS FOR APPLICABILITY TO THE 21 METER MOREHEAD SPACE TRACKING ANTENNA

---

A Thesis

Presented to

the Faculty of the College of Science & Technology

Morehead State University

---

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Prabhakara Rao Eluru

October 08, 2008

Accepted by the faculty of the College of Science & Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

Director of Thesis

Master's Committee: Ahmad Zargari, Chair

Thomas Pannuti

11-3-2008
Date

ANALYSIS AND EVALUATION OF EXISTING C-BAND FEED HORNS FOR APPLICABILITY TO THE 21 METER MOREHEAD SPACE TRACKING ANTENNA

Prabhakara Rao Eluru M.S.
Morehead State University, 2008

Director of Thesis: ______________________

The proposed C-Band feed for the 21 Meter Space Tracking Antenna will be used to conduct radio astronomical observations and represent a vital addition to the current system of existing feeds. This project involved testing of several candidate feeds in the anechoic chamber, subsequent data analysis, radiation pattern, Voltage Standing Wave Ratio (VSWR) measurements, evaluation of the dish geometry of 21 Meter, and comparison with data from existing L and Ku-band specifications. Finally, the best feed with the best performance work at C-band (5GHz) for the 21 Meter was determined. At this frequency range, the C-band represents a crucial balance between sensitivity and resolution for medium aperture radio telescopes like the 21 Meter. The C-band feed aperture will also attain an improvement over the existing angular resolution at L-band. This will ensure the 21-Meter remains a powerful and versatile instrument for astronomical research.

Accepted by: ______________________, Chair

______________________

______________________

## Acknowledgements

The author wishes to express appreciation to all of the individuals who assisted in the completion of this thesis. The author expresses heartfelt thanks to Dr. Benjamin Malphrus, thesis director, and Director of the Space Science Center for continuous support, conducting reviews, providing constructive ideas and offering guidance during the course of completion of the thesis.

Specifically, the author expresses honest thanks to Prof. Jeff Kruth who was the leader of this project right from proposal. He assisted in testing the feeds as well as provided information required for the accomplishment of the thesis.

Sincere gratitude is expressed to Dr. Ahmad Zargari, Chair of Industrial Engineering & Technology (IET), whose continuous encouragement and support has been valuable for the completion on the thesis.

Thanks to Dr. Thomas Pannuti for constructive comments and support during the thesis as well as for serving on the thesis committee.

The author also wishes special thanks to his parents, Mr. Sankar Rao Eluru & Mrs. Vasantha Eluru for the continuous encouragement, motivation, and support towards his entire career and his life.

## Table of Contents

**List of Figures**

## List of Tables

# CHAPTER I: Introduction

The 21 Meter Space Tracking Antenna is located on the campus at Morehead State University (MSU) in Morehead, Kentucky, and operated by the Space Science Center (SSC). The 21 Meter - antenna is a dual purpose instrument capable of observing astronomical targets and supporting satellite missions. The astronomical research conducted with the 21 Meter includes investigations of supernova remnants (SNRs), star formation regions, pulsars, nuclear emission from nearby galaxies, active galactic nuclei (AGNs), blazars and quasars. The 21 Meter supports research and services for government organizations as well as various commercial entities like the Kentucky Science & Technology Corporation (KSTC) and the Kentucky Space Program. The 21 Meter is the main earth station for the KySat series of orbiting satellites and provides exceptional directional gain, as well as sensitivity sufficient for tracking, commanding and acquiring data from satellites. In radio astronomy mode, the 21 Meter is a medium size aperture instrument when compared to the largest radio telescopes, which feature apertures of 100 m or larger.

## General Area of Concern

One of the goals of a system such as the 21 Meter is to make it capable of as many diverse tasks as possible to help capitalize on its potential. A key element of this strategy is to provide operation in as many frequencies regimes as possible for radio astronomy observations. To accomplish this, the feed system must be either broadband (not very efficient) or different feeds must be installed. The goal of this project is to extend the operating frequencies of the 21 Meter to include a feed that is sensitive at the C-band (4.8 – 5.0 GHz), a project that adds significant value to the system. To be efficient, any feed system must be optimized for the geometry and performance of a particular dish, thus making them expensive and challenging to build. A lower cost solution was sought, namely to convert an existing feed made for a different dish, into a feed that may operate at 5 GHz (C-band): this frequency range is particularly important for radio astronomy.

The proposed C-band feed for the 21 Meter Space Tracking Antenna will represent a vital addition to the current system of feeds in place. Currently, three feeds are in use with the 21 Meter: these feeds operate at the Ku-, S-, and L-bands, respectively. The first two bands correspond to frequency regimes dominated by the telecommunications industry, while the L-band is most suitable for formal astronomical research (although significant telecommunication work is also done at L-band). Furthermore, with a full-width at half-maximum (FWHM) of 34.8 arc minutes, the angular resolution of the 21 Meter at L-band is inadequate for some scientific investigations that requires better angular resolution. The design and implementation of the C-band feed will help address two pressing needs for astronomical research with this instrument. First, observations of astronomical sources at C-band feed will both complement observations made with the L-band as well as secondly will add additional spectral analysis capabilities.

By comparing measured fluxes at L-band and C-band for a particular source, an observer can determine if the amount of flux increases or decreases proceeding from longer to shorter wavelengths. An increasing flux would indicate that a source has a thermal spectrum while a decreasing flux would indicate that a source has a non-thermal spectrum (a spectrum of the latter type would most likely be produced by synchrotron emission, probably produced by relativistic electrons gyrating in compressed interstellar magnetic fields). Second, we anticipate that the angular resolution that the 21 Meter will attain with this proposed C-band feed will have a FWHM of approximately 10 arc minutes, which will represent a significant improvement over the angular resolution attained with the L-band. The achievement of feed performance levels close to predicted practical values when integrated into the 21 Meter system is crucial to achieving the level of performance needed to adequately support the radio astronomy mission.

Examples of astronomical sources which may be observed and detected by the proposed C-band feed include solar system objects (such as the moon and Jupiter), supernova remnants (SNRs), star formation regions, pulsars, the Galactic Center, disk and nuclear emission from nearby galaxies, active galactic nuclei (AGNs), blazars and quasars. The types of observations of these phenomena will include continuum imagery, radiometry, time – domain variability and polarization studies.

**Statement of the Problem**

The purpose of this project is to test and characterize the custom built C-band feed used for the MSU 21 Meter Space Tracking Antenna. The research consists of a series of tests and analyses to select the best feed that will work at 5GHz for the

21 Meter. This study will validate the feed system using experimental results, there by quantifying its capabilities.

**Significance of the Study**

Significant sensitivity performance is needed to support radio astronomy at 5 GHz. The goal of this project is to accomplish the frequency extension to C-band at efficient cost. This involved locating, selecting and evaluating a number of candidate feeds by testing them in an anechoic chamber as well as analysis of the specifications of the commercially produced L and Ku-Band feeds for the 21 Meter. These tests were used to select the best feed that will work at 5 GHz with adequate performance for the 21Meter.

**Research Objectives**

1. What are appropriate experimental methods necessary to characterize the C-Band feed performance?
2. Based on the 21Meter geometry and 5 GHz operational requirements (as derived from 21 Meter for operations made at L and Ku-band), compare 4 GHz feeds for use at 5 GHz and determine which feed horn has the best performance.
3. Finally evaluate and empirically determine the C-Band feed performance by comparing its performance characteristics with the existing L & Ku-Band performance characteristics.

**Assumptions**

- RF feeds built to operate at 4 and 6 GHz will also operate at high efficiency in the 4.4-5.0 GHz band.
- Accurate data can be obtained using the small anechoic chamber in possession of the MSU Space Science Center.
- Test procedures are accurate and repeatable, providing confidence in the results.

**Limitations**

The scope of this project will not permit the installation of the feed in the antenna to evaluate the final performance value of the selected feed in site. Other key factors need to be established to predict and determine the system performance (in situ) such as:

- Illumination function when installed in the dish
- LNA performance
- Aperture efficiency

**Definition of Terms**

Antenna feed - The mechanism that illuminates the reflecting surface of an antenna or that distributes the input power to the radiating elements of an array antenna.

Antenna gain - The gain or power gain is a measure of the ability to concentrate in a particular direction the net power accepted by the antenna from the connected transmitter.

Antenna Radiation Pattern - The radiation pattern is a graphical representation of the relative field strength transmitted from or received by the antenna. The patterns are usually presented in polar or rectilinear form with a dB strength scale.

Anechoic Chamber - An anechoic chamber is a room in which there are no echoes. It is commonly used in acoustics and RF testing to conduct experiments to attain precise "free space" conditions. In other words, the sound energy will be traveling away from the source with almost none being reflected back. Typically, a material that absorbs radio waves is used to line the room.

Arc minute - It is a unit of angular measurement, equal to (1/60) of one degree. Since one degree is defined as one three hundred sixtieth (1/360) of a circle. Therefore, 1 MOA or arcmin = 1/21600 of the amount of arc in a closed circle, measured in degrees.

Beamwidth - The amount of angle (either azimuth or apex) covered by the antennas maximum gain (in decibels) until the signal drops of 3dB in each direction. The distance between two opposite sides of a beam at a specific range from its source.

C-Band - Frequencies approximately used from 3.7-4.2 and 5.8 - 6.4 GHz for satellite downlink and uplink transmission, respectively. The corresponding radio astronomy frequency allocation is 4.8-5.0 GHz.

Directivity - The directivity is defined as 4 pi times the ratio of the maximum radiation intensity to the total power radiated by the antenna. The directivity of the antenna is independent of its radiation efficiency and its impendence match to connected transmission line.

FWHM - A full width at half maximum (FWHM) is an expression of the extent of a function, given by the difference between the two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value.

Gain - A logarithmic measure of how well an antenna radiates or receives when compared to a reference antenna.

G/T - Gain of the antenna over system temperature.

HPBW - The half power beam width is the angular separation between the half power points on the antenna radiation pattern. For a reflector antenna it may be expressed by as HPBW = k $\lambda$/ D, where, k = Constant, $\lambda$ = Wave length and D = Diameter of the dish.

Network Analyzer - A network analyzer is an instrument used to analyze the properties of electrical networks, especially those properties associated with the reflection and transmission of electrical signals known as scattering parameters.

Parabolic reflector or dish – A parabolic shape which consists of a reflective mechanism: it is used to collect or distribute energy such as light, sound or radio waves.

VSWR - Voltage Standing Wave Ratio, a measurement of mismatch in a cable, waveguide, or antenna system. In other words, the amount of reflected energy from the system. It is used to evaluate and measure impedance matching in frequency electronic circuitry and transmission media, to achieve best signal transmission.

Supernova - A supernova is a stellar explosion that creates an extremely luminous object.

Supernova Remnant - A supernova remnant (SNR) is the expanding shell of material resulting from the enormous explosion of a star in a supernova.

# CHAPTER II: REVIEW OF LITERATURE

This Chapter provides background literature to introduce the use of C-band systems for Radio Astronomy Research and the Morehead State University 21 Meter Space Tracking Antenna.

## History of C-Band (5GHz) Radio Astronomy

"The first C-Band radio astronomy observations were made during January 1968 with the 140-ft (43 m) telescope of the National Radio Astronomy Observatory (NRAO), (Green Bank, WV) at 5 GHz (Kellermann, Pauliny-Toth, and Williams 1968). The aperture efficiency of the 140 ft telescope was about 60% at the zenith so at that a point source provided an antenna temperature of 0.30 k per flux unit" (Pauliny-Toth & Kellermann, 1968). The radiometer consisted of a tunnel diode RF amplifier, followed by a detector, an audio amplifier, and a synchronous detector. The total system noise temperature was about 700.0 K and the bandwidth was about 300 MHz with its center frequency at 5.0 GHz. "The half-power beam width was 6.2 min. of arc in the E plane and 5.8 min. of arc in the H plane". [Pauliny-Toth & Kellermann, 1968]

The NRAO 140-foot consist of prime focus front-end receiver system contains 3.7 cm, 6cm, and 11.1 cm respectively, the scientific instrument features a very large collecting area that produces a high level of sensitivity. [Benjamin K. Malphrus, 1996]. The contribution of 140-ft scientific using the National Radio Astronomy Observatory telescope was to measure the flux densities of 480 sources at a frequency of 5.0 GHz (6 cm).

This survey consisted of approximately all extragalactic sources in the revised 3C catalogue and a number of other sources, particularly from the Parkes catalog. An accuracy of measurement of better than 0.05 flux unit (1 flux unit = $10^{-26}$ $W/m^2/Hz$ = 1 Jansky) was achieved for the majority of the sources. A number of interesting optical objects such as Seyfert and compact galaxies and "radio quiet" quasi-stellar galaxies were also observed and radio emission was detected. [Pauliny-Toth and Kellermann, 1968]

Later, strong source surveys were made at 5 GHz with 43-m telescope (also operated by the NRAO and were reobserved with 100-m telescope of the Max-Planck Institute, Bonn, Germany at 4.9 GHz. Since 1968, a number of surveys at frequency of 5 GHz ($\lambda$ = 6cm) have been reported these include the "S" surveys namely S1 survey (Kellermann, 1968b) and S2, S3 surveys (Pauliny-Toth and Kellermann, 1972b). The results of the S4 survey are combined with those previous 5 GHz surveys. To combine the surveys, a 5 GHz strong source sample derived from Parkes was matched with samples taken from deeper surveys made at 5 GHz to identify the source counts, the source spectra and their relation to the optical identifications.

The additional survey S4 taken by (Kellermann, K. and Fomalont, E.) using the 300 foot (92-m) instrument transit telescope of NRAO equipped with a cooled parametric amplifier giving a system noise temperature of about 160 K and a band-width of 150 MHz centered at 5000 MHz. The telescope motion and the data recording, made at a rate of 10 samples per second, were under computer control. [Pauliny-Toth, Witzel, and Preuss, 1978].

The reobservation of sources with the 100-m telescope at frequencies at 2.7, 4.9, and 10.7GHz were made in August 1972, December 1972 and December 1974 respectively. "To develop calibration of the flux-density scales, they observed 3C 123, 3C 147 and 3C 295 at 2.7 and 4.9 GHz and compared their data with Kellermann et al. 1969. For the latter frequency, the 5.0 GHz flux densities given in KPW were adjusted to 4.9 GHz using the spectral index computed from the KPW 2.7 and 5.0 GHz flux densities" [Pauliny-Toth, Witzel, and Preuss, 1978]

Also, surveys of radio sources at the frequency of 5 GHz covering a large part of the sky (including several hundred sources having flux densities greater than 0.6 Jy) were conducted with the 100-meter telescope Max Planck, Bonn, Germany (Pauliny-Toth et al. 1978). A region near the North Celestial Pole has been surveyed at 4.85 GHz down to a flux density limit of 14 mJy and 82 sources above this flux density have been detected. [Pauliny-Toth, Witzel, Preuss, Baldwin, and Hills, 1978].

**21 Meter Space Tracking Antenna**

The 21 Meter Space Tracking Antenna of Morehead State University operates in the radio frequencies regimes at different frequencies, namely the L, S, and Ku-bands. The sensitivity and versatility of the telescope design facilitate the study of a wide variety of astronomical research as well as tracking a variety of satellites [Malphrus, 2001]. The capabilities of the 21Meter antenna system combined with telemetry receivers and supporting hardware allows the 21Meter to track most Low Earth Orbit (LEO) satellites and obtain telemetry and data. The 21 Meter antenna system is involved in various radio astronomy projects and serves as a ground station for LEO satellites, including activities related directly to NASA missions and other commercial missions like the Kentucky Satellite (KySat) series of the orbiting satellites. (http://ssc.moreheadstate.edu/sta-starscienceprg.php). Tables 2.1 and 2.2 list the primary mechanical and radio frequency (RF) performance characteristics.

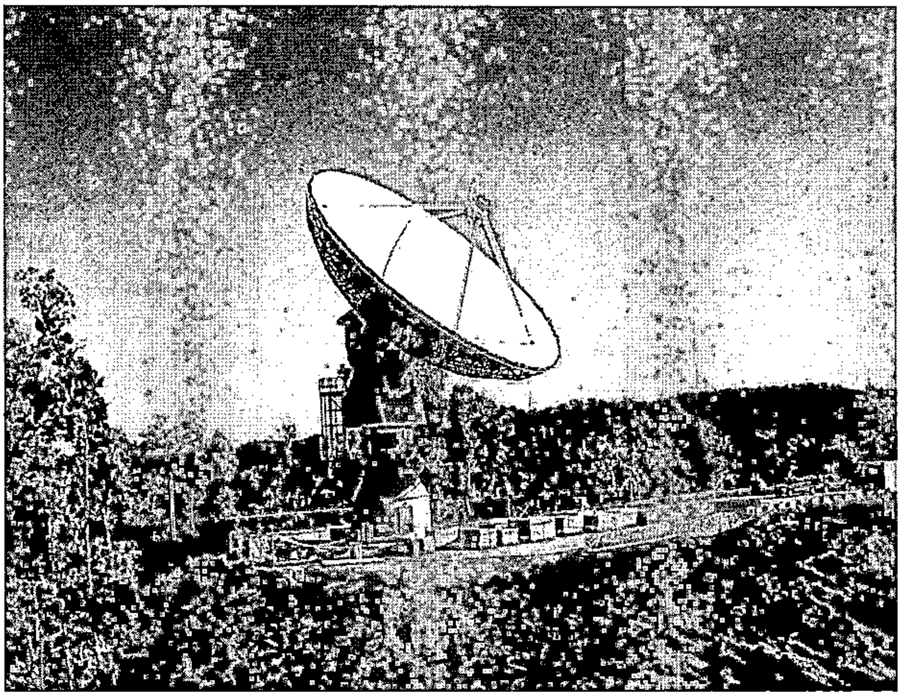


Figure 2.1 21 M Morehead State Space Tracking Antenna photo taken by M. Combs, 2008

Table 2.1 21-M Mechanical Performance Characteristics

| *Performance Criterion* | *Expected or Calculated Values* |
|---|---|
| Diameter | 21.0 meters |
| Surface Tolerance @ 35 mph | 0.14" (<0.02" RMS) |
| F/D | 0.363 |
| Locked Rotor Frequency (LRF) | >2 Hz |
| Azimuth Speed | >3° per sec |

| | |
|---|---|
| Elevation Speed | 1.5° per sec |
| Azimuth Acceleration | 2° per sec2 |
| Elevation Acceleration | 0.5° per sec2 |
| Pointing Error | ~32" (RMS) |
| Resonance | >2 Hz |
| Range | Azimuth: ±270°<br>Altitude: -2° to +92° |

American Institute of Aeronautics and Astronautics (Malphrus, 2008)

Table 2.2 RF Performance Characteristics

| Performance Criterion | Ku-Band | L-Band |
|---|---|---|
| Half-Power Beam Width (HPBW) (arc minutes) | 1.8 | 34.8 |
| Antenna Gain G (dBi) | 65.96 | 48.05 |
| LNA Temperature TLNA (K) | Theoretical: 70.0 | Theoretical: 25.0 |
| | Experimental: 70.0 | Experimental: 23.6 |
| Aperture Efficiency η | 0.5486 | 0.5528 |
| System Temperature Tsys (at 40° elevation) (K) | 48.0 | 45.0 |
| G/Tsys (at 45° elevation) (dB/K) | 44.3 | 31.2 |
| ΔSmin* (Jy)<br>Δt= 1 second | Theoretical: 1.16 | Theoretical: 0.67 |
| | Experimental: 2.0 | Experimental: 2.0 |
| Δt= 10 seconds | Theoretical: 0.37 | Theoretical: 0.21 |
| Δt= 30 seconds | Theoretical: 0.21 | Theoretical: 0.12 |

American Institute of Aeronautics and Astronautics (Malphrus, 2008)

# CHAPTER III: METHODOLOGY

## Feed Design Overview

The C-Band system is composed of the feed horn antenna, the preamplifier/amplifier and housing, mounting and fixturing, a down converter system and associated cabling of required components. The plan described in this thesis is designed to implement this system component with maximum efficiency. An existing horn will be identified and modified if needed to properly illuminate the 21 Meter antenna. The feed design (based on calculated illumination beamwidth) will be verified by pattern plotting using the anechoic chamber. The C-Band system proposed will cover, as a minimum, the radio astronomy spectrum from 4800 MHz to 5000 MHz (6.25 to 6.0 cm).

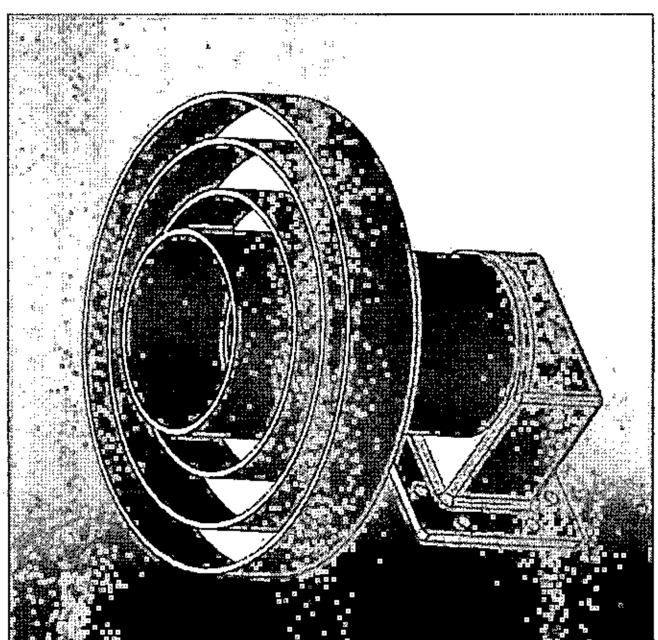


Figure 3.1 Chaparral Style C-Band 3 Dimensional View

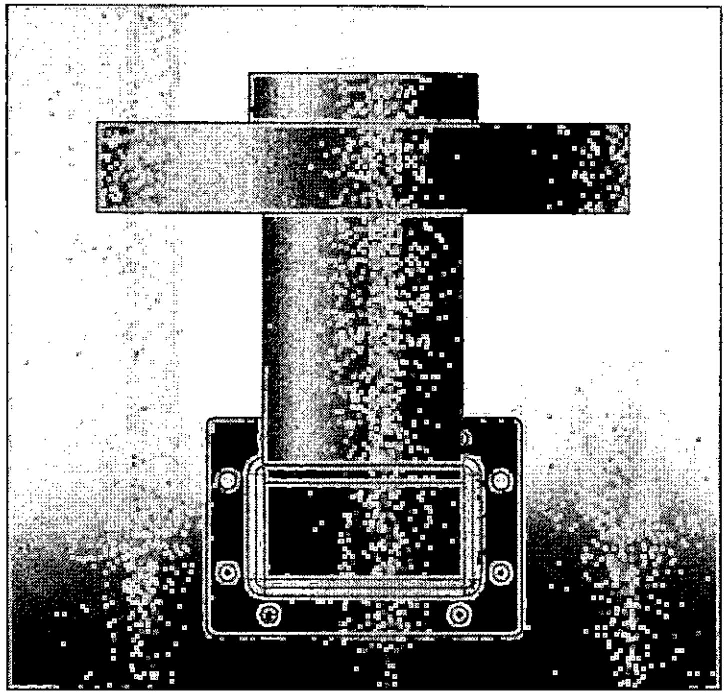


Figure 3.2 Chaparral Style C-Band Top View

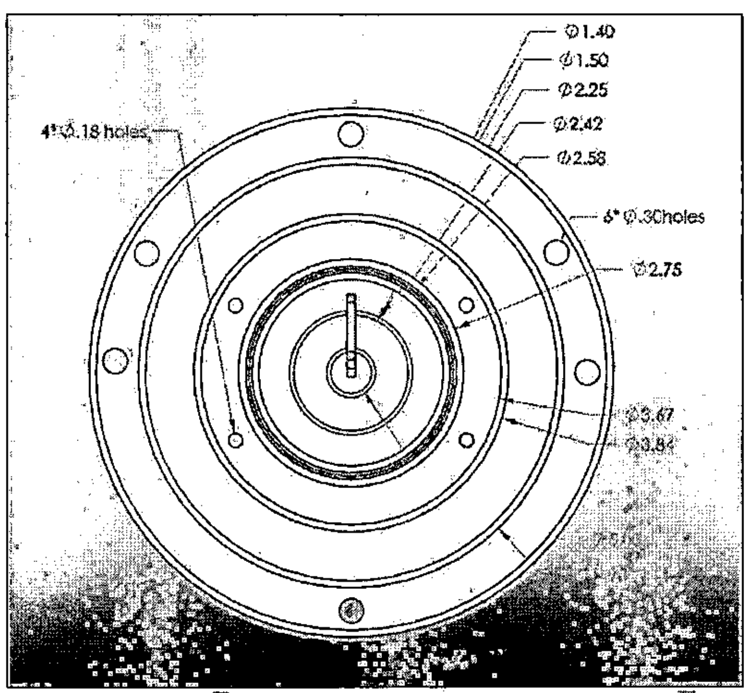



Figure 3.3 Chaparral Style C-Band Front View

**Results for Research Objective #1**

**Resources for Method of Measurement**

There are two main types of feed measurements: indoor range tests and out door range tests (far field tests). An indoor test range is a setup using an anechoic chamber whose interior is covered with radio frequency absorbing material. This absorber is designed to reduce reflected signal over its design frequency range. Testing indoors offers many advantages to conventional outdoor ranges including improved security, avoiding unwanted surveillance and improved productivity due to less time lost because of weather and other environment related factors. The advantages of testing indoors are primarily responsible for the trend toward more advanced test ranges such as the compact range and both near and field ranges. The desire is to adapt an existing feed selected from several available candidate feeds. The candidate antenna feeds will be characterized in the small MSU anechoic chamber.

**Antenna Characteristics**

It is important to know what the gain of the dish would be under the correct conditions for proper operation. This calculation assumes a typical efficiency for a prime-focus fed parabolic dish using an optimum taper feed horn. This system has a typical efficiency of 55%. The best efficiency attainable in an antenna of this type occurs with an offset fed parabola and has a maximum in the 75% range. For a number of reasons, the 21 Meter was designed as a standard paraboloid.

Finding Gain of the dish at 5.0 GHz

The gain of a circular aperture antenna (such as a parabola) is given by

$$G = \eta\ (\pi\ D/\lambda)^{2}$$

Where:

$\eta$ = efficiency, D = diameter in meters (21), $\lambda$ = wave length in meters

$\lambda = C/F$ C = speed of light = $3 \times 10^{-8}$

F = frequency for gain calculation (5.0 GHz)

Example 1 $\eta$=100% (perfect case)

$$G = \eta\ (\pi\ D/\lambda)^{2} = 1.2 \times 10^{\wedge}6$$

$$10 \log (1.2 \times 10^{\wedge}6) = 60.8 \text{ dB of gain}$$

Example 2 $\eta$=55% (typical case)

$$G = \eta\ (\pi\ D/\lambda)^{2} = 6.6 \times 10^{\wedge}5$$

$$10 \log (6.6 \times 10^{\wedge}5) = 58.1 \text{ dB of gain}$$

In this regime, the difference between perfect and typical is 2.7 dB, not a significant difference on this scale.

**VSWR Test procedure**

Voltage Standing Wave Ratio (VSWR) is a measurement of mismatch (reflected or lost power) in a RF system, such as a cable, waveguide, or antenna system. In other words, this test determines the amount of reflected energy from the system at the test frequencies and thus indicates the performance of the unit under test at those frequencies selected for the test.

Before any tests of the antenna feeds were performed in the anechoic chamber, the return loss of the feed was determined for that feed. This prevented measuring antennas whose basic performance was unsuitable for the 5 GHz project. These preliminary tests of return loss used a Scalar Network analyzer (HP8757) with appropriate detectors (HP11664A) as the receiver (response), a sweep signal generator (HP8350B sweeper with plug-in for the 5 GHz band) as the transmitter (stimulus), a high precision, high-directivity directional coupler (NARDA 5292) as the signal separation device (selects reflected wave from the transmission line to the antenna), along with a plotter (HP7475A) to make a permanent record of the frequency response plot shown on the analyzer screen. The test unit which is connected to the reflection port of the directional coupler is either a very good (precision) test dummy load with a return loss greater than we are trying to measure and the actual antennas-under-test (AUT).

The scalar analyzer "R" in channel (reference channel) is connected via a generator through the coupler and the antenna feed on the other end. (Channel "A" from scalar analyzer port is directly connected to a coupler as shown in Figure 3.5 below. When the power passes from the generator it is split in two by the Weinschel 1506 Power Divider, with one arm taken reference as "R". The energy from the other arm of the divider passes through the directional coupler to the AUT. In an ideal case, the antenna transmits all energy sent to it (100% efficiency), but in practical scenarios the antenna reflects back some energy, which is referred to as return loss. Thus, the comparison between "A/R" is displayed in the network analyzer.

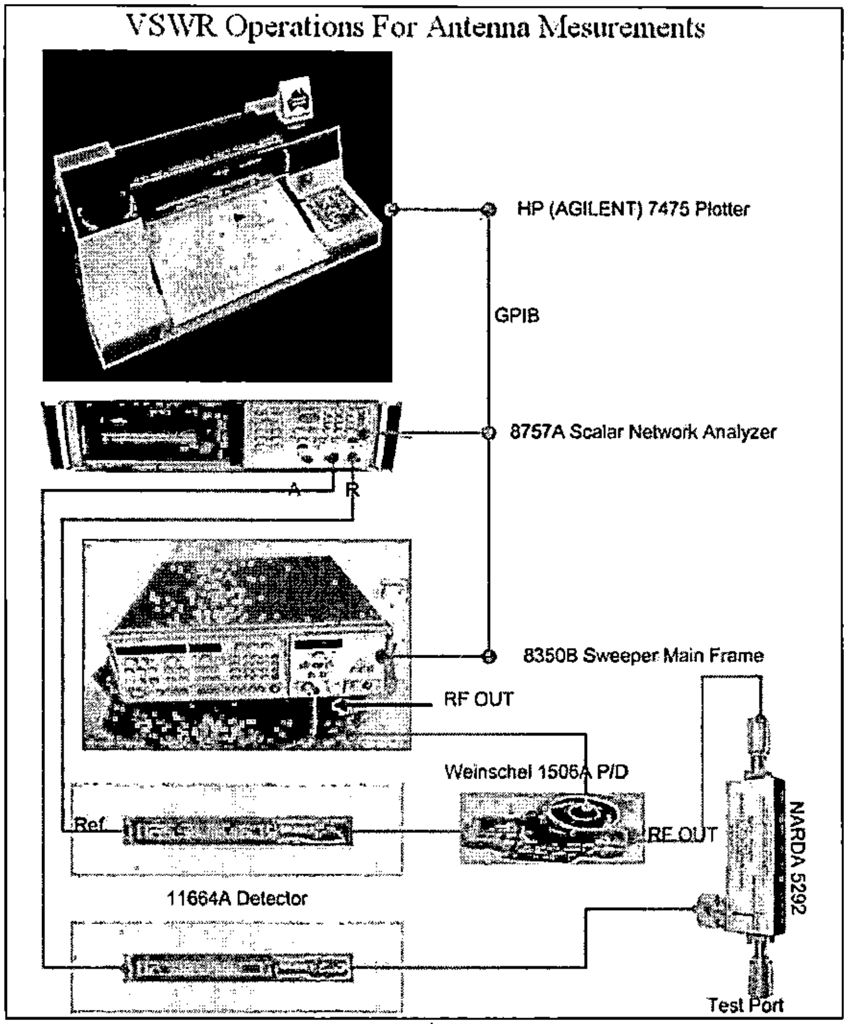



Figure 3.4 VSWR test antenna setup

This energy is coupled through the directional coupler, detected by the HP 11664A detector and shown on the analyzer as Channel "A". The analyzer can take a ratio of the power in the R channel and the A channel giving the ratio A/R. This is very useful, as it removes the effects of any variation of the generator output power versus frequency, a common source of error in unratioed measurements.

Generally, the more power reflected back from an antenna (feed) indicates poorer overall performance at that frequency. In the same manner the opposite is true, the less power reflected back from the feed, the better the performance "A/R" ratio the better, and conversely, if the ratio is more positive the feed more performs more poorly.

The feeds are then tested as per our frequency requirements starting at 3.5 GHz, ending at 6.5 GHz and centered at 5.00 GHz. The procedures are as follows: first turn on the sweeper and the plotter, then power on the scalar network analyzer "8757" as well as the position control unit connected to Digital Syncro display. Next, setup the frequency range as per our requirement that the sweeper starts at 3.7 GHz and stops at 6.5 GHz. The researcher is interested in testing the feeds at 4.5 GHz, 4.75 GHz, and 5 GHz to determine the feed gain at these frequencies. The operational steps are shown in Table 3.1.

| Table 3.1 Operation steps for testing the candidates |
| --- |
| Turn on equipment in order plotter, sweeper, then 8757 (Scalar Network Analyzer) |
| When 8757 starts & DAC bit fail, then press "MEASURE MENU" |
| Engage "PRESET" Green Button – Zeros all states of 8757 & 8350, sets to default |
| First step sweeper (8350), turn off "square MOD" |
| Start at 3.7 GHz |
| Stop at 6.5 GHz |
| Power level is 10dbm (turn CW filter off) |
| Sweeper done |
| Then 8757 machine turn off channel 2 (gets rid of $2^{nd}$ trace) |
| Scale at 10db |
| MEAS at A/R |
| REF Level at 0db |
| DISPLAY "MEAS - MEM" |
| CURSOR – use knob to set cursor to freq of interest |
| To Plot |

| | |
|---|---|
| Load paper | |
| System – Plot – Plot all | |

Antenna Test under Anechoic Chamber

"An anechoic chamber is better than the traditional far-field range for many RF tests. The testing that can be accomplished on an antenna test range is the method of testing that allows an operator to employ an indoor anechoic chamber at a reasonable cost and avoid the problems associated with weather and security often encountered when using an outdoor test range". [Fordham, May 2002].

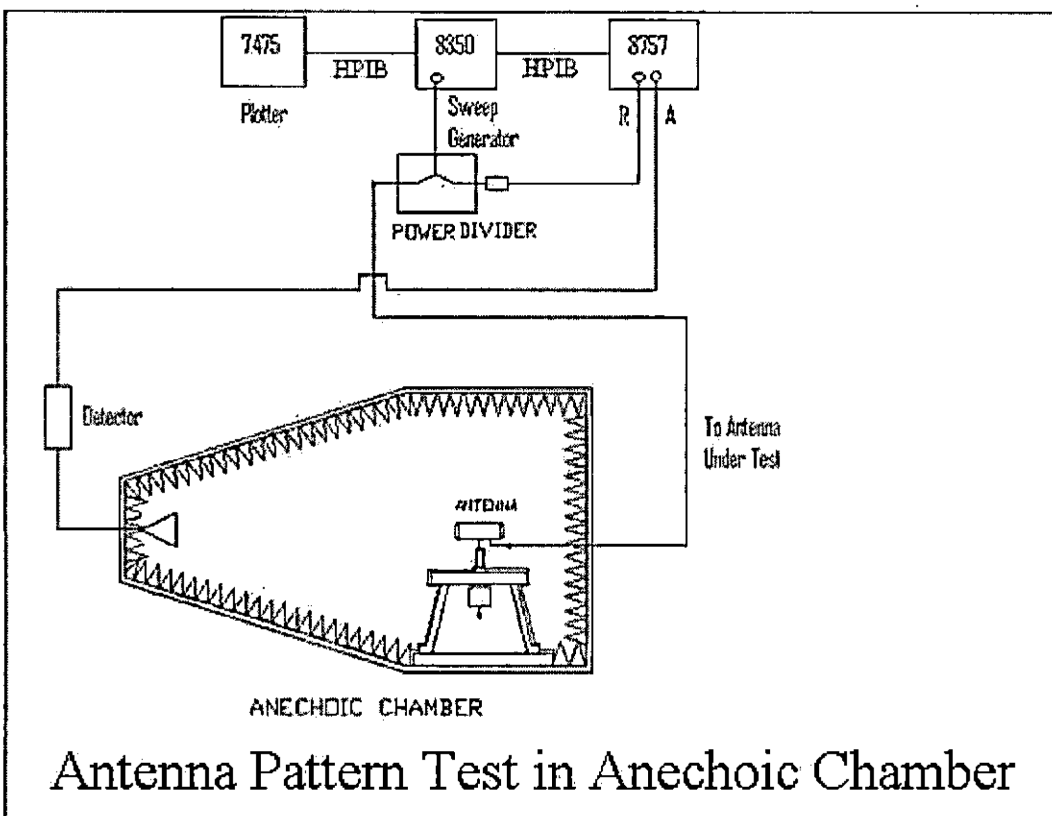



Figure 3.5 Antenna under test in anechoic chamber

**Gain Measurement and Illumination Function**

Generally, always power "ON" the equipment three hours before testing the candidates (antenna feeds) in the chamber: this avoids power drifts in the equipment. The anechoic chamber has a transmitting antenna on one end and a receiving antenna on other end of the chamber. The receiving antenna is a standard horn fixed at the throated end of the chamber. The antenna under test (AUT) in this case is the transmitting antenna, which is changed for each measurement. The feeds under the AUT are 1.) Scientific Atlanta Standard Gain Horn 2.) Chaparral Style 3.) Equatorial 4.) Square Military Horn each one is configured as the AUT to make these measurements. For every individual feed test in chamber, first we mount the antenna in a fixture on the rotating table at zero degrees position. The rotating table is controlled manually with a positioner controller. For every setup, the feed should be aligned to "Bore sight". This means that the operator manually rotates the antenna through a small angular range (typically+/- 5°) each side of the center position to see the maximum gain has been attained. This is determined by observing the Network Analyzer display for maximum upwards deflection of the trace.

Once verifying that a particular degree angle of the rotor position of the antenna shows maximum gain, the angle offset switches are set to make the digital display read 0.000 degrees (corresponding to the position of the feed) on the Digital Syncro display. Once the test starts, it is important to close the anechoic chamber door to avoid any errors in measurement. For every individual feed test in the anechoic chamber, the feed under test is notated using the antenna positioner and at every 5° the gain is recorded. The rotation of the antenna is continued through 360° to make a polar plot. The process is repeated at frequencies of 4.5 GHz, 4.75 GHz and 5.00 GHz and displayed on Network analyzer. The values were recorded at every 5° manually using the computer. Patterns that were constructed at each individual frequency are shown from Pages 40-53.

**Dish Geometry**

Generally, "a parabolic reflector functions due to the geometric properties of the paraboloid shape, if the angle of incidence to the inner surface of the collector equals the angle of reflection, then any incoming ray that is parallel to the axis of the dish will be reflected to a central point, or "focus". (Wikipedia, 2008)

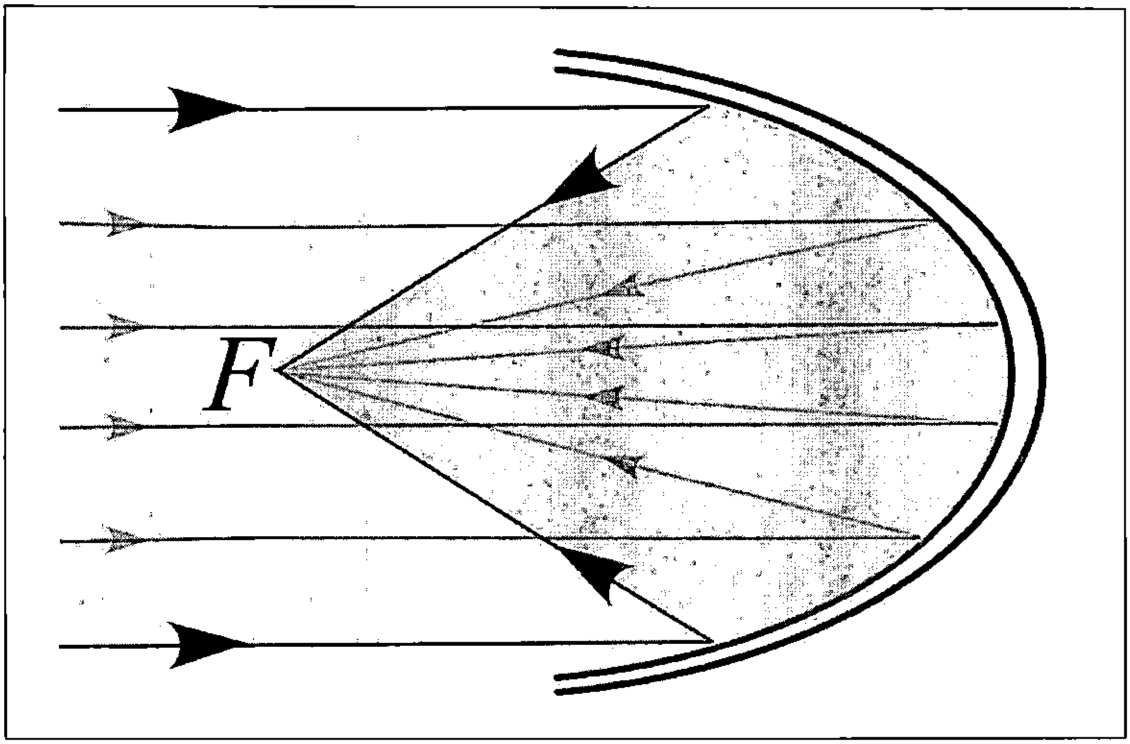



Figure 3.6 Parallel waves coming in to a parabolic mirror are focused at focal point F (http://en.wikipedia.org/wiki/Parabolic_reflector)

The following formulas describe the geometry and "optics" of the 21 Meter.

F/D = .363 (for 21 M antenna),

Where, F= Focal Length,

D= Diameter of the dish

Free Space loss = $\lambda^2 / (4\pi f)^2$ (Center of dish)

Free space loss = $\lambda^2 / (4\pi l)^2$ (Edge of assuming illumination to the dish),

Where, l = Focus to Rim,

Radius of the Dish = D/2

F/D = .363 → F = .363 * 21 = 7.623 m

Depth (edge to dish) = $D^2 / (F * 16)$, Also finding the half power Beamwidth:

Aperture in wave lengths = $D_\lambda = D/\lambda$

For Circular Aperture like parabolic antennas consider tapered conditions

⇨ $66°/D_\lambda$ (Appendix 4, Relation of beam width and side-lobe level to Aperture Distribution by Kraus, Radio Astronomy, 2nd Ed.)

Therefore, $66°/D/\lambda = 66°\ \lambda/D$

Where, $\lambda = 6$ cm = 0.06 m, D = 21 Meter

$D_\lambda = 21/0.06 = 350$

$66°/D_\lambda = 66/350 = 0.188°$ Half Power Beamwidth @ 3dB pts @ C-band (5GHz)

$66°/D_\lambda = 66/100 = 0.66°$ Half Power Beamwidth @ 3dB pts @ L-band (1.4GHz)

$66°/D_\lambda = 66/840 = 0.078$ Half Power Beamwidth @ 3dB pts @ Ku-band (12 GHz)

The focus or beam angle ($2\alpha$) amplitude response of the feed to dish as shown in Figure 3.7. The results provided in Table 4.2 describe the geometry properties of the dish at C-band. Table 4.3 illustrates the 21 Meter's geometric properties at L-band for comparison while Table 4.4 illustrates the properties at Ku-band.

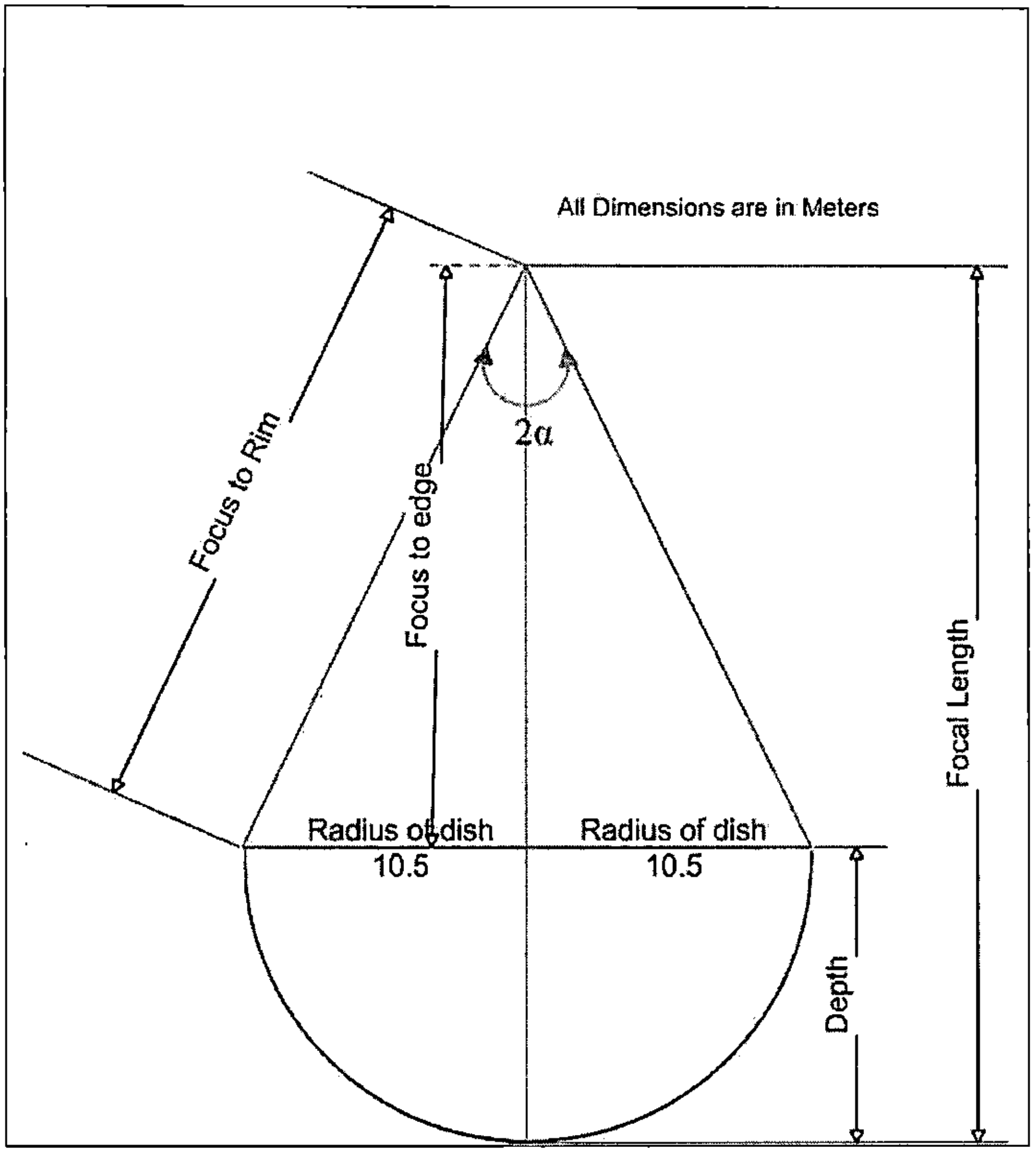



Figure 3.7 Dish Geometry Analysis

## CHAPTER IV: FINDINGS AND ANALYSIS

This chapter examines the findings and analyses of the measurements of VSWR, Gain, and illumination function data from the anechoic chamber. These data are compared to theoretical values determined from the dish geometry and also compared with the existing L-Band and Ku-Band feeds constructed by Vertex. The VSWR plots and results are shown below.

The researcher's main goal is to find the best feed for C-band (5GHz) operation with the 21 Meter antenna. From the VSWR results, we selected three feeds based on the return loss shown in Table 4.1. After selecting the feeds from the VSWR results, every individual feed was tested in the anechoic chamber. Results of these measurements are shown in Figures 4.2-4.9.

VSWR Plots

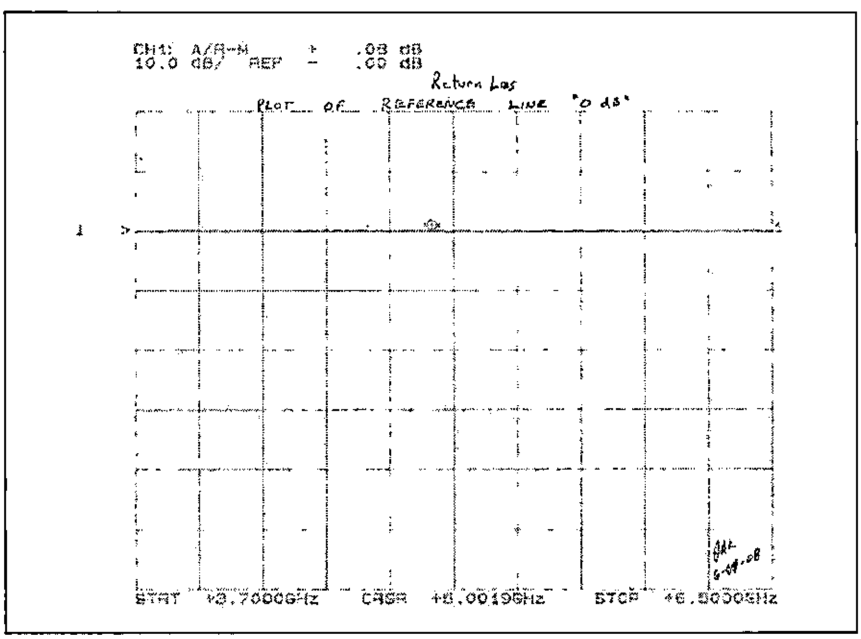



Figure 4.1 Reference line Plot at zero dB

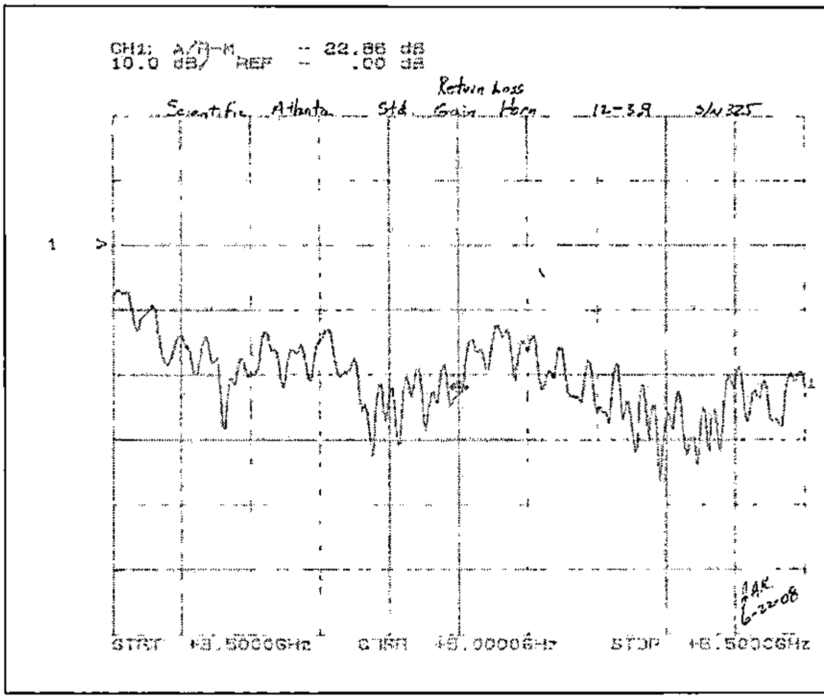



Figure 4.2 Scientific Atlanta Standard Gain Horn 12-3.9

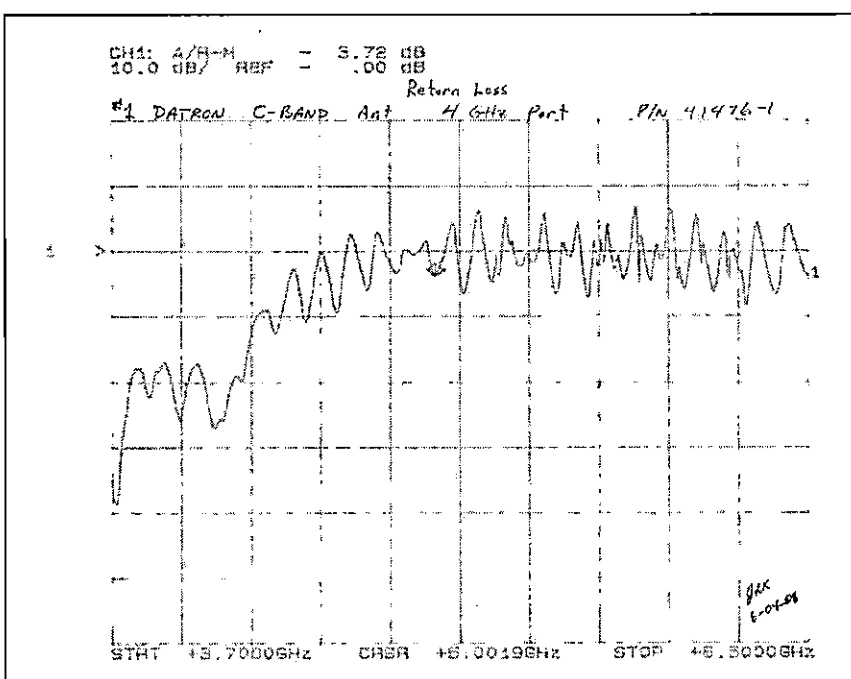



Figure 4.3 Datron C-band Antenna 4 GHz Port

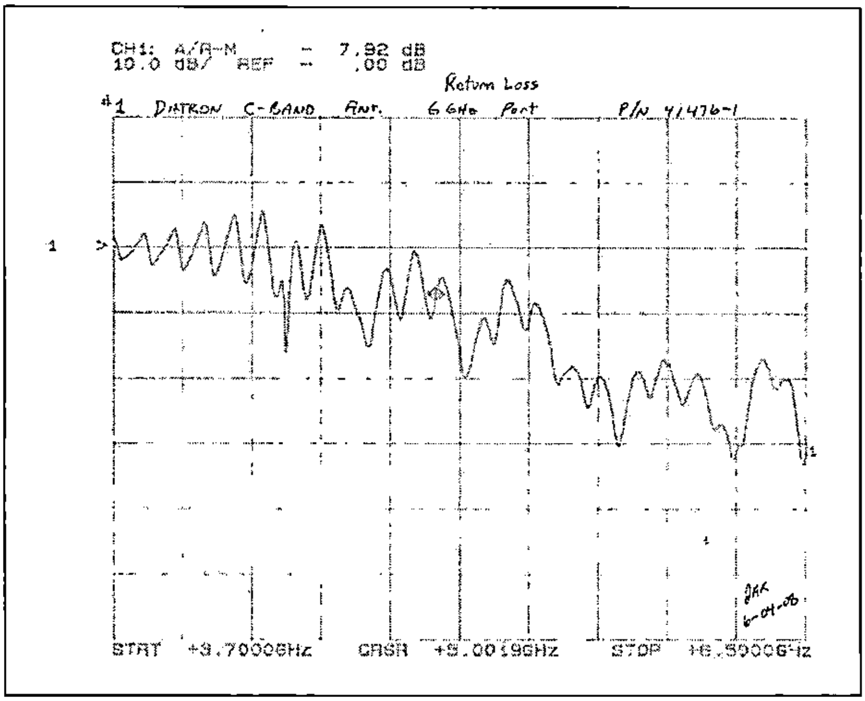



Figure 4.4 Datron C-band Antenna 6GHz Port

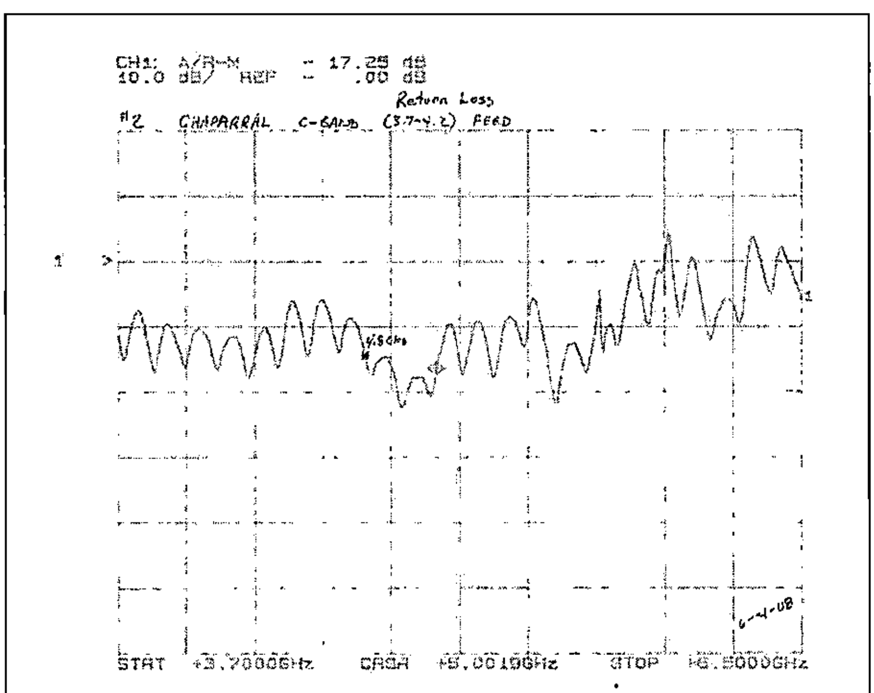



Figure 4.5 Chaparral C-band (3.7-4.2) feed

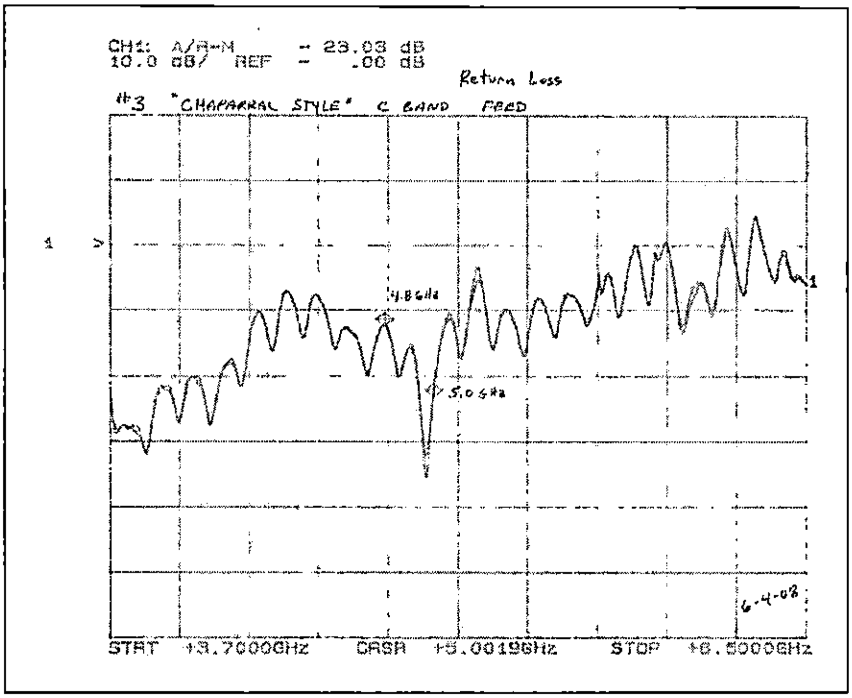



Figure 4.6 Chaparral Style C-band feed

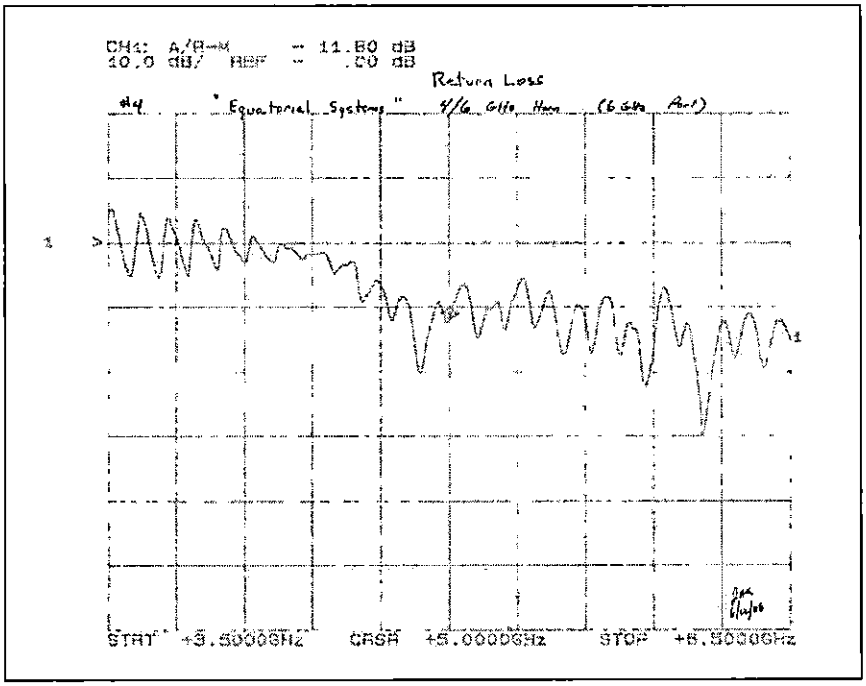



Figure 4.7 Equatorial System 6 GHz Port

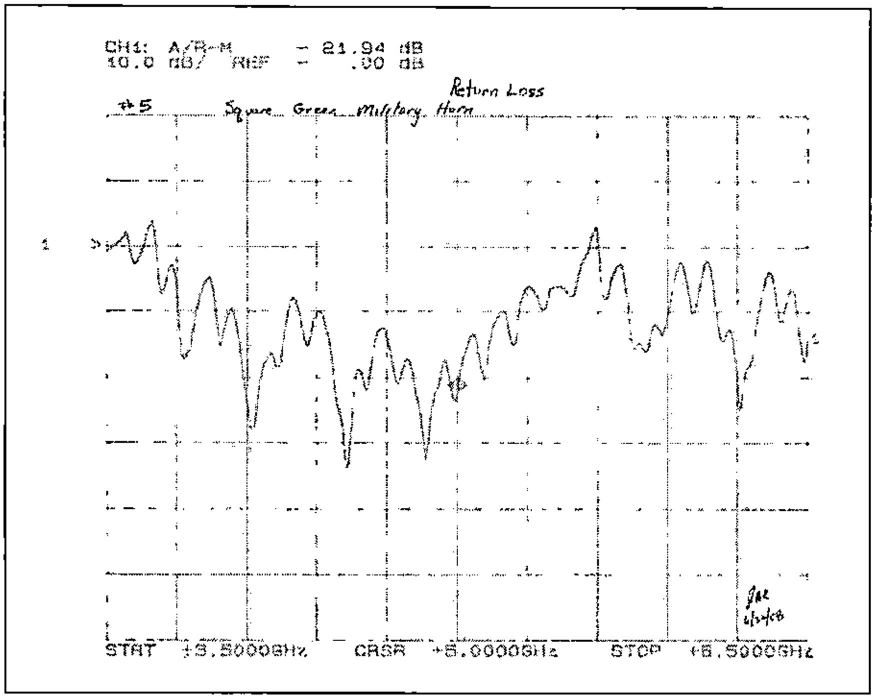



Figure 4.8 Square Military Horn

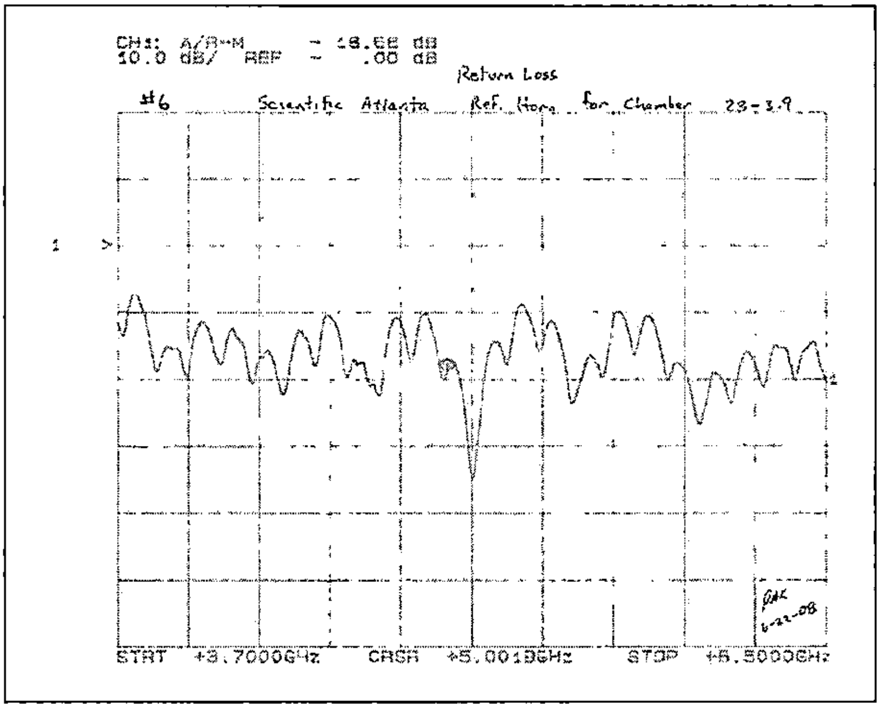



Figure 4.9 Scientific Atlanta Reference Horn Chamber

A summary of the VSWR experimental results are provided in Table 4.1. The lower return loss is required for proper operation. The actual value depends upon the system constraints: usually a value of -15 dB is considered acceptable, -20 dB is good and -30 dB is excellent. Antennas with greater than -10 dB return loss were rejected immediately for our purposes. The values for acceptance/rejection are based upon practical experience (private communications of Jeff Kruth, Faculty of Morehead State University). Since there were two "Chaparral" style types, only the better one was selected for further testing, due to time constraints. Several other types were tested to determine their pattern for the purpose of providing contrasting values for the research work. The pattern test in the anechoic chamber was performed next on the subset of selected horns.

Table 4.1 VSWR Results

| Name of the Feed | Return Loss of Gain (db) at 5 GHz | Selected for Chamber Test |
|---|---|---|
| Scientific Atlanta Std. Gain Horn 12-3.9 | -22.86 | Yes (Reference Transmit antenna) |
| Scientific Atlanta Std. Horn 23-3.9 | -18.68 | Yes (Reference Receiving antenna ) |
| Datron C-Band Antenna at 6 GHz Port | -7.92 | No |
| Datron C-Band Antenna at 4 GHz Port | -3.72 | No |
| Chaparral C-Band (3.7-4.2) | -17.25 | No |
| Chaparral Style C-Band | -23.03 | Yes |
| Equatorial Systems Horn at 6GHz Port | -11.80 | Yes |
| Square Green Military Horn | -21.94 | Yes |

**Results for Research Objective #2**

**Dish Geometry Analysis**

Results of the Dish geometry analysis with all dimensions are shown in Figure 4.10 below. i.e., the quantities illustrated include focus angle (2α) (which means the beam of energy that covers the dish) focal length (F), free space loss (edge), free space loss (center), and other factors based on the geometry of 21 Meter at C-Band (5GHz). The specific dish geometry is shown in Figure 4.8. All calculations are done using the formulas provided in Methodology.

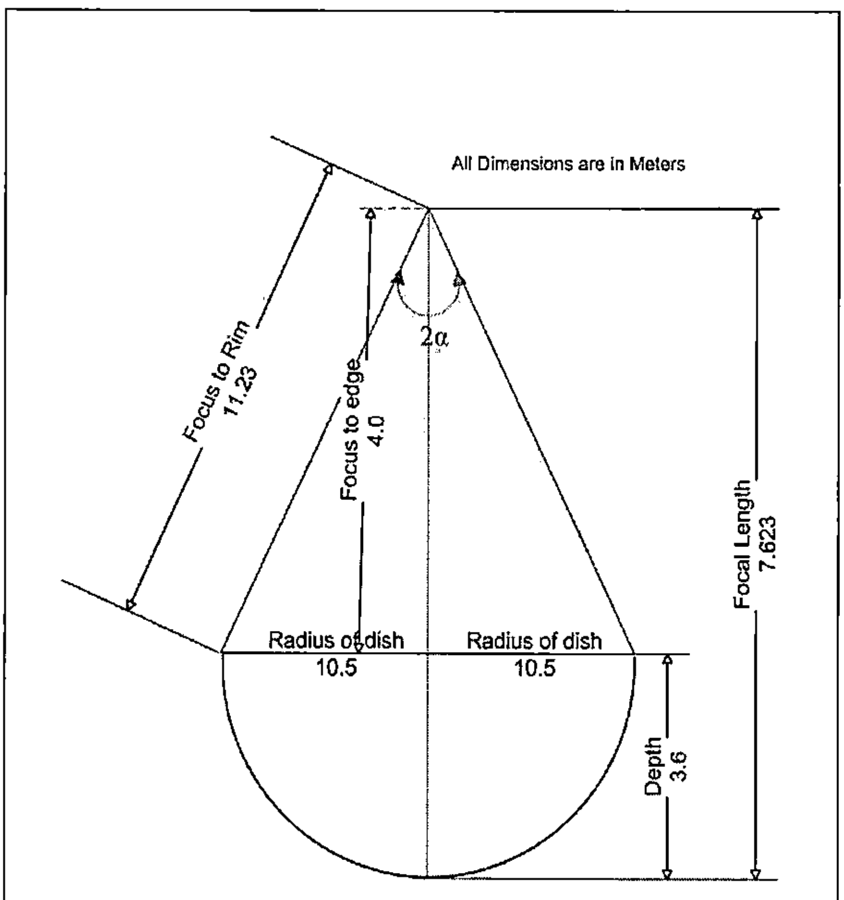



Figure 4.10 Dish Geometry analysis diagram with all dimensions provided

Table 4.2 Dish Geometry Analysis at C-Band Frequency

| | Value | Units |
|---|---|---|
| Input diameter (M) | 21 | m |
| Input f/D ratio | 0.363 | 21M |
| Focal length (f) | 7.623 | m |
| Depth (d) | 3.615702479 | m |
| Distance from edge (x) | 4.007297521 | m |
| Radius of Dish (y) | 10.5 | m |
| Focus to rim (l) | 11.23870248 | m |
| Speed of light © | 3.00E+08 | m/s |
| Frequency (F) | 5.00 | GHz |
| Wave length (λ) | 6.00E-02 | m |
| Free Space Loss (edge) | 1.80489E-07 | |
| Free Space Loss (edge) | -67.43548842 | dB |
| Free Space Loss (center) | 3.92E-07 | |
| Free Space Loss (center) | -64.06368333 | dB |
| Difference (center to edge) | 3.371805092 | dB |
| Sin α | 0.934271551 | |
| Focus angle (2α) | 2.416236211 | radians |
| Focus angle (2α) | 138.4402542 | degrees |

Finally focus angle $2\alpha = 138 \rightarrow \alpha = 69 \approx 67.5$ (For purposes of interpolation)

Table 4.3 Dish Geometry Analysis at L-Band Frequency

| | Value | Units |
|---|---|---|
| Input diameter (D) | 21 | m |
| Input f/D ratio | 0.363 | 21 M |
| Focal length (f) | 7.623 | m |
| Depth (d) | 3.61570248 | m |
| Distance from edge (x) | 4.00729752 | m |
| Radius of Dish (y) | 10.5 | m |
| Focus to rim (l) | 11.2387025 | m |
| Speed of light © | 3.00E+08 | m/s |
| Frequency (F) | 1.40 | GHz |
| Wave length (λ) | 2.14E-01 | m |
| Free Space Loss (edge) | 2.3022E-06 | |
| Free Space Loss (edge) | -56.378649 | dB |
| Free Space Loss (center) | 5.00E-06 | |
| Free Space Loss (center) | -53.006844 | dB |
| Difference (center to edge) | 3.37180509 | dB |
| Sin α | 0.93427155 | |
| Focus angle (2α) | 2.41623621 | radians |
| Focus angle (2α) | 138.440254 | degrees |

Table 4.4 Dish Geometry Analysis at Ku-Band Frequency

| | Value | Units |
|---|---|---|
| Input diameter (M) | 21 | m |
| Input f/D ratio | 0.363 | 21M |
| Focal length (f) | 7.623 | m |
| Depth (d) | 3.61570248 | m |
| Distance from edge (x) | 4.00729752 | m |
| Radius of Dish (y) | 10.5 | m |
| Focus to rim (l) | 11.2387025 | m |
| Speed of light © | 3.00E+08 | m/s |
| Frequency (F) | 12.20 | GHz |
| Wave length (λ) | 2.46E-02 | m |
| | | |
| Free Space Loss (edge) | 3.0316E-08 | |
| Free Space Loss (edge) | -75.183285 | dB |
| Free Space Loss (center) | 6.59E-08 | |
| Free Space Loss (center) | -71.81148 | dB |
| Difference (center to edge) | 3.37180509 | dB |
| Sin α | 0.93427155 | |
| Focus angle (2α) | 2.41623621 | radians |
| Focus angle (2α) | 138.440254 | degrees |

$\alpha = 1.2081$ radians, $\alpha = 67.5$ degrees

**Gain Measurement**

The recorded data from the anechoic chamber measurements include characterization of 1.) Scientific Atlanta Standard Gain Horn (Reference antenna), 2.) Chaparral Style, 3.) Equatorial and 4.) Square Military Horn. A summary of the measured values as well as individual plots are shown Tables 4.5, 4.6, 4.7, and 4.8.

**Illumination Function**

The illumination function of the horn antenna is the distribution of electromagnetic energy as it passes from the feed and distributes or illuminates the dish. Illumination functions of the candidate feeds were measured and compared to the boundaries of the illumination function of the L and Ku-band feeds. Considering all individual feeds polar plots, dish geometry analysis of focus angle or beam angle (2α) and comparing with Vertex L & Ku-band performances the goal was to find the best feed for work at C-band (5 GHz). The included candidate feeds which are provided below are the results of the radiation pattern measurements for each candidate feed along with the directivity function data, (Note all frequencies are in Gigahertz GHz as implemented in).

The polar plot (Figures 4.11-4.26) is a graphical representation of the relative field strength transmitted from or received by the antenna. The patterns are usually presented in polar form with a dB strength scale over $360^0$. Recorded values at frequencies of 4.5, 4.75, and 5.00 GHz are shown as individual plots in Figure 4.1 to 4.16. Each plot shows the energy distribution over the polar plot angle from 0-360°.

Table 4.5 Standard Gain Reference Antenna Gain by Frequency

| Angle | Frequency 1 | Frequency 2 | Frequency 3 |
|---|---|---|---|
| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
| 0 | 0 | 0 | 0 |
| 5 | -0.67 | -0.74 | -0.84 |
| 10 | -2.71 | -2.93 | -3.28 |
| 15 | -5.91 | -6.25 | -6.91 |
| 20 | -9.52 | -9.74 | -10.56 |
| 25 | -13.2 | -13.14 | -13.97 |
| 30 | -15.57 | -15.95 | -17.28 |
| 35 | -18.3 | -19.64 | -21.61 |
| 40 | -22.15 | -24.6 | -25.48 |
| 45 | -26.18 | -28.79 | -26.99 |
| 50 | -28.91 | -30.21 | -28.04 |
| 55 | -29.83 | -31.51 | -30.07 |
| 60 | -31.06 | -32.84 | -33.87 |
| 65 | -34.9 | -33.06 | -36.93 |
| 70 | -36.61 | -36.93 | -38.99 |
| 75 | -35.97 | -40.35 | -41.99 |
| 80 | -37.51 | -40.96 | -44.21 |
| 85 | -42.54 | -42.25 | -44.96 |
| 90 | -42.99 | -44.53 | -44.28 |
| 95 | -40.41 | -40.37 | -44.78 |
| 100 | -46.41 | -45.31 | -42.32 |
| 105 | -42.21 | -43.64 | -44.8 |
| 110 | -38.99 | -40.87 | -39.8 |
| 115 | -41.06 | -44.64 | -40.21 |
| 120 | -41.55 | -46.79 | -44.19 |
| 125 | -46.99 | -44.89 | -38.12 |
| 130 | -46.54 | -42.9 | -40.71 |
| 135 | -36.8 | -44.76 | -38.41 |
| 140 | -39.56 | -44.36 | -38.41 |
| 145 | -36.99 | -37.93 | -38.17 |
| 155 | -36.59 | -36.66 | -40.01 |
| 160 | -33.76 | -35.33 | -37.07 |
| 150 | -36.47 | -37.82 | -39.11 |
| 170 | -34.54 | -38.86 | -40.18 |
| 175 | -30.16 | -33.72 | -35.89 |
| 180 | -29.27 | -31.86 | -33.45 |

| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
|---|---|---|---|
| 185 | -31.24 | -33.75 | -35.91 |
| 190 | -35.24 | -38.45 | -42.63 |
| 195 | -35.12 | -39.87 | -40.2 |
| 200 | -33.67 | -37.43 | -38.21 |
| 205 | -36.18 | -40.09 | -40.91 |
| 210 | -36.18 | -42.19 | -38.51 |
| 215 | -35.25 | -39.76 | -39.05 |
| 220 | -41.51 | -41.64 | -45.66 |
| 225 | -40.96 | -46.55 | -41.98 |
| 230 | -37.61 | -45.99 | -43.94 |
| 235 | -42.03 | -46.97 | -38.02 |
| 240 | -38.76 | -44.96 | -43.58 |
| 245 | -41.03 | -46.91 | -45.27 |
| 250 | -40.35 | -42.83 | -41.88 |
| 255 | -40.1 | -43.05 | -44.36 |
| 260 | -46.98 | -45.81 | -44.53 |
| 265 | -46.19 | -42.44 | -39.98 |
| 270 | -43.85 | -39.59 | -44.75 |
| 275 | -38.73 | -44.65 | -40.75 |
| 280 | -43.81 | -40.01 | -40.11 |
| 285 | -37.42 | -37.93 | -44.51 |
| 290 | -34.65 | -39.52 | -38.42 |
| 295 | -36.4 | -34.35 | -34.56 |
| 300 | -32.11 | -31.34 | -33.66 |
| 305 | -29.51 | -31.16 | -30.18 |
| 310 | -27.9 | -32.05 | -28.05 |
| 315 | -25.23 | -30.41 | -27.09 |
| 320 | -22.43 | -25.39 | -25.64 |
| 325 | -19.28 | -19.84 | -21.41 |
| 330 | -16.29 | -15.92 | -17.13 |
| 335 | -13.61 | -13.21 | -14.09 |
| 340 | -10.06 | -10.08 | -10.87 |
| 345 | -6.11 | -6.28 | -6.81 |
| 350 | -2.84 | -2.94 | -3.13 |
| 355 | -0.73 | -0.74 | -0.74 |
| 0 | 0 | 0 | 0 |

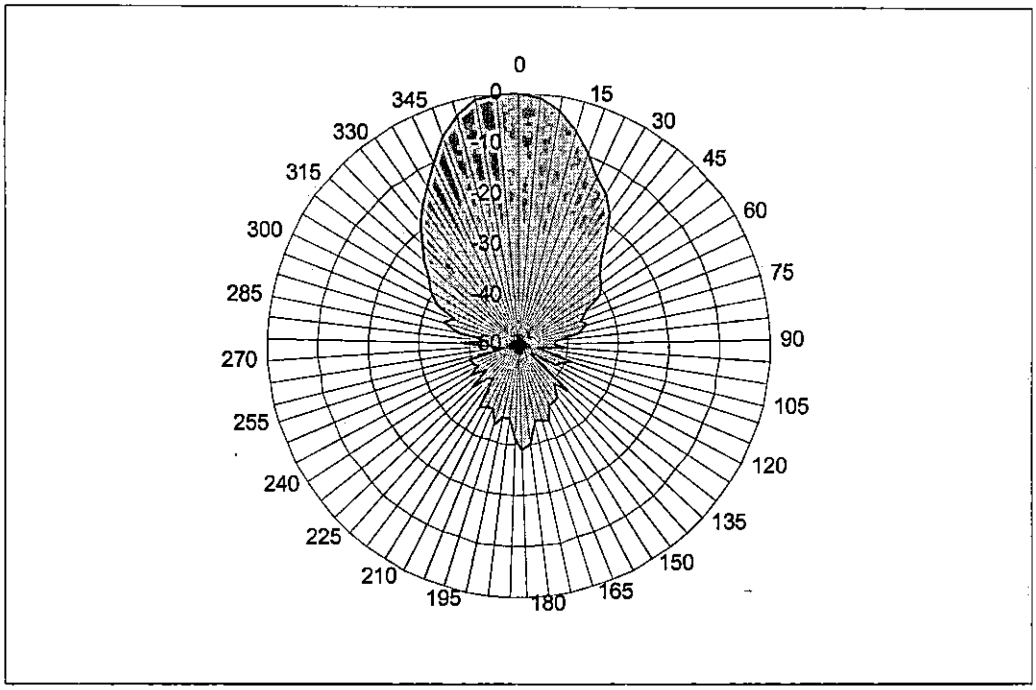



Figure 4.11 Radiation Pattern of Scientific Atlanta Standard Gain Horn at 4.5 GHz

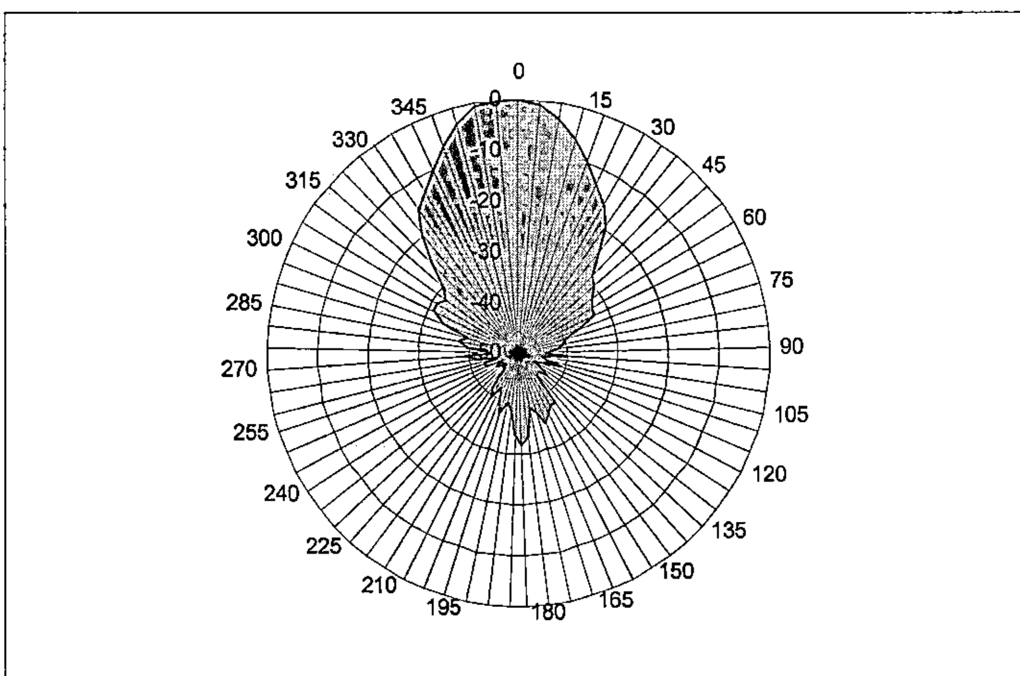



Figure 4.12 Radiation Pattern of Scientific Atlanta Standard Gain Horn at 4.75 GHz

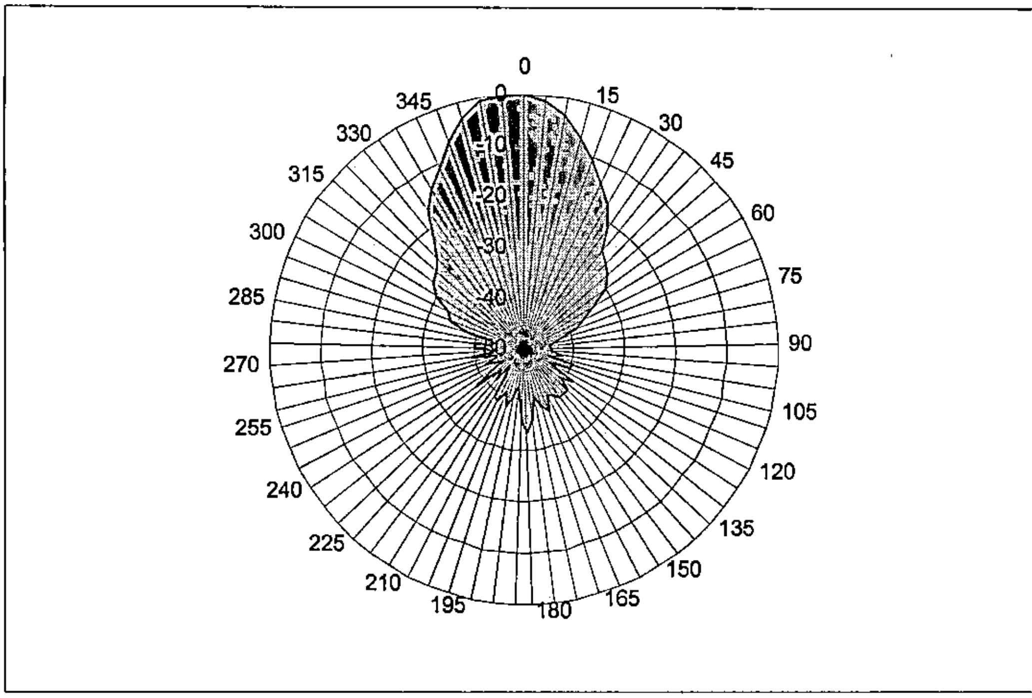



Figure 4.13 Radiation Pattern of Scientific Atlanta Standard Gain Horn at 5.00 GHz

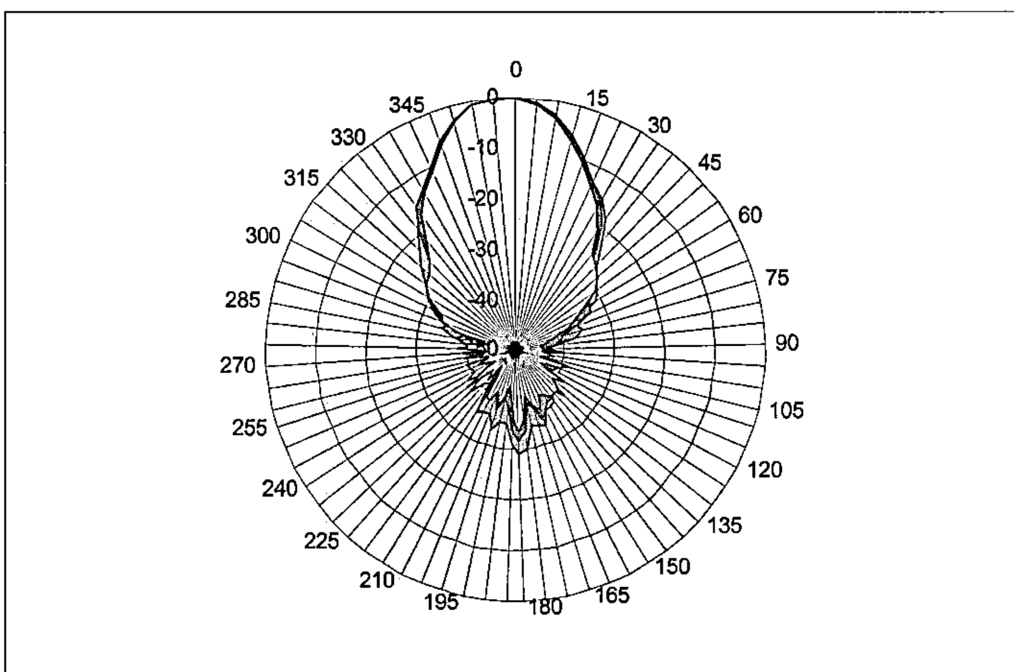



Figure 4.14 Radiation Pattern of Scientific Atlanta Standard Horn with Combination

Table 4.6 Chaparral Style Antenna Gain by Frequency

| Angle | Frequency 1 | Frequency 2 | Frequency 3 |
|---|---|---|---|
| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
| 0 | -10 | -9.83 | -10.03 |
| 5 | -10 | -9.85 | -10.04 |
| 10 | -10.18 | -10.16 | -10.46 |
| 15 | -10.58 | -10.67 | -11.14 |
| 20 | -11.05 | -11.35 | -11.93 |
| 25 | -11.6 | -12.08 | -12.89 |
| 30 | -12.2 | -12.85 | -13.94 |
| 35 | -12.86 | -13.69 | -14.98 |
| 40 | -13.68 | -14.54 | -16.18 |
| 45 | -14.7 | -15.5 | -17.65 |
| 50 | -15.92 | -16.73 | -19.05 |
| 55 | -17.4 | -18.17 | -20.33 |
| 60 | -19.02 | -19.74 | -21.92 |
| 65 | -20.72 | -21.6 | -23.86 |
| 70 | -22.67 | -23.55 | -25.64 |
| 75 | -25.49 | -25.48 | -27.50 |
| 80 | -26.46 | -27.64 | -29.50 |
| 85 | -28.65 | -29.72 | -32.07 |
| 90 | -30.67 | -31.96 | -35.01 |
| 95 | -32.45 | -33.98 | -37.22 |
| 100 | -34.44 | -36.01 | -39.63 |
| 105 | -36.45 | -39.45 | -40.25 |
| 110 | -41.02 | -41.81 | -40.12 |
| 115 | -43.21 | -43.78 | -41.03 |
| 120 | -40.64 | -44.36 | -43.86 |
| 125 | -40.38 | -45.58 | -44.89 |
| 130 | -42.65 | -44.02 | -44.01 |
| 135 | -46.14 | -45.91 | -44.32 |
| 140 | -46.58 | -45.36 | -43.16 |
| 145 | -46.9 | -45.92 | -41.85 |
| 150 | -46.83 | -46.52 | -41.35 |
| 155 | -46.68 | -46.12 | -43.36 |
| 160 | -46.98 | -46.32 | -42.44 |
| 165 | -47.81 | -46.87 | -42.76 |
| 170 | -46.91 | -46.27 | -43.53 |
| 175 | -45.64 | -43.92 | -43.26 |
| 180 | -44.23 | -42.79 | -42.71 |

| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
|---|---|---|---|
| 185 | -43.09 | -43.14 | -42.37 |
| 190 | -43.57 | -45.8 | -41.37 |
| 195 | -44.67 | -46.46 | -41.37 |
| 200 | -44.54 | -46.55 | -43.18 |
| 205 | -45.67 | -45.76 | -44.03 |
| 210 | -46.9 | -45.58 | -42.23 |
| 215 | -45.91 | -44.43 | -42.99 |
| 220 | -45.63 | -44.75 | -44.46 |
| 225 | -47.39 | -44.31 | -45.04 |
| 230 | -46.66 | -45.48 | -44.93 |
| 235 | -45.01 | -45.66 | -45.36 |
| 240 | -41.94 | -43.14 | -43.81 |
| 245 | -42.75 | -43.26 | -37.66 |
| 250 | -41.41 | -43.74 | -36.79 |
| 255 | -36.18 | -40.69 | -42.52 |
| 260 | -33.94 | -36.78 | -39.95 |
| 265 | -32.32 | -33.83 | -36.08 |
| 270 | -30.3 | -32.41 | -34.12 |
| 275 | -29.45 | -30.91 | -30.45 |
| 280 | -27.55 | -28.07 | -28.55 |
| 285 | -25.03 | -25.78 | -27.16 |
| 290 | -22.96 | -24.09 | -24.95 |
| 295 | -21.3 | -22.38 | -22.88 |
| 300 | -19.55 | -20.38 | -21.38 |
| 305 | -17.91 | -18.62 | -20.05 |
| 310 | -16.36 | -17.25 | -18.871 |
| 315 | -15.09 | -16.09 | -17.26 |
| 320 | -14.08 | -15.04 | -16.1 |
| 325 | -13.21 | -14.17 | -15.07 |
| 330 | -12.4 | -13.42 | -14.07 |
| 335 | -11.85 | -12.61 | -13.02 |
| 340 | -11.37 | -11.71 | -12.21 |
| 345 | -10.84 | -11 | -11.39 |
| 350 | -10.36 | -10.53 | -10.71 |
| 355 | -10.01 | -10.24 | -10.27 |
| 0 | -10 | -9.83 | -10.03 |

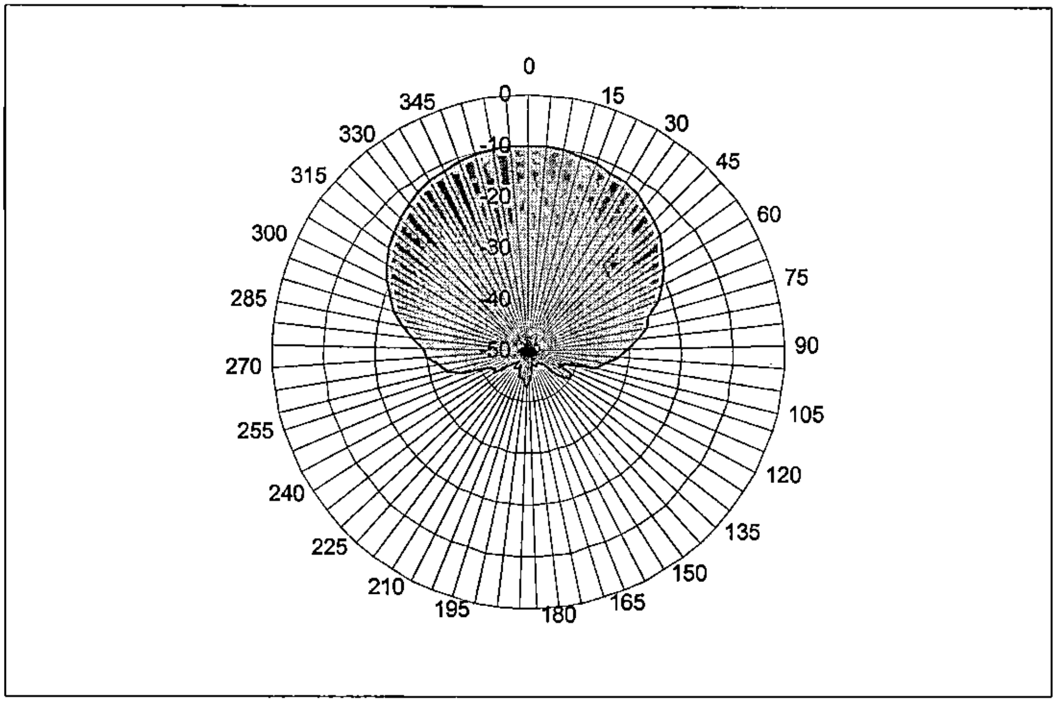



Figure 4.15 Radiation Pattern of Chaparral Style at 4.5 GHz

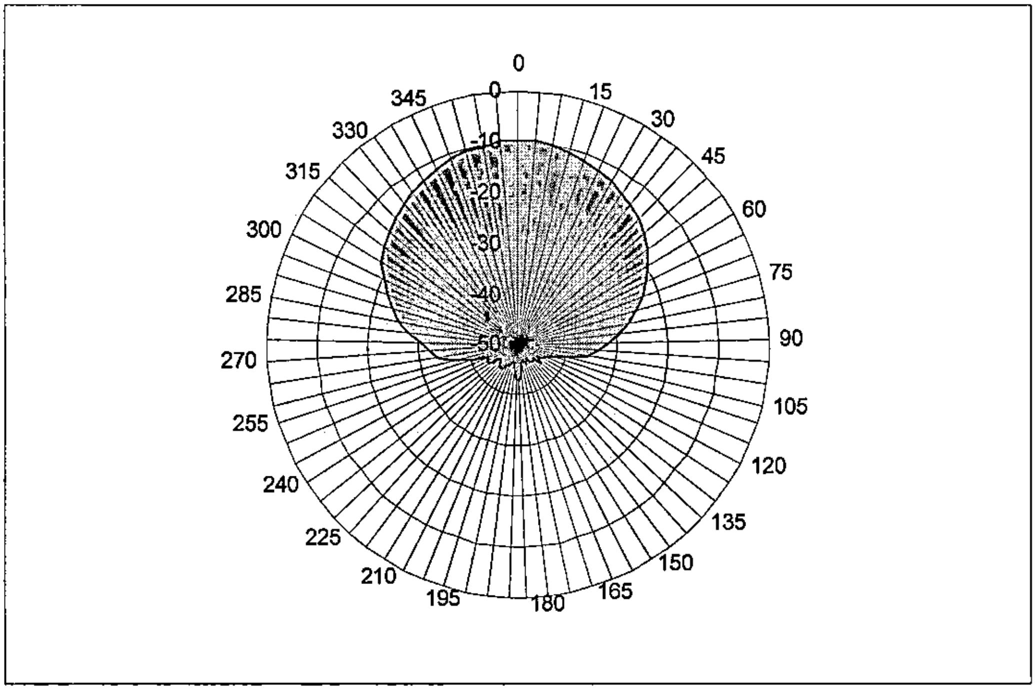



Figure 4.16 Radiation Pattern of Chaparral Style at 4.75 GHz

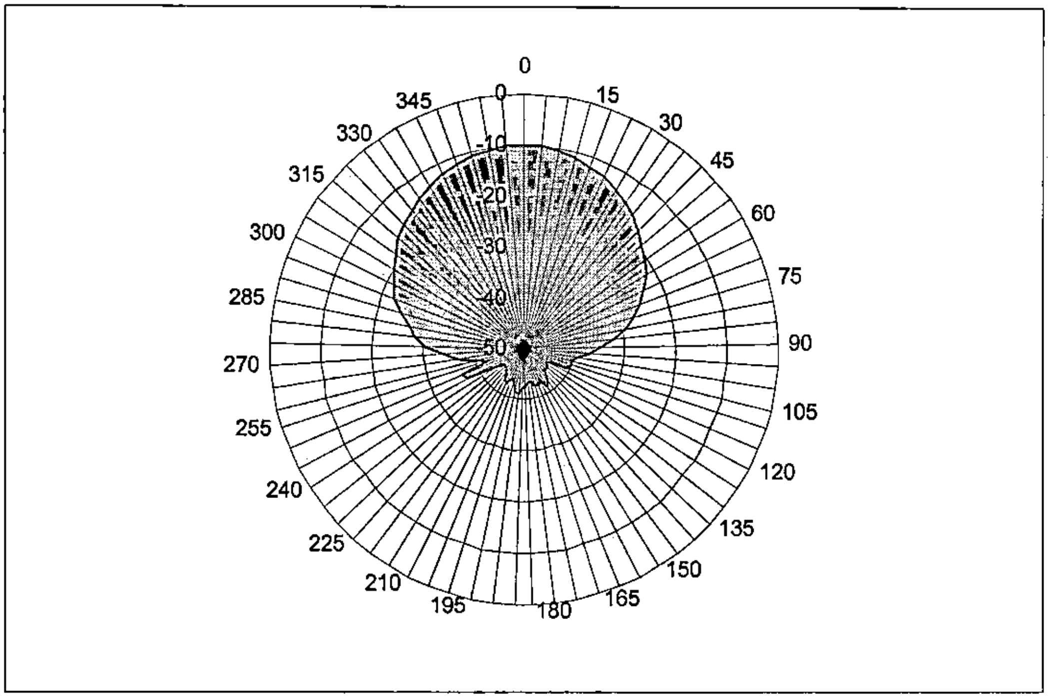



Figure 4.17 Radiation Pattern of Chaparral Style at 5.00 GHz

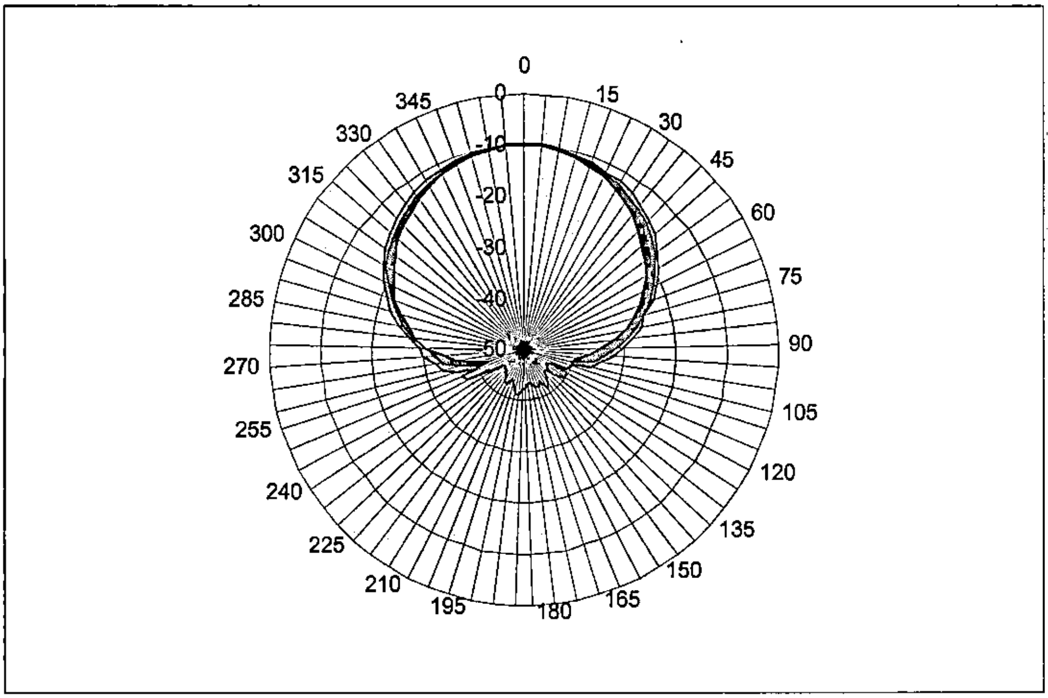



Figure 4.18 Radiation Pattern of Chaparral Style with Combination

Table 4.7 Equatorial Antenna Gain by Frequency

| Angle | Frequency 1 | Frequency 2 | Frequency 3 |
|---|---|---|---|
| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
| 0 | 0.08 | 1.32 | 2.44 |
| 5 | -1.35 | 0.35 | 1.99 |
| 10 | -2.96 | -1.38 | 0.4 |
| 15 | -3.94 | -2.59 | -2.22 |
| 20 | -6.88 | -5.82 | -4.9 |
| 25 | -9.08 | -8.75 | -8.94 |
| 30 | -12.64 | -12.68 | -12.32 |
| 35 | -16.18 | -16.36 | -16.53 |
| 40 | -19.65 | -19.26 | -18.99 |
| 45 | -21.98 | -21.65 | -21.07 |
| 50 | -23.75 | -23.83 | -22.56 |
| 55 | -25.63 | -24.41 | -25.57 |
| 60 | -28.69 | -26.61 | -27.16 |
| 65 | -29.03 | -30.38 | -28.1 |
| 70 | -30.89 | -30.98 | -33.62 |
| 75 | -33.02 | -32.94 | -34.35 |
| 80 | -33.3 | -34.47 | -33.97 |
| 85 | -37.39 | -35.02 | -34.09 |
| 90 | -36.81 | -36.32 | -34.76 |
| 95 | -36.95 | -35.96 | -34.72 |
| 100 | -37.04 | -36.28 | -34.36 |
| 105 | -37.46 | -36.32 | -35.89 |
| 110 | -37.26 | -35.76 | -34.9 |
| 115 | -37.54 | -36.33 | -34.35 |
| 120 | -37.61 | -35.72 | -33.94 |
| 125 | -37.54 | -36.42 | -34.76 |
| 130 | -37.46 | -36.96 | -35.28 |
| 135 | -37.86 | -36.63 | -35.28 |
| 140 | -37.69 | -37.03 | -35.3 |
| 145 | -38.65 | -36.54 | -34.96 |
| 150 | -37.45 | -36.07 | -34.72 |
| 155 | -37.45 | -36.57 | -34.38 |
| 160 | -37.3 | -37.94 | -34.99 |
| 165 | -37.66 | -36.23 | -34.76 |
| 170 | -36.84 | -35.68 | -34.99 |
| 175 | -36.98 | -35.25 | -34.98 |
| 180 | -37.88 | -36.14 | -35.36 |

| Degrees | 4.5 GHz | 4.75 GHz | 5.00GHz |
|---|---|---|---|
| 185 | -37.45 | -36.43 | -34.98 |
| 190 | -37.44 | -36.97 | -34.62 |
| 195 | -37.42 | -37.37 | -34.65 |
| 200 | -37.74 | -35.51 | -33.83 |
| 205 | -37.41 | -36.73 | -34.46 |
| 210 | -37.4 | -36.32 | -35.47 |
| 215 | -35.69 | -36.92 | -35.22 |
| 220 | -36.92 | -36.56 | -35.11 |
| 225 | -36.77 | -36.69 | -33.84 |
| 230 | -36.9 | -36.63 | -34.38 |
| 235 | -36.95 | -36.31 | -35.35 |
| 240 | -37.51 | -36.35 | -35.53 |
| 245 | -36.92 | -36.54 | -34.45 |
| 250 | -36.95 | -36.66 | -34.63 |
| 255 | -37.76 | -36.35 | -33.66 |
| 260 | -37.01 | -35.58 | -34.55 |
| 265 | -36.18 | -36.31 | -34.89 |
| 270 | -37.41 | -35.37 | -34.31 |
| 275 | -34.77 | -33.22 | -34.9 |
| 280 | -32.77 | -33.85 | -31.56 |
| 285 | -31.66 | -30.65 | -32.43 |
| 290 | -28.62 | -29.56 | -31.22 |
| 295 | -27.45 | -27.49 | -27.49 |
| 300 | -26.86 | -25.32 | -24.55 |
| 305 | -25.09 | -23.89 | -22.32 |
| 310 | -22.63 | -21.6 | -20.51 |
| 315 | -19.48 | -19.36 | -18.59 |
| 320 | -16.32 | -16.49 | -16.15 |
| 325 | -13.38 | -12.86 | -12.39 |
| 330 | -10.18 | -9.39 | -9.16 |
| 335 | -7.02 | -5.97 | -5.11 |
| 340 | -4.05 | -3.79 | -2.68 |
| 345 | -2.7 | -0.94 | 0.15 |
| 350 | -0.99 | 0.28 | 1.38 |
| 355 | -0.51 | 0.81 | 2.34 |
| 0 | -0.34 | 2.68 | 2.12 |

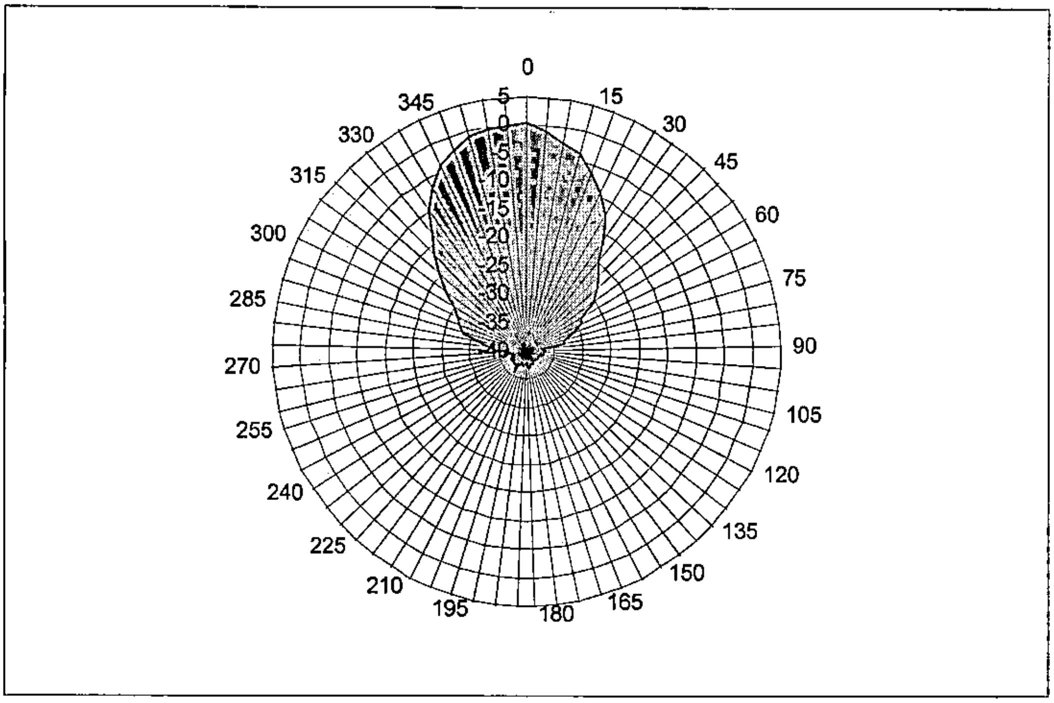



Figure 4.19 Radiation Pattern of Equatorial Antenna at 4.5 GHz

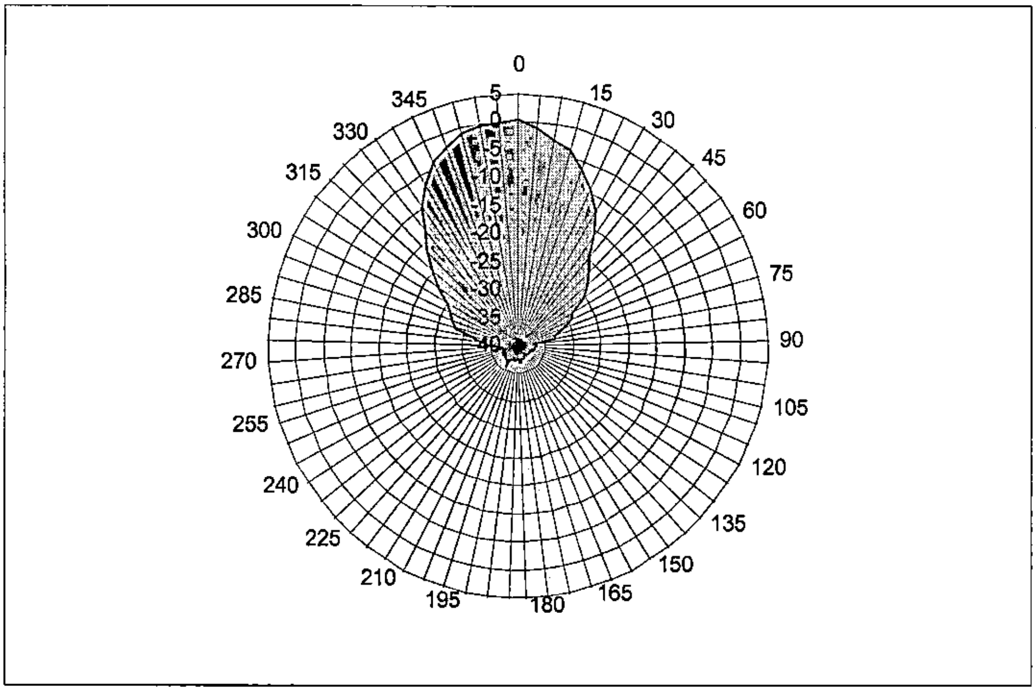



Figure 4.20 Radiation Pattern of Equatorial Antenna at 4.75 GHz

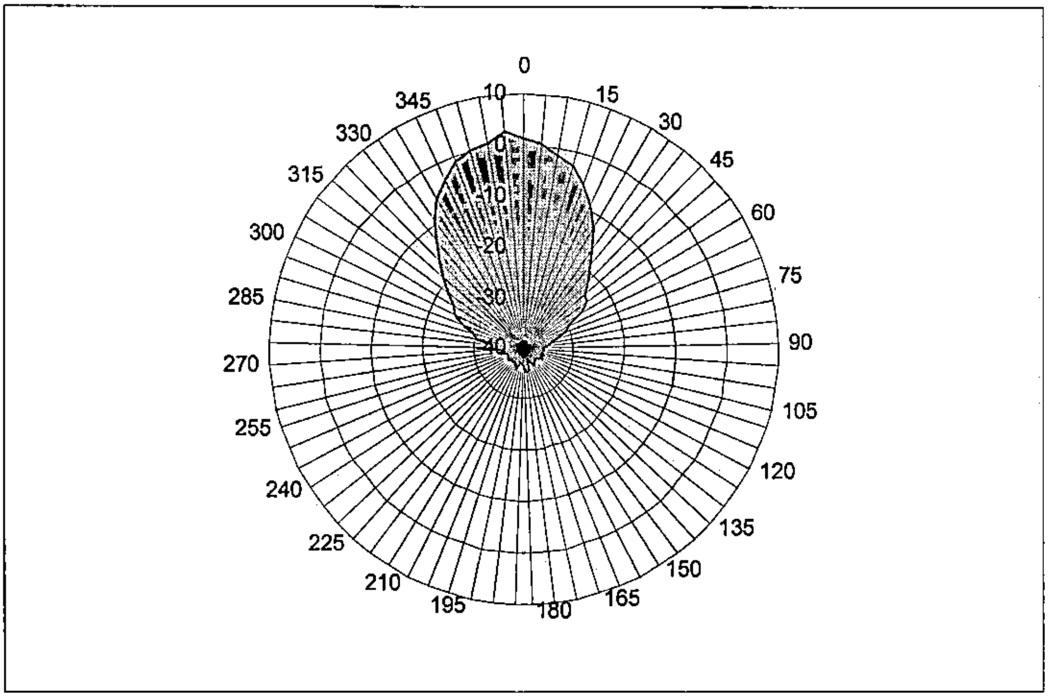



Figure 4.21 Radiation Pattern of Equatorial Antenna at 5.00 GHz

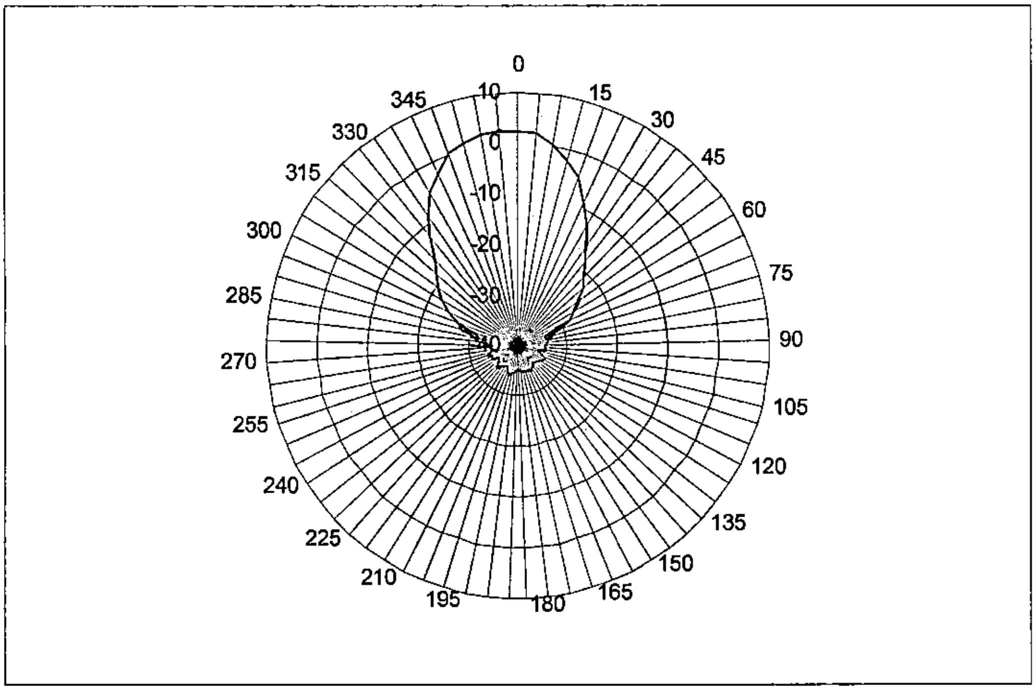



Figure 4.22 Radiation Pattern of Equatorial Antenna with Combination

Table 4.8 Square Military Horn Antenna Gain by Frequency

| Angle | Frequency 1 | Frequency 2 | Frequency 3 |
|---|---|---|---|
| Degrees | 4.5 | 4.75 | 5 |
| 0 | -5.25 | -5.03 | -5.04 |
| 5 | -5.6 | -5.43 | -5.49 |
| 10 | -6.51 | -6.3 | -6.52 |
| 15 | -7.91 | -7.69 | -8.22 |
| 20 | -9.73 | -9.71 | -10.48 |
| 25 | -11.97 | -12.51 | -13.65 |
| 30 | -14.61 | -16.23 | -18.28 |
| 35 | -17.88 | -20.98 | -25.39 |
| 40 | -22.38 | -26.67 | -31.01 |
| 45 | -27.59 | -29.18 | -26.24 |
| 50 | -28.45 | -25.84 | -22.96 |
| 55 | -26.73 | -23.67 | -21.16 |
| 60 | -25.66 | -22.74 | -20.88 |
| 65 | -26.14 | -22.31 | -21.36 |
| 70 | -27.43 | -23.29 | -27.43 |
| 75 | -26.74 | -26.32 | -21.98 |
| 80 | -25.79 | -26.62 | -24.26 |
| 85 | -26.64 | -25.64 | -26.52 |
| 90 | -29.79 | -27.56 | -26.43 |
| 95 | -31.85 | -32.08 | -28.32 |
| 100 | -32.07 | -33.51 | -33.12 |
| 105 | -32.63 | -32.22 | -37.06 |
| 110 | -32.33 | -31.05 | -34.02 |
| 115 | -33.63 | -30.9 | -32.22 |
| 120 | -34.25 | -32.31 | -32.12 |
| 125 | -35.52 | -33.43 | -35.65 |
| 130 | -38.34 | -35.02 | -37.32 |
| 135 | -42.98 | -37.96 | -38.07 |
| 140 | -46.21 | -38.86 | -40.47 |
| 145 | -39.52 | -38.34 | -40.15 |
| 150 | -35.76 | -37.84 | -39.46 |
| 155 | -35.23 | -37.41 | -37.61 |
| 160 | -37.68 | -37.43 | -35.54 |
| 165 | -42.26 | -37.96 | -36.14 |
| 170 | -41.81 | -38.36 | -40.11 |
| 175 | -37.76 | -36.25 | -41.89 |
| 180 | -36.35 | -34.78 | -40.42 |

| Degrees | 4.5 | 4.75 | 5 |
|---|---|---|---|
| 185 | -37.02 | -35.03 | -42.85 |
| 190 | -42.52 | -41.05 | -45.56 |
| 195 | -46.91 | -43.54 | -45.78 |
| 200 | -42.57 | -39.79 | -41.35 |
| 205 | -41.85 | -37.08 | -38.12 |
| 210 | -41.15 | -36.55 | -37.62 |
| 215 | -41.03 | -37.48 | -35.72 |
| 220 | -43.7 | -35.56 | -35.3 |
| 225 | -41.99 | -35.51 | -35.89 |
| 230 | -38.51 | -37.61 | -40.85 |
| 235 | -40.91 | -37.12 | -40.02 |
| 240 | -42.48 | -37.96 | -34.97 |
| 245 | -36.36 | -33.35 | -32.57 |
| 250 | -32.61 | -30.1 | -32.44 |
| 255 | -31.27 | -29.91 | -32.72 |
| 260 | -31.73 | -31.6 | -30.55 |
| 265 | -32.41 | -30.34 | -27.31 |
| 270 | -29.26 | -26.88 | -24.65 |
| 275 | -26.71 | -24.6 | -22.97 |
| 280 | -25.59 | -23.47 | -22.76 |
| 285 | -25.21 | -22.82 | -22.63 |
| 290 | -25.18 | -23.2 | -21.97 |
| 295 | -26.1 | -24.07 | -21.41 |
| 300 | -28.31 | -24.65 | -21.56 |
| 305 | -31.55 | -26.39 | -22.22 |
| 310 | -31.68 | -29.71 | -23.87 |
| 315 | -25.19 | -29.08 | -26.86 |
| 320 | -19.81 | -22.43 | -24.77 |
| 325 | -15.79 | -17.32 | -18.86 |
| 330 | -12.65 | -13.54 | -14.34 |
| 335 | -10.23 | -10.71 | -11.11 |
| 340 | -8.37 | -8.55 | -8.7 |
| 345 | -7.02 | -6.97 | -7 |
| 350 | -6.1 | -5.86 | -5.85 |
| 355 | -5.6 | -5.27 | -5.26 |
| 0 | -5.25 | -5.03 | -5.04 |

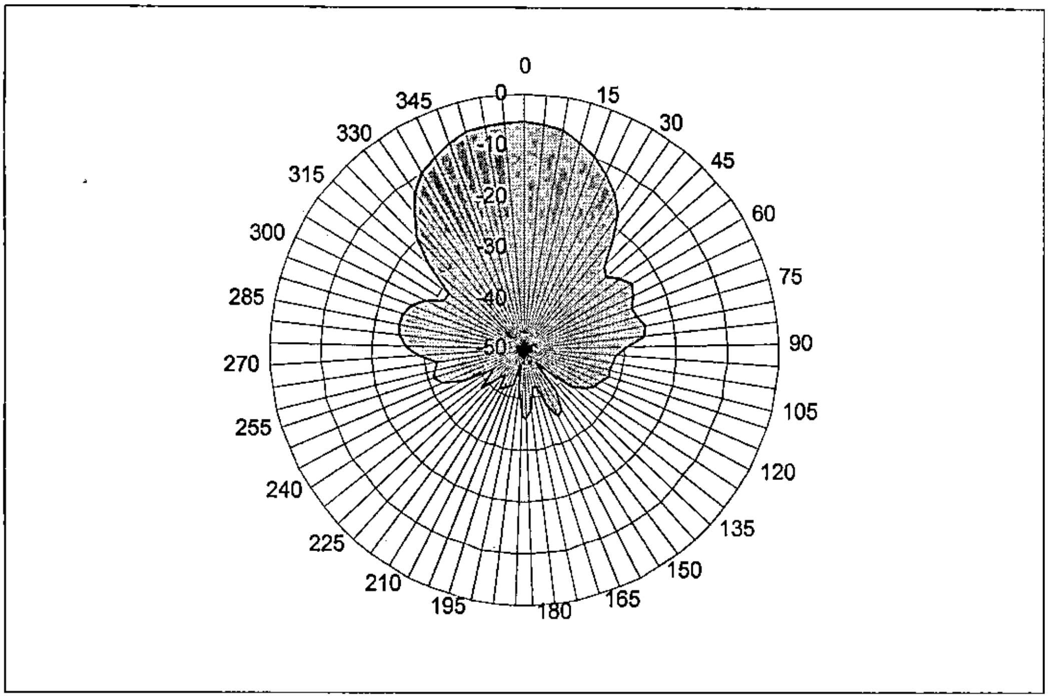



Figure 4.23 Radiation Pattern of Square Green Military Horn Antenna at 4.5 GHz

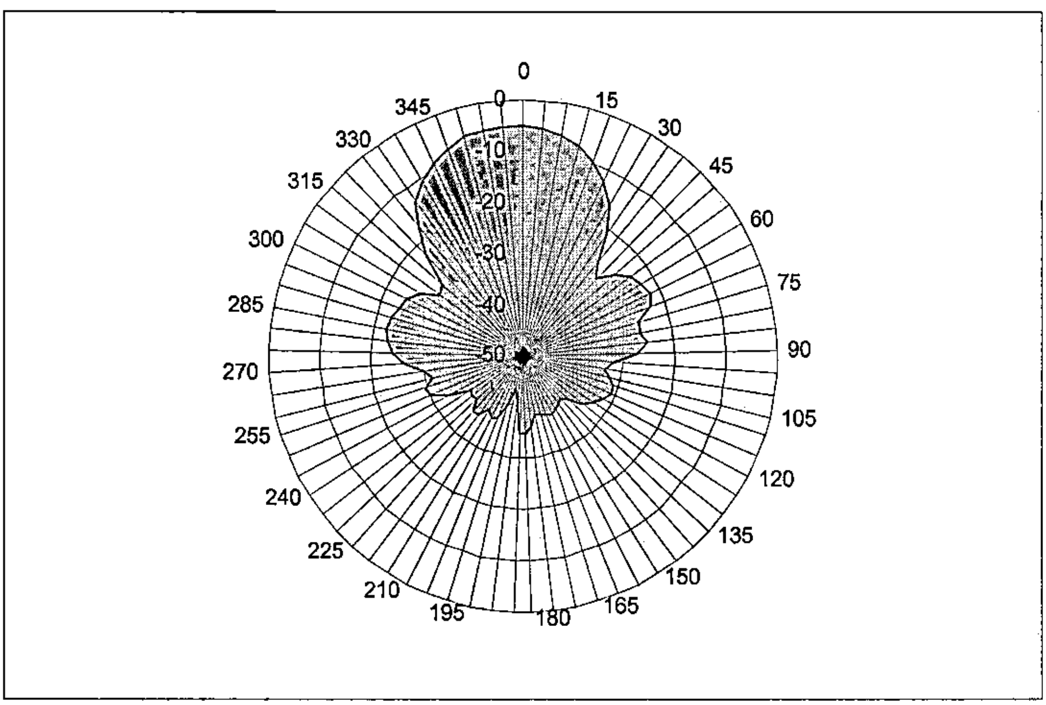



Figure 4.24 Radiation Pattern of Square Green Military Horn Antenna at 4.75 GHz

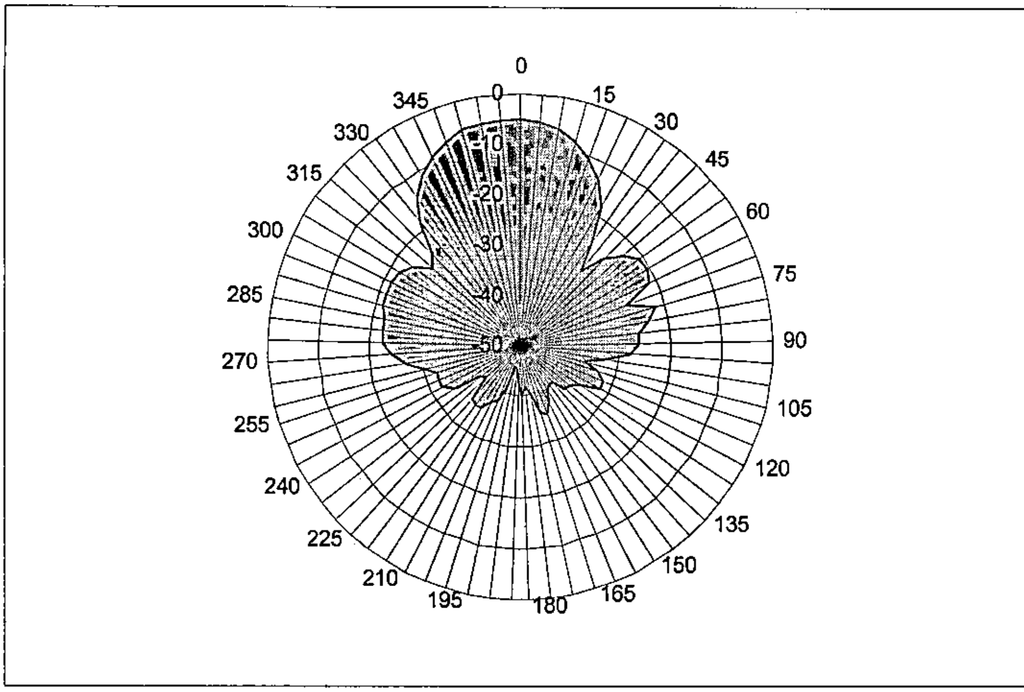



Figure 4.25 Radiation Pattern of Square Green Military Horn Antenna at 5.00 GHz

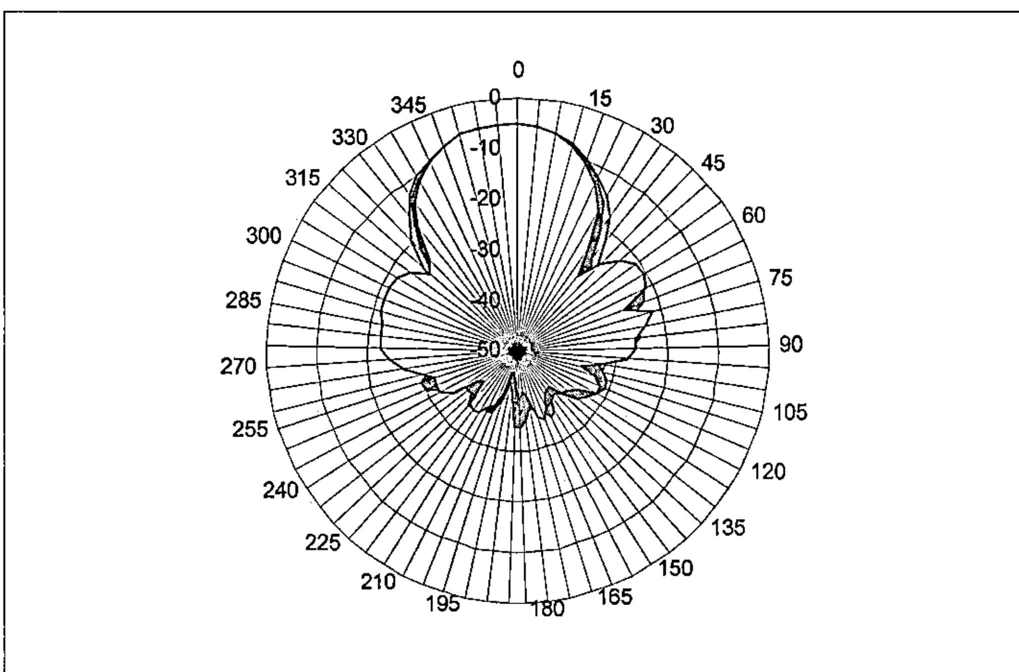



Figure 4.26 Radiation Pattern of Square Military Horn Antenna with Combination

**Results for Research Objective #3**

**Comparison and Analysis to Determine the Best Feed**

A Scientific Atlanta Standard Gain Horn (Model 12-3.9) was used as a reference antenna and other antennas (Chaparral Style, Equatorial, and Square Green Military Horn) were compared against the reference antenna. Polar plots of their Radiation patterns, analyses the dish geometry, and comparison of the L-Band and Ku-Band specifications of the 21 Meter antenna were assembled to select the best antenna feed for work at C-Band at 5.00 GHz by using the measured feed data collected from chamber results. The response at 67.5° as shown in Tables 4.9-4.13.

This number is based on dish geometry analysis, and was actually found to be approximately 68 degrees, but for purposes of this evaluation, it is easier to evaluate the Vertex data at 67.5 degrees and the difference is insignificant for these antenna types chosen. The gain was found and expressed, in "dB" response of the corresponding values at $67.5^0$ from anechoic chamber data Tables 4.4 -4.8 and using mathematical interpolation method. Tables 4.9 – 4.13 show these results for each feed using the data interpolation method.

| Table 4.9 Chaparral Style feed | | | | |
|---|---|---|---|---|
| Formula | Degrees | 4.5 GHz | 4.75 GHz | 5.00 GHz |
| A | 0 | -10 | -9.83 | -10.03 |
| B = (B-A = X) | 65 | -20.72 (-10.72) | -21.6 (-11.77) | -23.86 (-13.83) |
| C = (X+Y)/2 | 67.5 | -11.69 | -12.74 | -14.72 |

| | | | | |
|---|---|---|---|---|
| D = (D-A = Y) | 70 | -22.67 (-12.67) | -23.55 (-13.72) | -25.64 (-15.61) |

| Table 4.10 Equatorial Feed | | | | |
|---|---|---|---|---|
| Formula | Degrees | 4.5 GHz | 4.75 GHz | 5.00 GHz |
| A | 0 | -0.08 | -1.32 | -2.44 |
| B = (B-A = X) | 65 | -29.03 (-28.95) | -30.38 (-29.06) | -28.1 (-25.66) |
| C = (X+Y)/2 | 67.5 | -29.88 | -29.36 | -28.42 |
| D = (D-A = Y) | 70 | -30.89 (-30.81) | -30.98 (-29.66) | -33.62 (-31.18) |

| Table 4.11 Square Green Military Feed Horn | | | | |
|---|---|---|---|---|
| Formula | Degrees | 4.5 GHz | 4.75 GHz | 5.00 GHz |
| A | 0 | -5.25 | -5.03 | -5.04 |
| B = (B-A = X) | 65 | -26.14 (-20.89) | -22.31 (-17.28) | -21.36 (-16.32) |
| C = (X+Y)/2 | 67.5 | -21.58 | -17.77 | -19.35 |
| D = (D-A = Y) | 70 | -27.43 | -23.29 (-18.26) | -27.43 (-22.39) |

| Table 4.12 Scientific Atlanta Standard Gain Horn (Reference antenna) | | | | |
|---|---|---|---|---|
| Formula | Degrees | 4.5 GHz | 4.75 GHz | 5.00 GHz |
| A | 0 | 0 | 0 | 0 |
| B = (B-A = X) | 65 | -34.9 | -33.06 | -36.93 |
| C = (X+Y)/2 | 67.5 | -35.75 | -34.99 | -37.96 |
| D = (D-A = Y) | 70 | -36.61 | -36.93 | -38.99 |

| Table 4.13 Measured Feed data of gain in dB response @ α = 67.5 | | | |
|---|---|---|---|
| Feed Name | 4.5 GHz | 4.75 GHz | 5.00 GHz |
| Chaparral Like | -11.69 | -12.74 | -14.72 |
| Equatorial | -29.88 | -29.36 | -28.42 |
| Square Green Military Horn | -21.58 | -17.77 | -19.35 |
| Reference Antenna | -35.75 | -34.99 | -37.96 |

**Graphical Analyses of L-Band & Ku-Band**

Empirically measured feed patterns and the overall behavior of the L & Ku-Band for the 21 Meter are shown in Appendix A and B. The Vertex RSI, L & Ku-Band performance (From the In-Plant Test Data for the 21 Meter) are summarized in Appendix A and B.

Values of the gain in "dB" response from the existing Vertex L-Band & Ku-Band feed, were determined by constructing functions at α = +/- 67.5° vertically and a horizontal line where the pattern intersects are shown in appendix "A and B". Table 4.14 shows the responses of the Vertex feeds for L and Ku-Band (vertical port) as well as horizontal port readings.

Table 4.14 Vertex L & Ku-Band Data

| 1.a Vertex Feed Test data in dB response Job 12677 L-Band Vert.port @ α = 67.5 | | |
|---|---|---|
| Frequency (1.400) | Frequency (1.550) | Frequency (1.700) |
| -13.75 | -14 | -15 |

| 1.b Vertex Feed Test data in dB response Job 12677 L-Band Horiz.port @ α = 67.5 | | |
|---|---|---|
| Frequency (1.400) | Frequency (1.550) | Frequency (1.700) |
| -13.5 | -14.5 | -15 |

| 2.a Vertex Feed Test data in dB response Job 12677 Ku-Band Vert.port @ α = 67.5 | | |
|---|---|---|
| Frequency (11.200) | Frequency (11.950) | Frequency (12.700) |
| -11 | -11.75 | -12.5 |

| 2.b Vertex Feed Test data in dB response Job 12677 Ku-Band Horiz.port @ α = 67.5 | | |
|---|---|---|
| Frequency (11.200) | Frequency (11.950) | Frequency (12.700) |
| -12.2 | -12.25 | -12.5 |

The results of the data collected by this study on the different feeds (Chaparral Style, Equatorial, and Square Green Military Horn) and summarized the global parameters measured in house are shown tables 4.09 to 4.13. The Chaparral feed closely matches the actual values of Vertex feed test data for both L-Band & Ku-Band at α = 67.5° (see Table 4.15).

| Table 4.15 Vertex Analysis of 1.a & 1.b from above table | | | |
|---|---|---|---|
| | Frequency (1.4-1.7) Values | In-Between | Range |
| 1.a | Δ dB = 1.25 | +/- .6.25 dB | 300 MHz |
| 1.b | Δ dB = 1.5 | +/-.75 dB | 300 MHz |
| 2.a | Δ dB = 1.5 | +/- .75 dB | 1500 MHz |
| 2.b | Δ dB = 0.3 | +/- .15 dB | 1500 MHz |

From Vertex analysis at both α = +/- 67.5

| | |
|---|---|
| Max | -15 dB |
| Min | -11 dB |

| Table of Measured Values of Gain for Chaparral Style at α = 67.5 | | |
|---|---|---|
| Frequency (4.5.0-5.0) Values | In-Between | Range |
| Δ dB = 3.03 | +/- 1.5 dB | 500 MHz |

Analysis indicates that the Chaparral Style feed is the feed which best fits within the boundaries corresponding to a Maximum at -14.7 and a Minimum at -11.7. Graphical representation of all operating parameters, among the measured feeds demonstrates that the "Chaparral Style feed values" shows a close match and falls within the Vertex L-Band and Ku-Band specifications at $\alpha = 67.5°$. (See Figures 4.27 - 4.30).

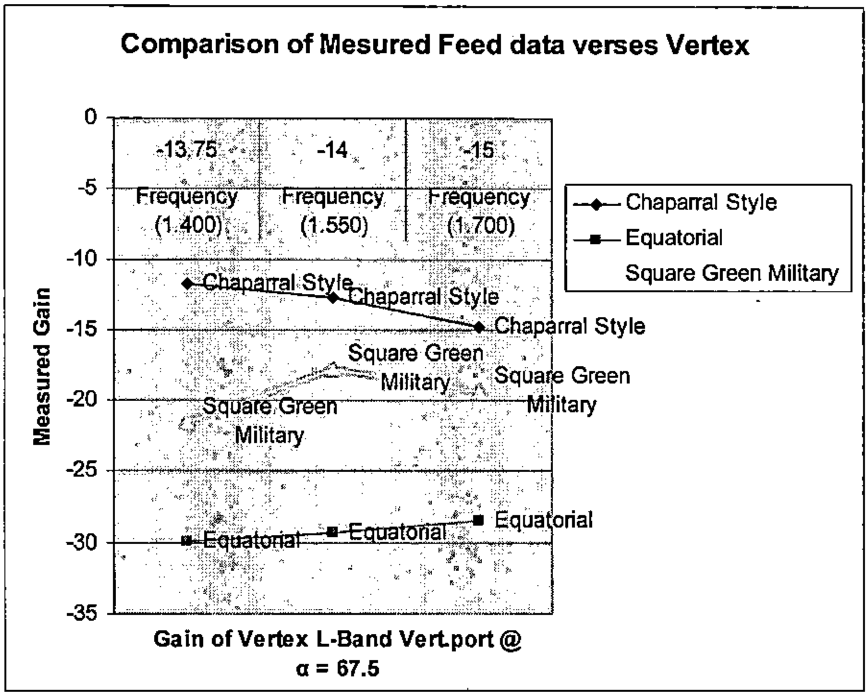



Figure 4.27 Measured Gain Versus Vertex RSI Data

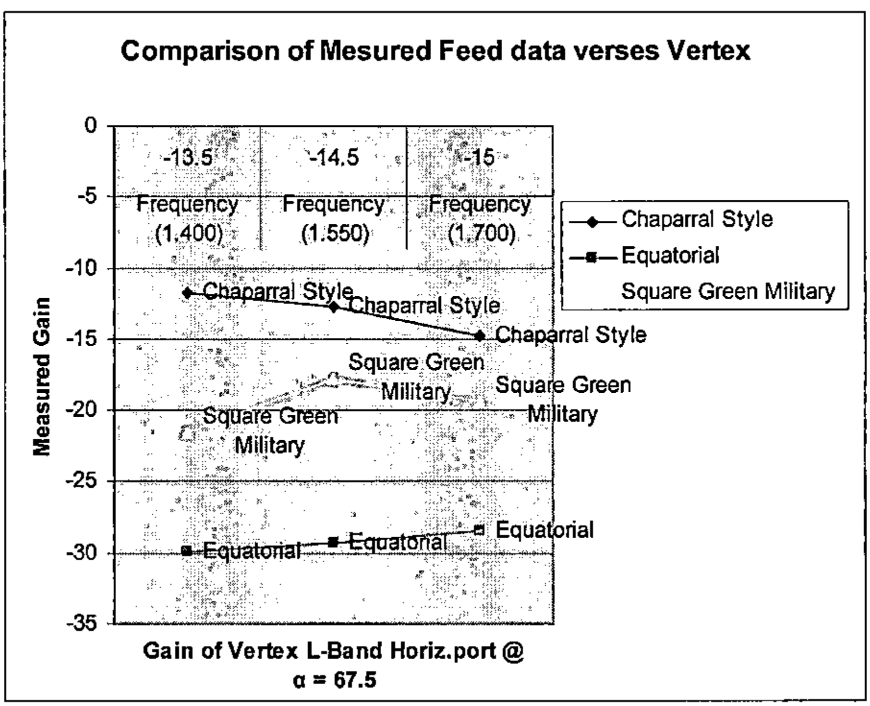



Figure 4.28 Measured Gain Versus Vertex RSI Data

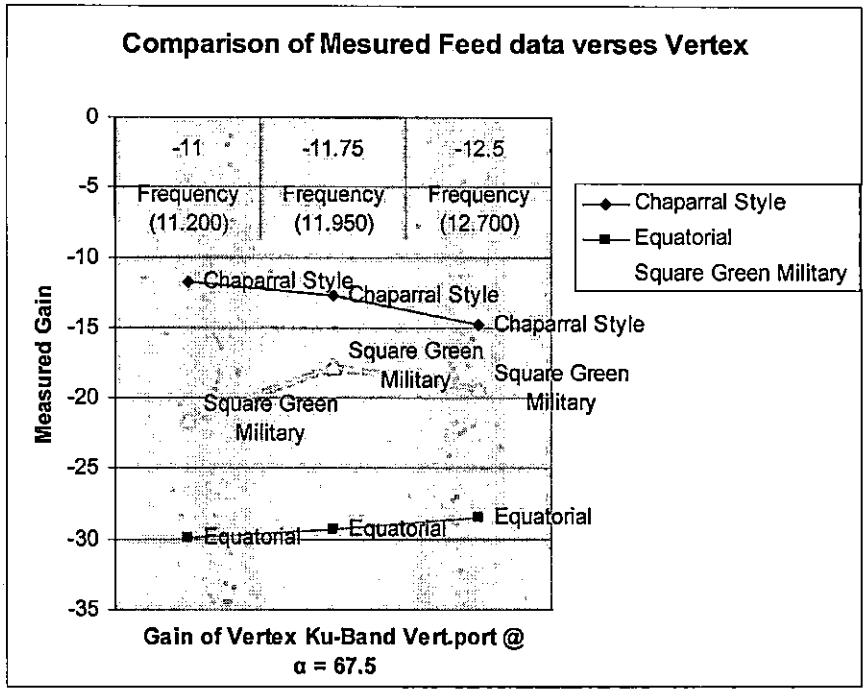



Figure 4.29 Measured Gain Versus Vertex RSI Data

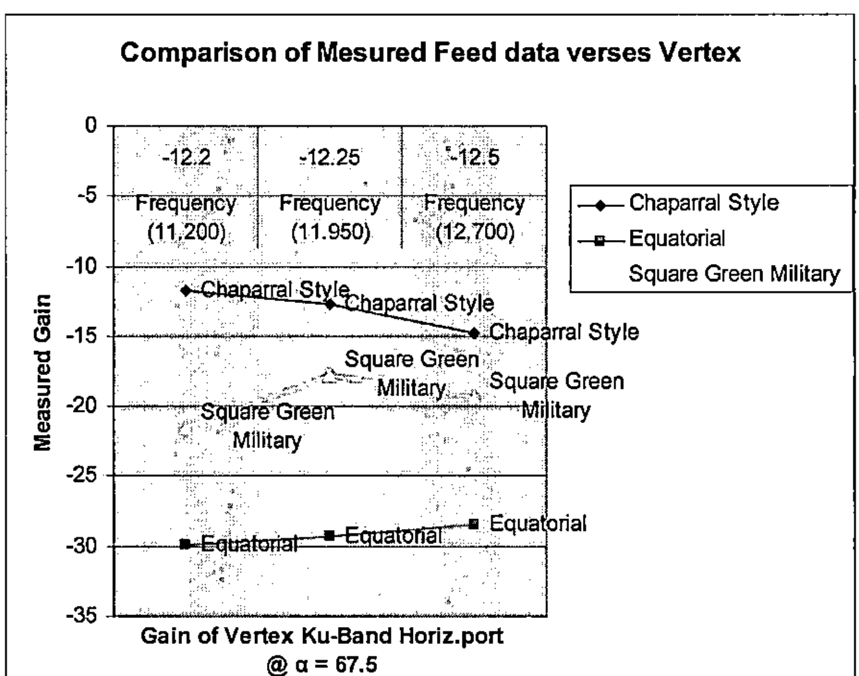



Figure 4.30 Measured Gain Versus Vertex RSI Data

# CHAPTER V: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

## Summary

Chapter 1 identified an area of concern related to C-band radio frequency technology developments which is relevant to the astronomical research of the 21 Meter Morehead Space Tracking Antenna. The current systems of feeds operating on the 21 Meter are L, S, and Ku-bands. L-band is primarily for formal astronomical research and the other two frequency regimes are utilized for telecommunication purposes. The Implementation of a C-band (5GHz) frequency feed will extend the capabilities of the 21 Meter and will fill a vital role in astronomical research. The research objective of "characterizing" the feed (Research Objective 1) included testing, developing appropriate experimental methods and analyzing of different feeds to select the most suitable feed for work at C-band with the best performance. The C-band system covers at a minimum, the radio astronomy spectral band from 4800 MHz to 5000 MHz. Experimental results of antenna test feeds in the anechoic chamber yielded empirical values for a voltage standing wave ratio (VSWR), gain and the illumination function of each feed in the study (Research Objective 3).

The findings and analyses are based on data collected from dish geometry analyses (For L, C, and Ku-band) and beamwidth ($2\alpha$) of the dish geometry. The best feed for operation at C-band (5GHz) was determined by comparing these data with existing L and Ku-band test data, and specification of the 21 Meter Space Tracking Antenna. These analyses proved that the Chaparral Style feed fits best and falls within the boundaries of Vertex L and Ku-band guidelines for beamwidth $\alpha = +/- 67.5°$

(Research Objective 2). Therefore, the Chaparral Style feed will be developed into a fully functional system.

**Conclusion**

In this project, the researcher conducted various tests of different feeds to select the best candidate that will work most efficiently at C-Band (5 GHz) for the 21 Meter Space Tracking Antenna. Using first a basic dish geometry analysis of the 21 M, antenna, the characteristic behavior of the instrument was determined for at certain illumination angle and beam angles (2 $\alpha = 135^0$ where and $\alpha = 67.5^0$ was selected. Overall, based on the existing L-Band & Ku-Band specifications, anechoic chamber data, and polar plots of various feed patterns, the Chaparral Style feed is very appropriate for work at the C-Band (5GHz) frequency with the 21 Meter.

**Recommendations for Further Research**

Based on the theoretical calculations as well as chamber test data, plots, and dish geometry analysis, the Chaparral Style was selected for installation on the 21 Meter Space Tracking Antenna. These tests were vital to identify a feed that could be used for the 5 GHz system. However, there is still considerable work to be done to bring the 5 GHz capability online. The feed must be mounted, the preamplifier installed, appropriate power and signal cabling connected and the 5 GHz-to-160 MHz frequency converter installed in the Lower Equipment Room (LER). The system's in situ performance will be measured by the Radio Star Method to determine G/T, system gain, system temperature and the corresponding antenna pattern.

These tests will be used to determine the overall system performance at 5 GHz. The above noted additional efforts are beyond the scope of this research project.

## REFERENCES


Bluewave, (1996, May). Glossary Bluewave, Retrieved May 10, 2007 from http://www.bluewaveantena.com/technical/glossary.html

Chaparral Communications. (1980). Retrieved July 2, 2008 from http://www.chaparral.net/products/feedhorns/dualfeed.html

Fordham, J (2002, May). An Introduction to Antenna Test Ranges, Measurements and Instrumentation. Microwave Instrumentation Technologies, LLC. Duluth, GA: MI Technologies.

Fthenakis, E. (1984, May). Manual of Satellite Communications. 1st ed. New York: McGraw-Hill.

Gandhi, P. (1981, January). Microwave Engineering and Applications. 3rd ed. Vol. 1. New York: Pergamon.

Griffith, M., & Wright, A. (1993). The Parkes-MIT-NRAO (PMN) Surveys. I. The 4850 MHz Surveys and Data Reduction. (American Astronomical Society). Provided by the NASA Astrophysics Data System.

Kraus, J (1950). Antennas, 2nd ed. United States: McGraw-Hill, Inc.

Kraus, J. (1986). Radio Astronomy, second ed. University of New Hampshire Printing Services: Cygnus-Quasar Books.

Malphrus, B. (1996). The History of Radio Astronomy and the National Radio Astronomy Observatory, 145- 148.

Malphrus, B. (2001). Research Program in Radio Frequency Astrophysics. Retrieved from Space Science Center.

http://ssc.moreheadstate.edu/sta-starscienceprg.php

Malphrus, B., Combs, M., Kruth, J., Pannuti, T., Carnevali, A., Carter, J., Atwood, W., Ennis, M., & Kroll, R. (2008). The development and testing of a 21 m Earth Station and Radio Telescope at Morehead State University for Research and Education. Provided by American Institute of Aeronautics and Astronautics.

Parabolic reflector (1990). Retrieved May 12, 2008 from Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Parabolic_reflector

Pauliny-Toth, I. & Kellermann, K (1968) Measurements of the Flux Density and Spectra of Discrete Radio Sources at Centimeter Wavelengths. II. The Observations at 5 GHz (6cm). (American Astronomical Society). Provided by the NASA Astrophysics Data System.

Pauliny-Toth, I. Witzel, I. Preuss, E. (1978). The 5 GHz Strong Source Surveys. IV. Survey of the Area between Declination 35 and 70 Degees and Summary of the source counts, Spectra and Optical Identifications. (American Astronomical Society). Provided by the NASA Astrophysics Data System.

Pauliny-Toth, I., Witzel, A., Preuss, J., Baldwin, E., and Hills, R. (1978). Astron. Astrophysics. Suppl.34, (253-258). A Deep Survey of A region near the North Celestial Pole at A Frequency of 4.85 GHz. (American Astronomical Society). Provided by the NASA Astrophysics Data System.

Pelton, N. (1995, July). The "How to" of Satellite Communications. 1st ed. Sonoma, CA: Design, Inc.

Private Communications with J.A. Kruth, RF Systems Engineer, Morehead State University, Department of Space Science Center.

Radiation Pattern about TV and FM Antennas. (2007, June) Retrieved Feb, 4 2008 from http://www.kyes.com/antenna/navy/rpatterns/radiapat.htm

Robert, C. (1985). Antennas and Radio wave Propagation. United States: McGraw-Hill, Inc.

Schwerdtfeger, R. (1990, August). Microwave Reflector Antenna. 7th ed. Vol. 1. Kilgore, Texas: Vertex RSI, 37-49.

Skolnik, M. (1970). Radar Handbook. 1st ed. New York: McGraw-Hill.

NASA Contractor Report (1971). 1st ed. Vol. III. Culver City, Calif. 90230: Huges Aircraft Company.

Stanley, D., & Richard F. (1994, October). Lines and Fields in Electronic Technology. 10th ed. Vol. 1. New Jersey: Prentice Hall.

Supernova, NASA's (2003, June). Retrieved from HEASARC. February, 10 2008 http://heasarc.gsfc.nasa.gov/docs/snr.html

Vertex (2006). L-Band In-Plant Test Data Job 12677 (Frequencies 1.40, 1.55, and 1.70 GHz). 21 M, Morehead Space Tracking Antenna.

Vertex (2006). Ku-Band In-Plant Test Data Job 12677 (Frequencies 11.20, 11.95, and 12.70 GHz). 21 M, Morehead Space Tracking Antenna.

Wood, P. (1980, November). Reflector Antenna Analysis and Design. 7th ed. Vol. 1. New York: Peter Peregrinus, Ltd, 9-33.

# APPENDIX A

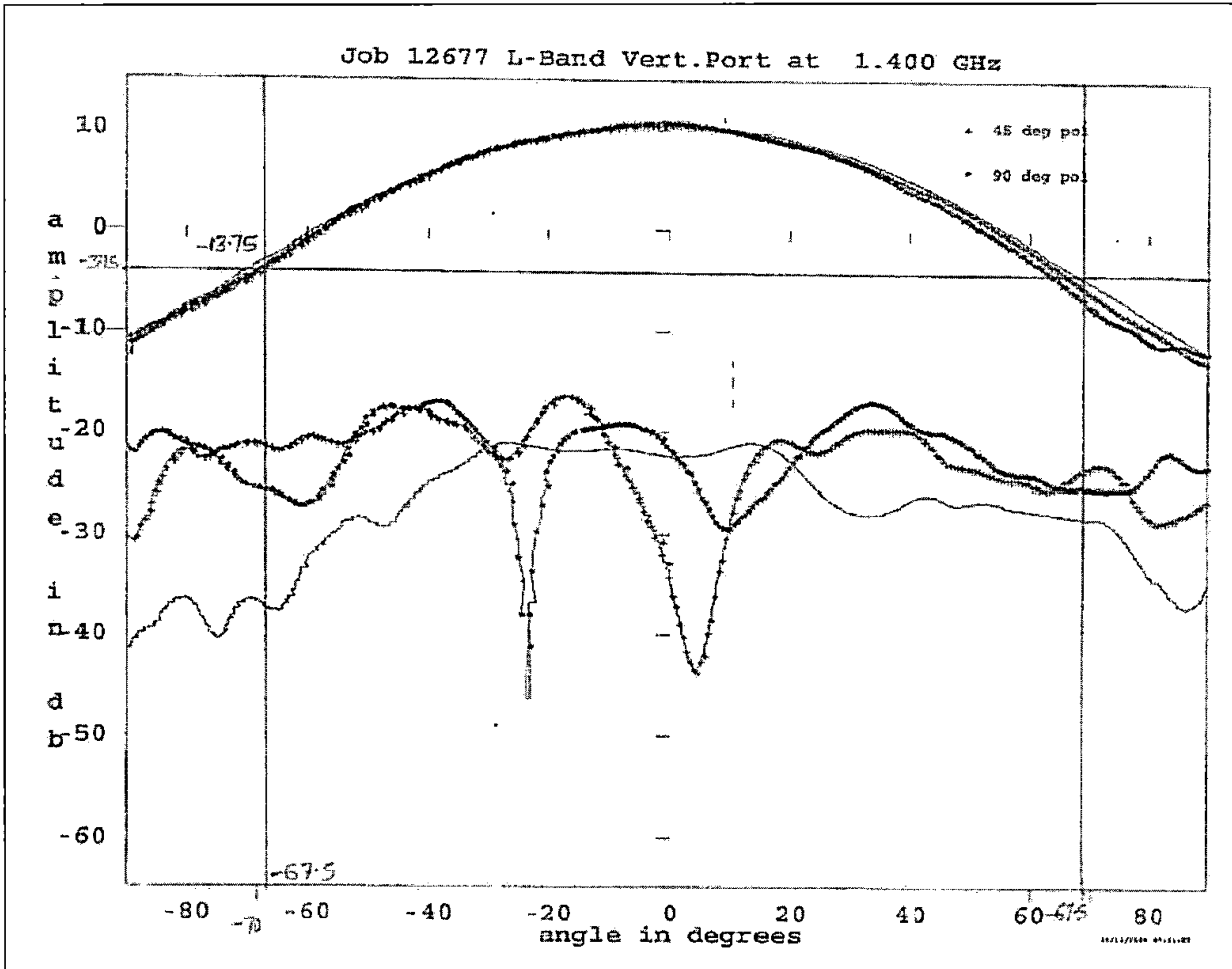
# VERTEX

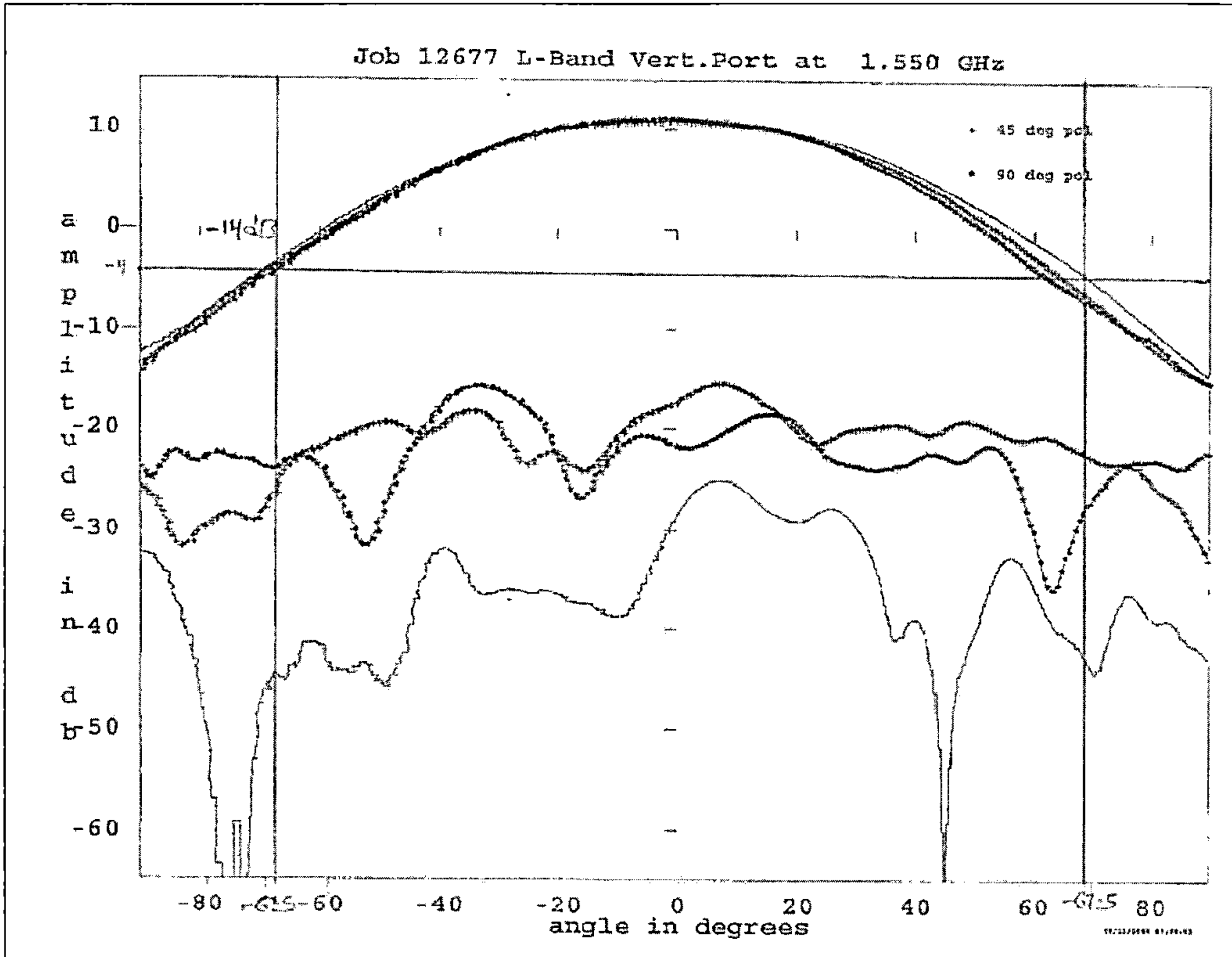
# Job 12677

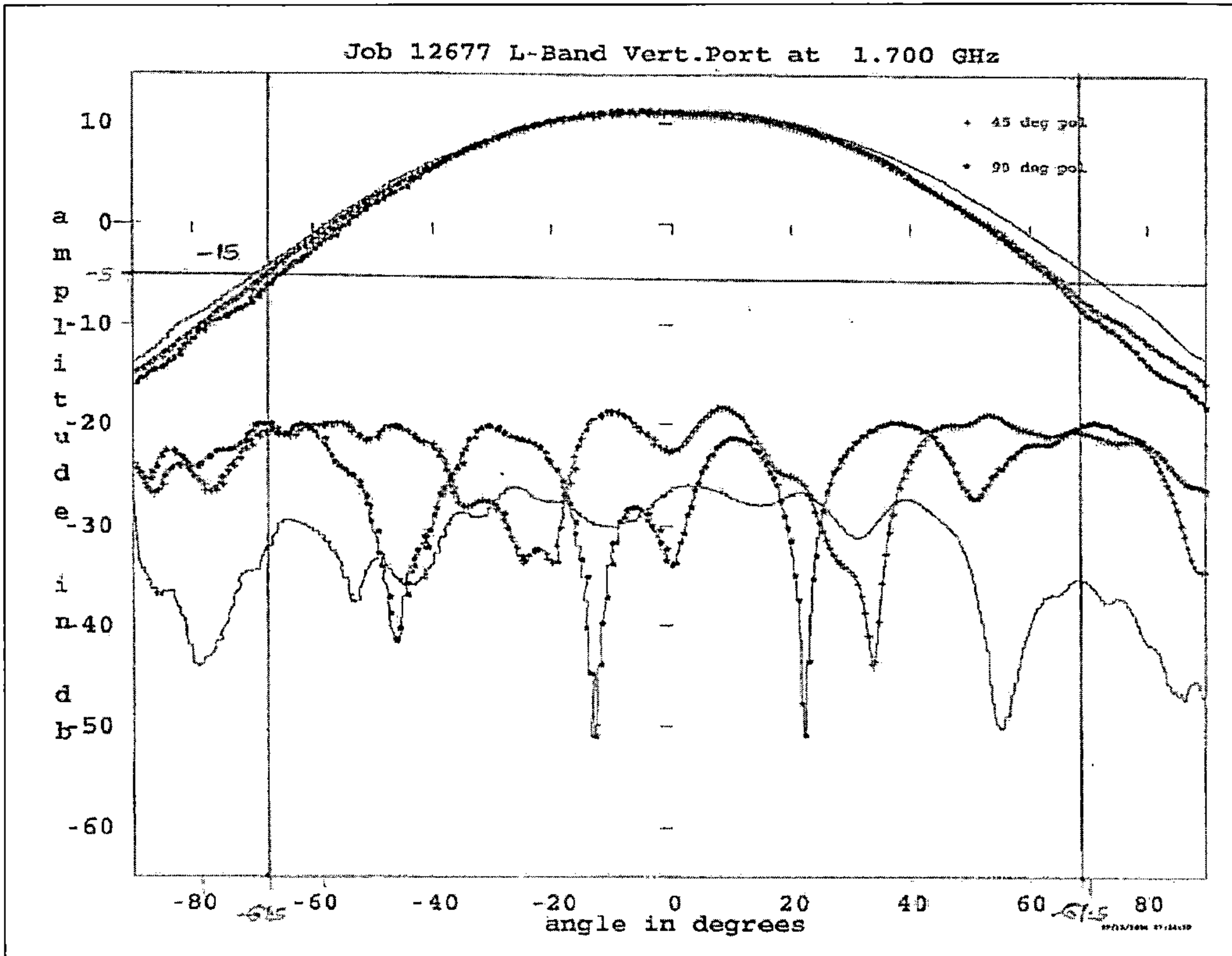
# L-Band In-Plant Test Data

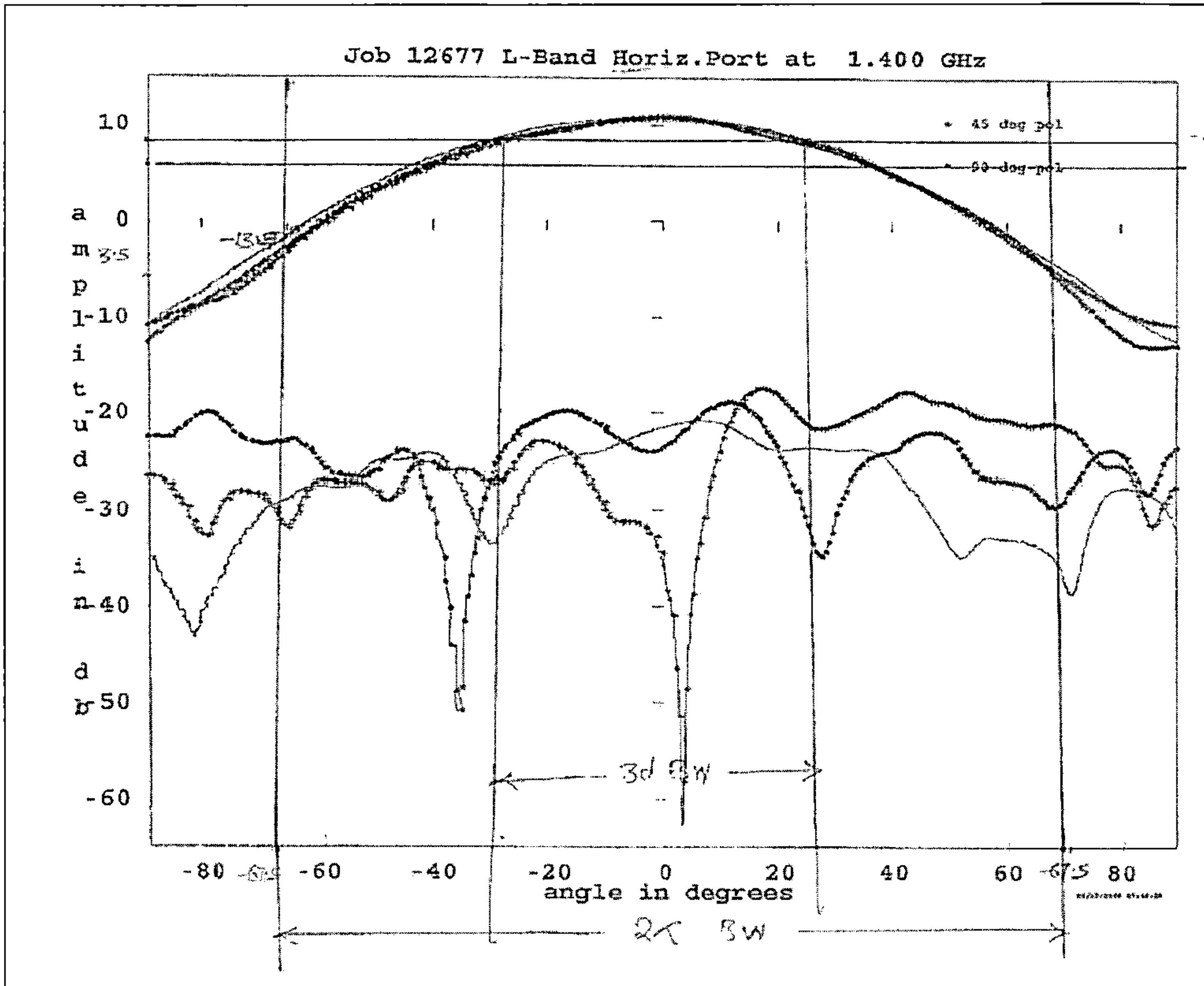
# 21 M, Morehead Space Tracking Antenna

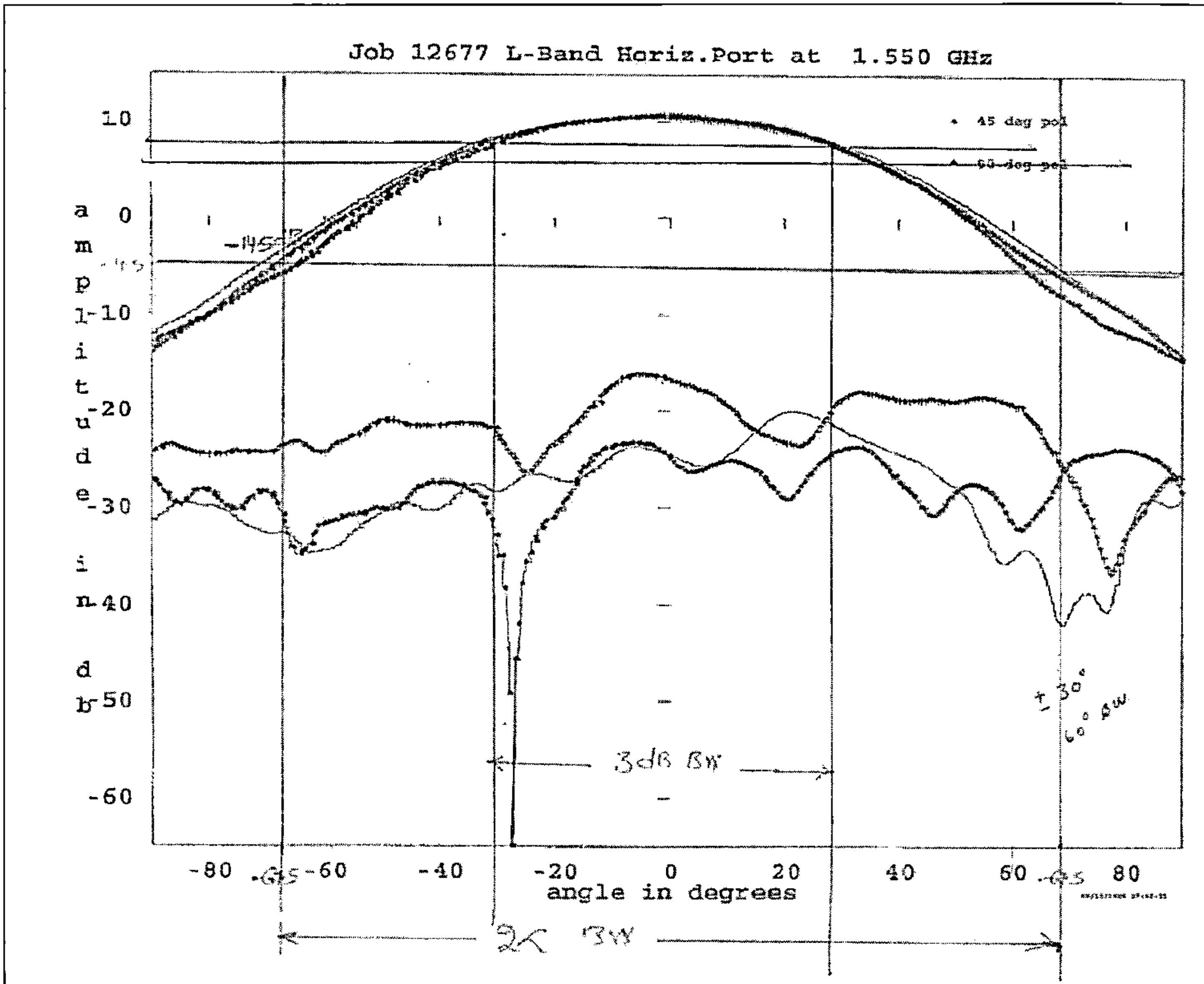
# Frequencies: 1.40 GHz, 1.55 GHz, 1.70 GHz

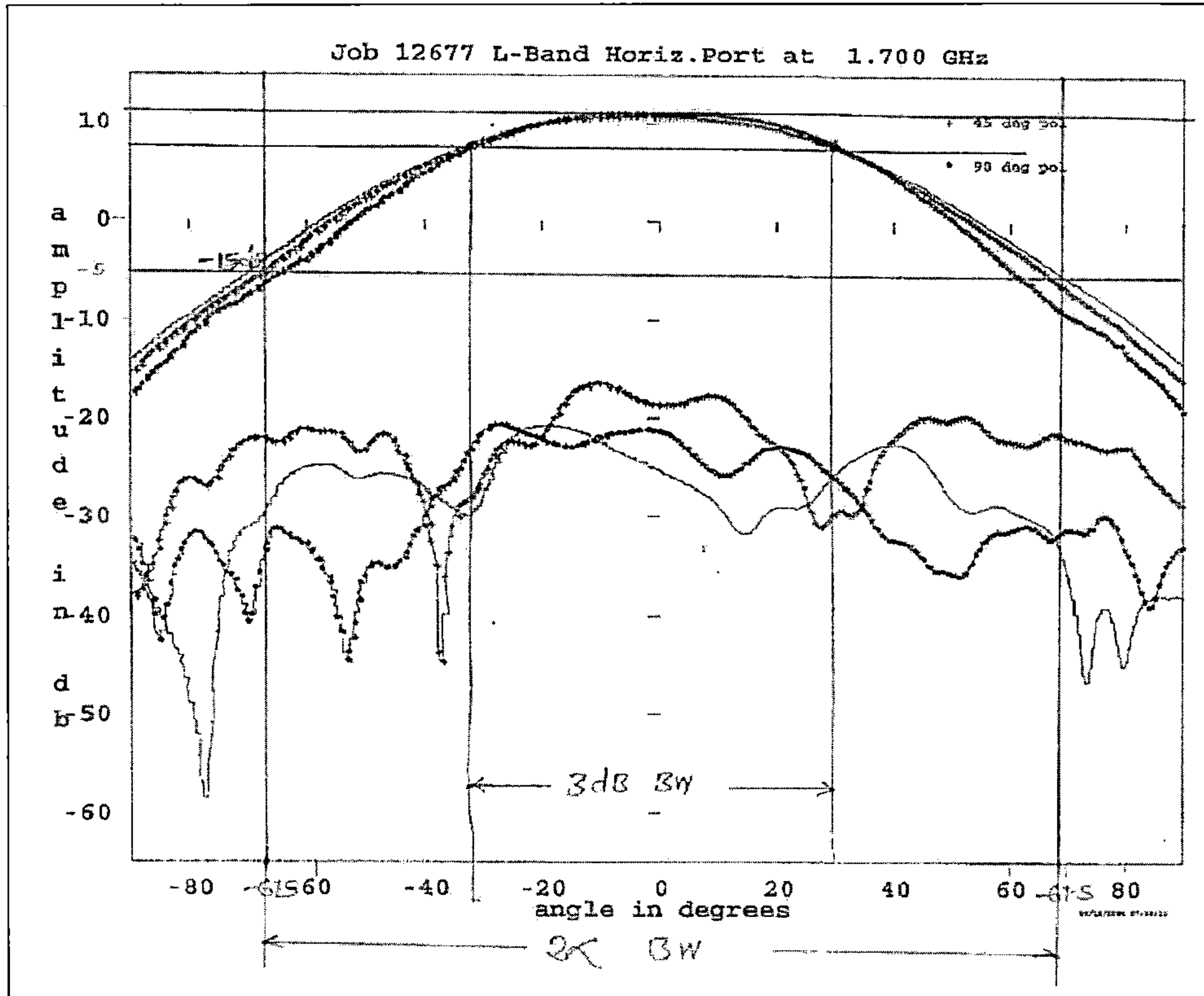

Job 12677 L-Band Vert.Port at 1.400 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
-13.75
-67.5
-70


Job 12677 L-Band Vert.Port at 1.550 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
-14dB
-61.5
67.5


Job 12677 L-Band Vert.Port at 1.700 GHz
+ 45 deg pol
* 90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-15
-5
-80
-60
-40
-20
0
20
40
60
80
angle in degrees


Job 12677 L-Band Horiz.Port at 1.400 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
50
-60
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
3d BW
2x BW
-67.5


Job 12677 L-Band Horiz.Port at 1.550 GHz
45 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
3dB BW


Job 12677 L-Band Horiz.Port at 1.700 GHz
+ 45 deg pol
• 90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
3dB BW

# APPENDIX B

## VERTEX

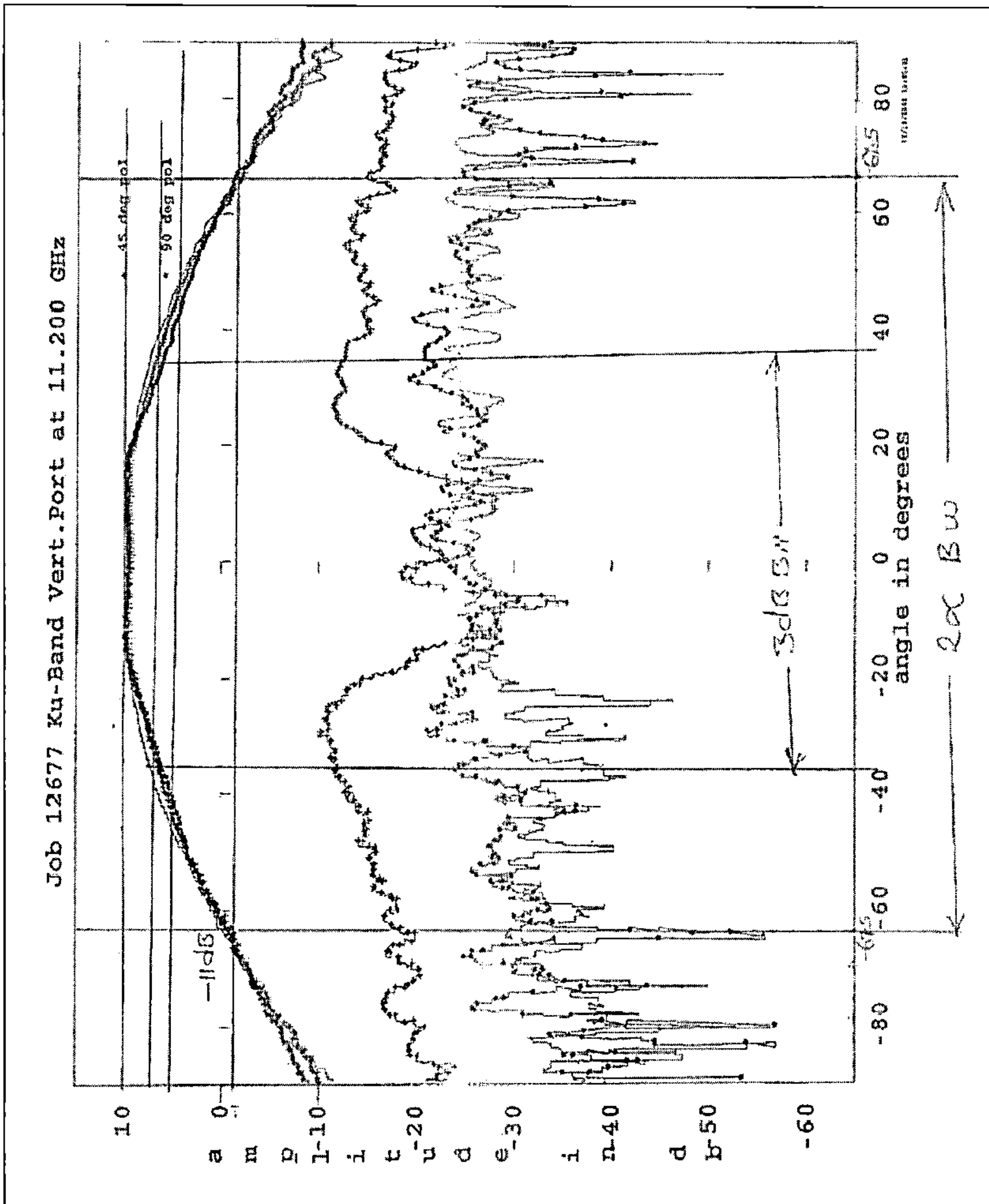
## Job 12677

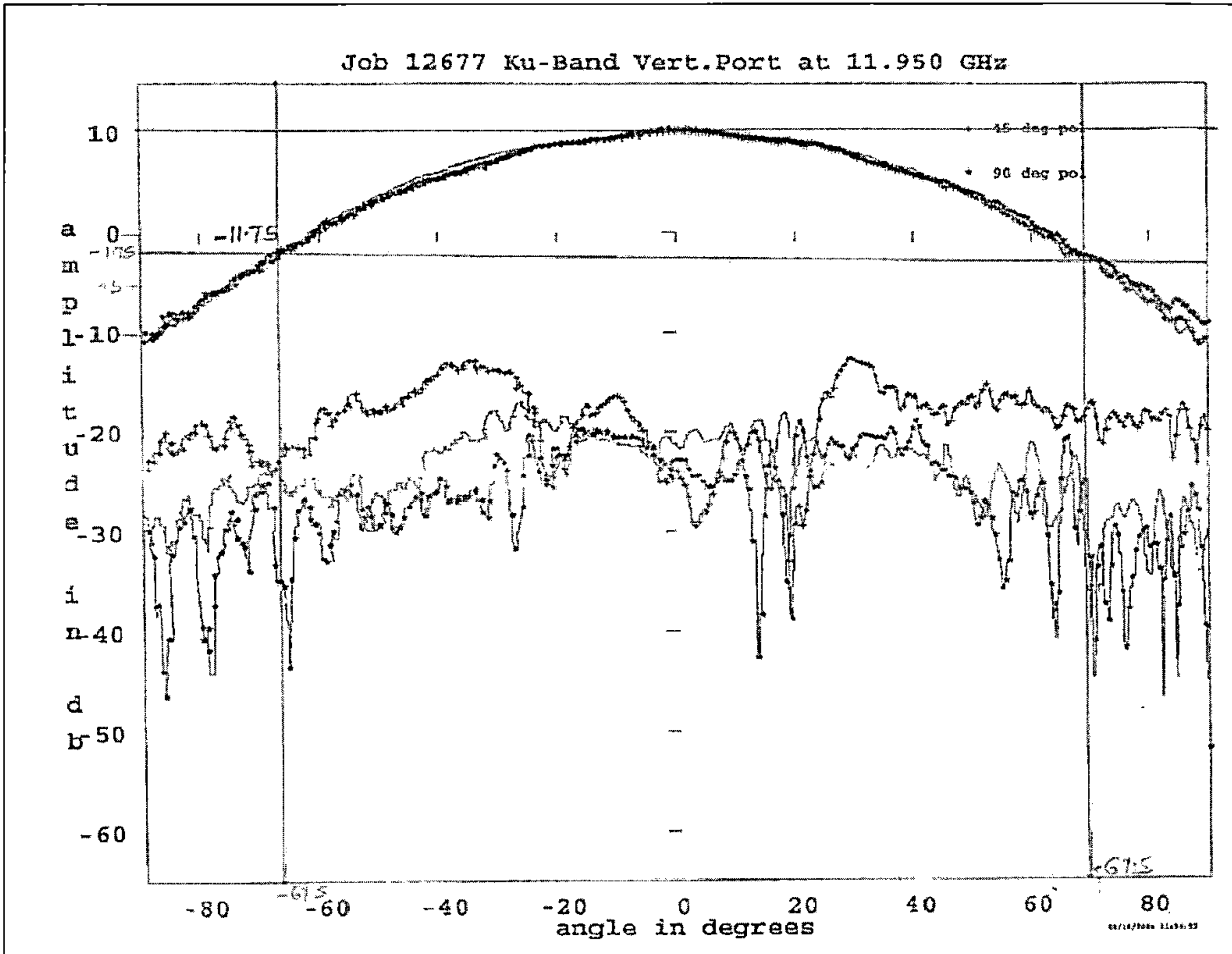
## Ku-Band In-Plant Test Data

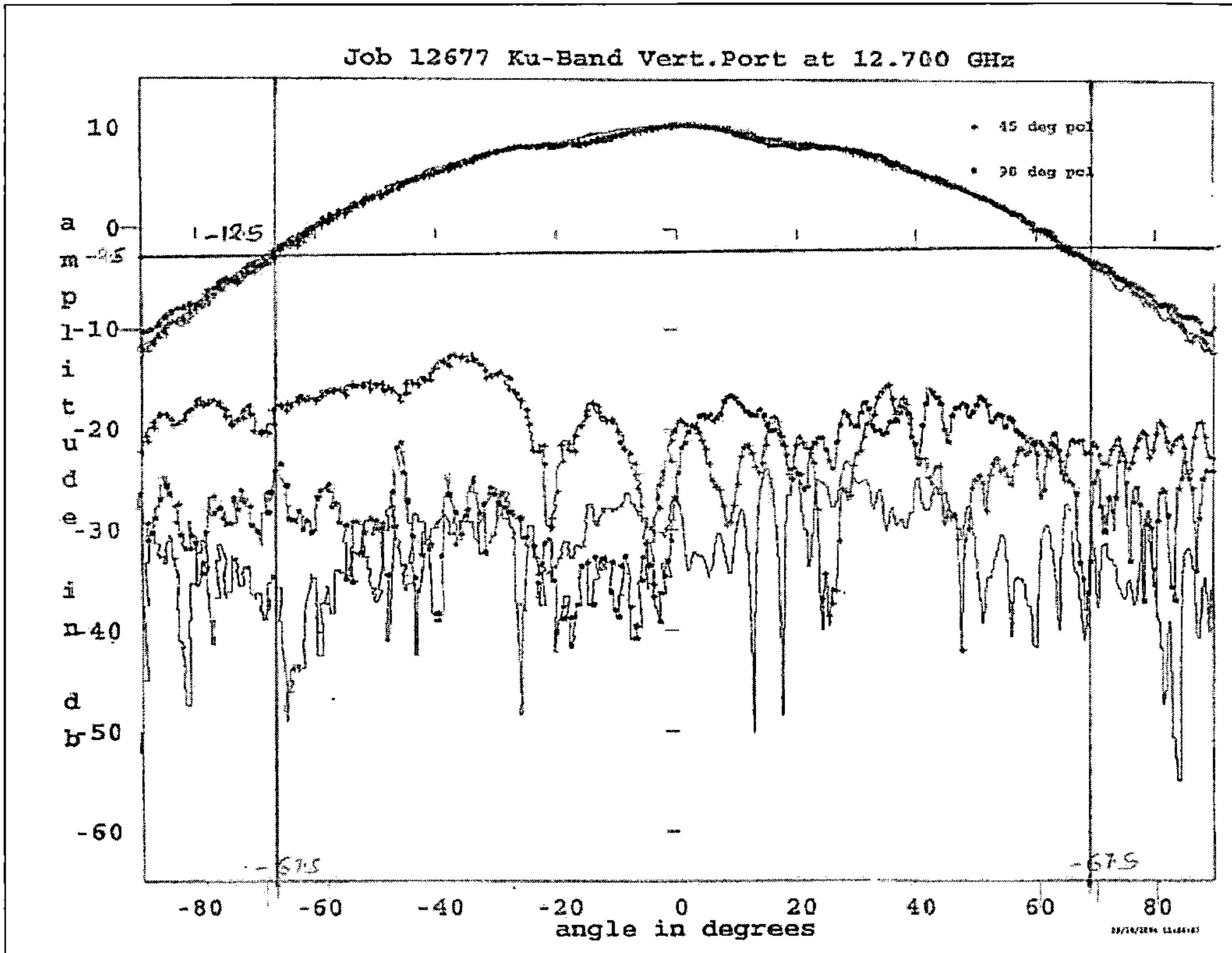
## 21 M, Morehead Space Tracking Antenna

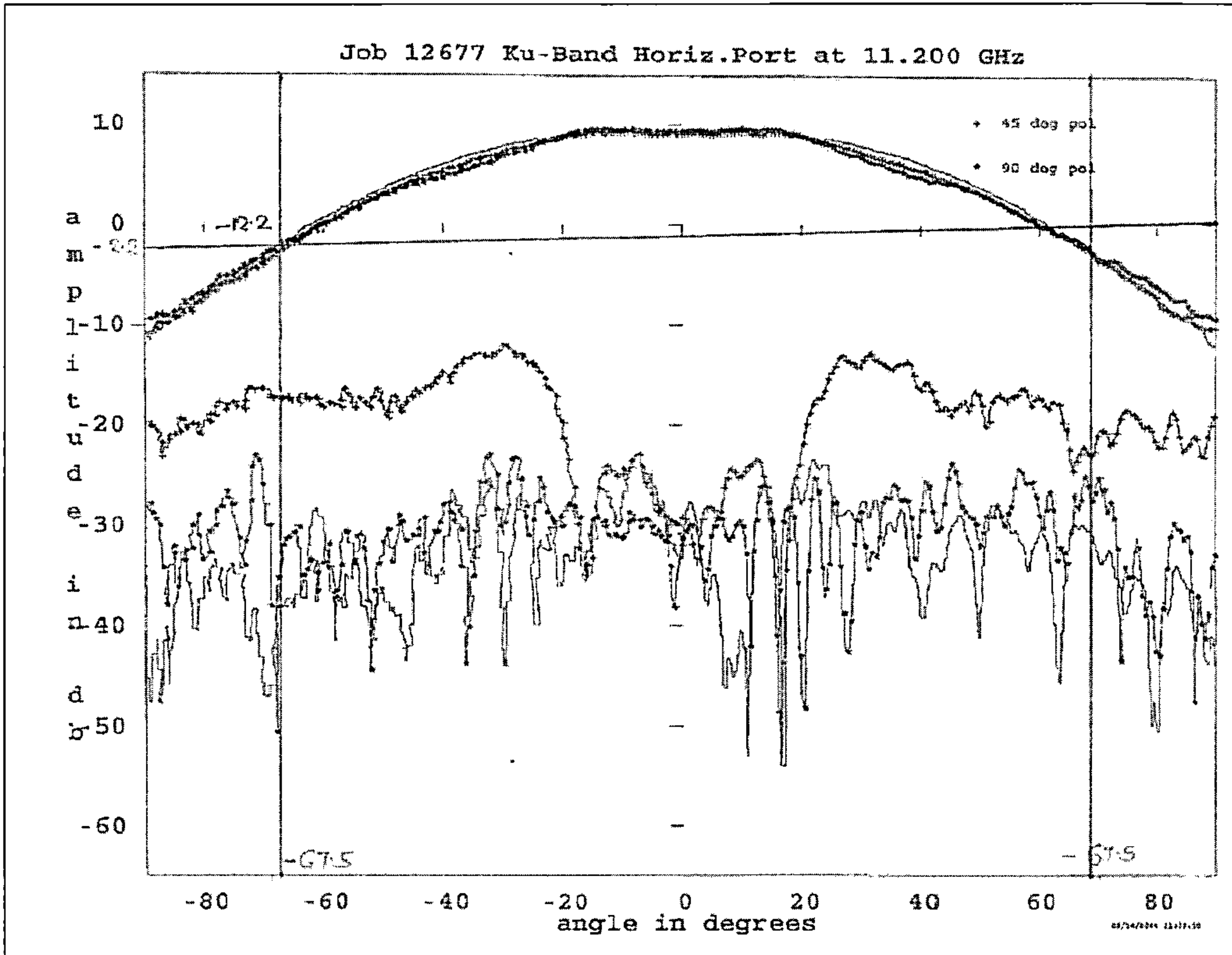
## Frequencies: 11.20GHz, 11.95GHz, 12.70GHz

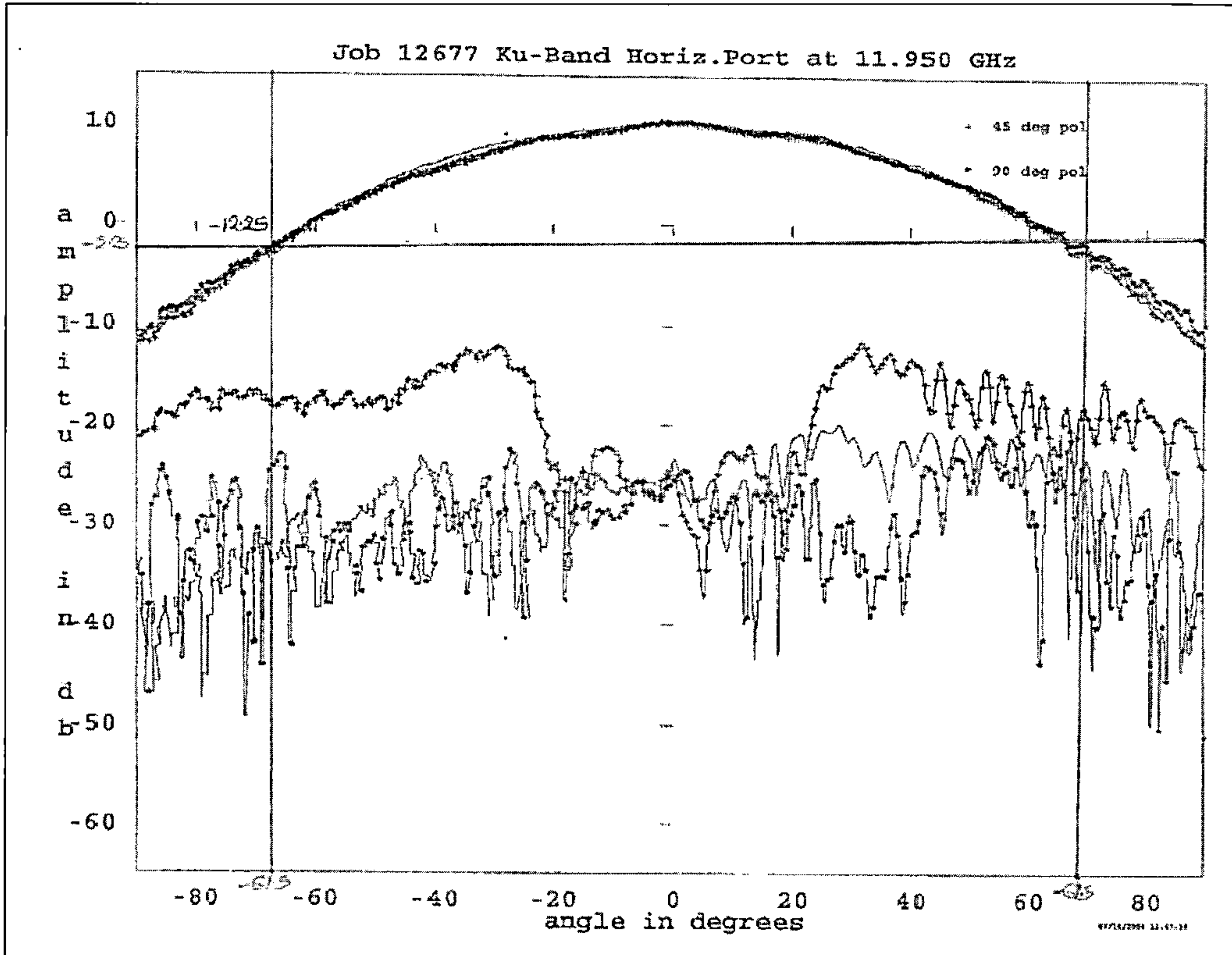
# APPENDIX B: Ku-Band In-Plant Test Data

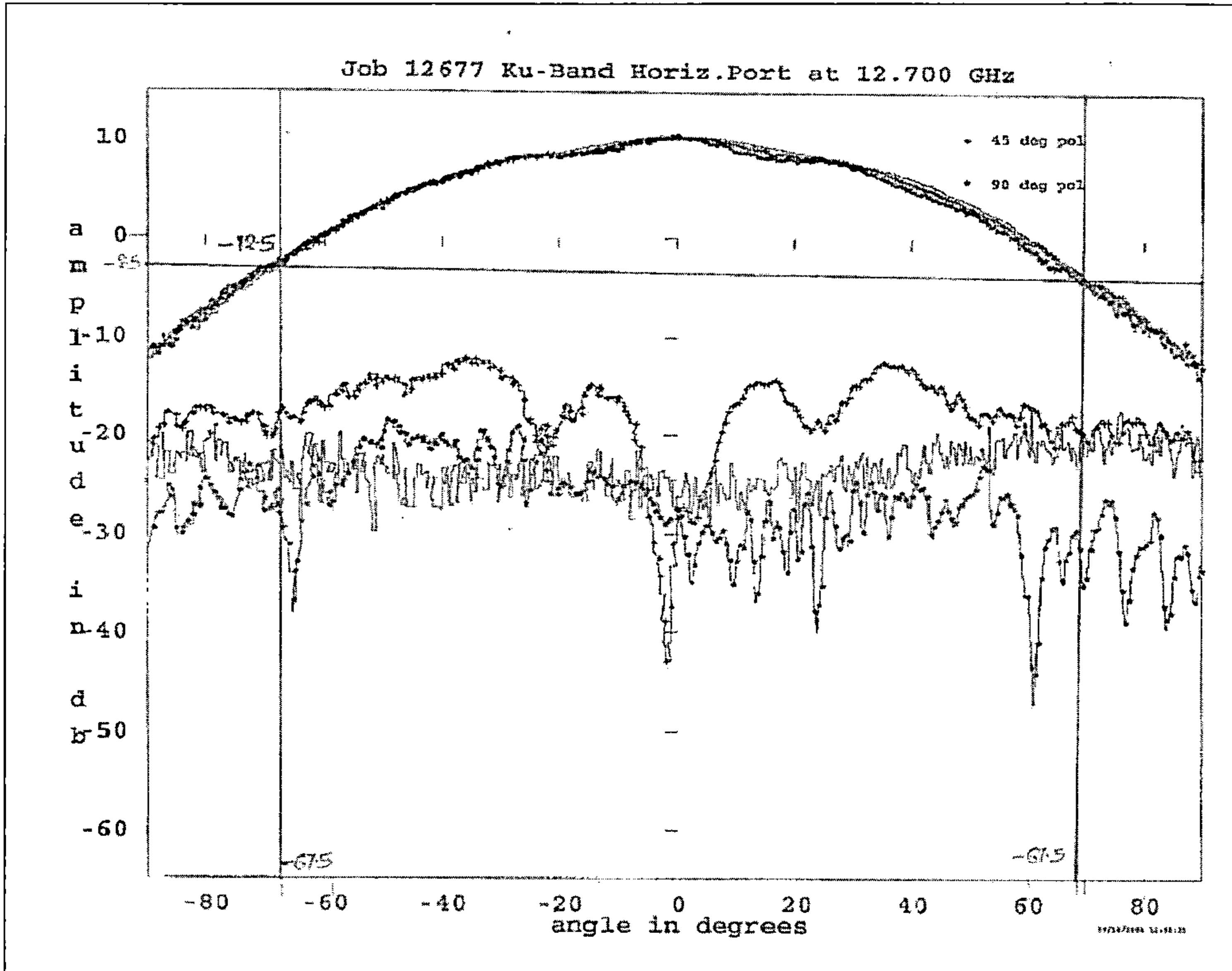



Job 12677 Ku-Band Vert.Port at 11.950 GHz
45 deg po
90 deg po
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-11.75
-80
-60
-40
-20
0
20
40
60
80
angle in degrees
-61.5
-61.5


Job 12677 Ku-Band Vert.Port at 12.700 GHz
amplitude in db
angle in degrees
45 deg pol
90 deg pol
10
0
-10
-20
-30
-40
-50
-60
-80
-60
-40
-20
0
20
40
60
80
-12.5
-9.5
-67.5
-67.5


Job 12677 Ku-Band Horiz.Port at 11.200 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-12.2
-67.5
67.5
-80
-60
-40
-20
0
20
40
60
80
angle in degrees


Job 12677 Ku-Band Horiz.Port at 11.950 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-12.25
-80
-60
-40
-20
0
20
40
60
80
angle in degrees


Job 12677 Ku-Band Horiz.Port at 12.700 GHz
45 deg pol
90 deg pol
amplitude in db
10
0
-10
-20
-30
-40
-50
-60
-12.5
-67.5
-67.5
-80
-60
-40
-20
0
20
40
60
80
angle in degrees

# APPENDIX C

# Description of Standard Gain Horn (Reference antenna)

# APPENDIX C: Description of Standard Gain Horn

## Antenna Measurement

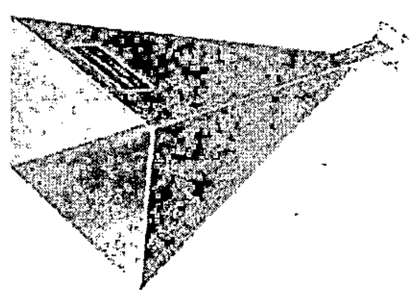
Antennas

## Series 12 Standard Gain Horn

Scientific-Atlanta manufactures a complete line of antennas, feeds, and accessories including gain standards, parabolic reflectors and feeds, log-periodic dipoles, rotary joints, and coax-to-waveguide adaptors.

These products are designed for use as source antennas and gain standards on test ranges and anechoic chambers. The source antennas are broad band units which feature interchangeable feeds which can be readily aligned for optimum results. The gain standards are calibrated for simple gain determination of experimental antennas.

### Standard Gain Horn Series 12



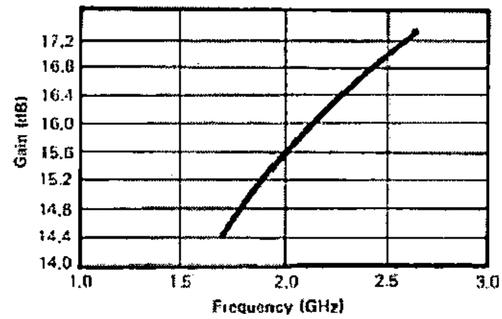
Series 12 Standard Gain Horns provide accurate and practical microwave antenna gain standards. The prime application of Series 12 Gain Horns is experimental gain determination of an antenna by the substitution method.

Several models of Standard Gain Horns are available to cover the frequency range from 0.35 to 90 GHz. Horn dimensions and calibration data are taken from NRL Report No. 4433. Gain versus frequency charts are supplied with each unit.

To prevent corrosion, all horns are plated prior to painting.

Mounting Flanges are available for all the Series 12 Standard Gain Horns.

**Scientific-Atlanta Standard Gain Horn Model 12-1.70**
**Frequency Range 1.70 - 2.60 GHz**




Calibration Data taken from NRL Report 4433

### Applications

Gain measurements with the standard gain horn and antenna under test are made by alternately connecting the two antennas to a matched receiver. Received power levels are equalized either with the precision IF attenuator in the wide range receiver, or with a precision variable RF attenuator. The Gain G, in decibels, of the antenna under test is

$$G = G_s + (A-A_s)$$

where $(A-A_s)$ is the decibel change in attenuation required to equalize the two received power levels and $G_s$ is the gain of the standard horn at the test frequency.*

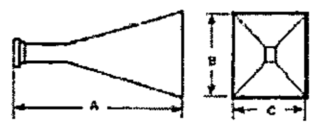
Two conditions are essential for accurate measurements: (1) The antenna being tested and the standard gain horn must be matched to the line, and (2) the gain of the standard above the gain of an isotropic radiator at the test frequency must be known.

*Gain Accuracy
Model 12-0.4 through Model 12-1.7
±0.5 dB
Model 12-2.6 through Model 12-60
±0.3 dB

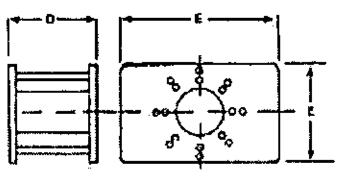
Antenna Measurement

Antennas

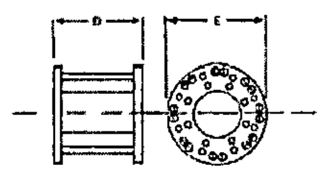
## Series 12 Standard Gain Horn



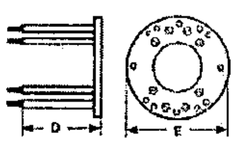
Model 12 Standard Gain Horn



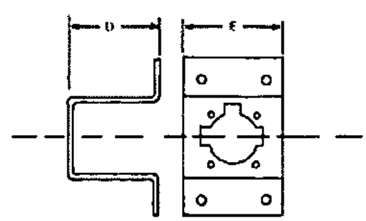
12F-0.4 and 12F-0.5 Mounting Flange



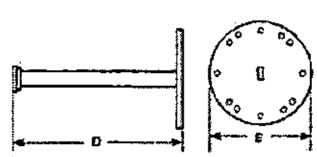
12F-0.75 Mounting Flange



lel 12F-0.9 to 12F-1.7 Mounting Flange



12FS-2.6 to 12FS-12 Mounting Flange



Model 12FA-18 to 12F-60 Mounting Flange

| TANDARD GAIN HORNS | | | | | | | MOUNTING FLANGES | | |
|---|---|---|---|---|---|---|---|---|---|
| Model Number | Freq Range (GHz) | Nominal Gain (dB) | Nominal Beamwidth (°) | | Weight lb (kg) | | Model Number | Weight lb (kg) | |
| | | | E-plane | H-plane | net | shipping | | net | shipping |
| 12-0.4 | 0.35 to 0.53 | 15.5 | 30 | 27 | 300(136) | 665(302) | 12F-0.4 | 27(13) | 60(27) |
| 12-0.5 | 0.49 to 0.75 | 15.5 | 30 | 27 | 180(82) | 403(183) | 12F-0.5 | 18(8) | 40(18) |
| 12-0.75 | 0.75 to 1.12 | 15.5 | 30 | 27 | 67(30) | 145(66) | 12F-0.75 | 12(6) | 27(13) |
| 12-0.9 | 0.95 to 1.15 | 13.7 | 40 | 35 | 25(11) | 50(23) | 12F-0.9 | 8(4) | 15(7) |
| 12-1.1 | 1.12 to 1.70 | 15.5 | 30 | 27 | 15(7) | 30(14) | 12F-1.1 | 3(2) | 6(3) |
| 12-1.7 | 1.70 to 2.60 | 15.5 | 30 | 27 | 8(4) | 15(7) | 12F-1.7 | 3(2) | 6(3) |
| 12-2.6 | 2.60 to 3.95 | 18.0 | 23 | 22 | 7(3) | 13(6) | 12FS-2.6 | 2(1) | 4(2) |
| 12-3.9 | 3.95 to 5.85 | 18.0 | 23 | 22 | 7(3) | 12(6) | 12FS-3.9 | 2(1) | 4(2) |
| 12-5.8 | 5.85 to 8.20 | 22.1 | 12 | 13 | 5(2) | 10(4) | 12FS-5.8 | 2(1) | 4(2) |
| 12-8.2 | 8.20 to 12.4 | 22.1 | 12 | 13 | 4(2) | 7(3) | 12FS-8.2 | 2(1) | 4(2) |

# Antenna Measurement

## Antennas

## Series 12 Standard Gain Horn

| | | Waveguide | | Cover Flange | | Dimensions Inches (cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model No. Suffix | Flange Material | Type | Internal Size in (cm) | Type or Equivalent | Geometry | A | B | C | D | E |
| −0.4 | aluminum | RG-291/U | 21.00 (53.3) x 10.50 (26.7) | * | rect. | 62.00 (157.5) | 73.03 (185.5) | 54.10 (137.4) | 16.0 (40.6) | 16.00 (40.6) x 25.00 (63.5) |
| −0.5 | aluminum | RG-202/U | 15.00 (38.1) x 7.50 (19.1) | * | rect. | 48.00 (121.9) | 48.25 (122.6) | 35.74 (98.0) | 13.0 (33.0) | 14.00 (35.6) x 19.00 (48.3) |
| −0.75 | aluminum | RG-204/U | 9.75 (24.8) x 4.88 (12.4) | * | rect. | 32.25 (81.9) | 32.57 (82.7) | 24.12 (61.3) | 9.75 (24.8) | 16 (40.6) |
| −0.9 | aluminum | RG-205/U | 7.70 (19.6) x 3.85 (9.8) | * | rect. | 23.23 (59.0) | 21.93 (55.7) | 16.25 (41.3) | 7.38 (18.8) | 12 (30.5) |
| −1.1 | aluminum | RG-103/U | 6.50 (16.5) x 3.25 (8.3) | UG-418B/U | rect. | 21.70 (55.1) | 21.93 (55.7) | 16.25 (41.3) | 6.12 (15.5) | 10 (25.4) |
| −1.7 | aluminum | RG-105/U | 4.30 (10.9) x 2.15 (5.5) | UG-437B/U | rect. | 14.43 (36.7) | 14.51 (36.9) | 10.75 (27.3) | 4.88 (12.4) | 8 (20.3) |
| −2.6 | aluminum | RG-76/U | 2.84 (7.2) x 1.34 (3.4) | UG-584/U | rd. | 16.65 (42.3) | 12.76 (32.4) | 9.45 (24.0) | 4.50 (11.4) | 8 (20.3) |
| −3.9 | aluminum | RG-95/U | 1.87 (4.7) x 0.87 (2.2) | UG-407/U | rd. | 12.14 (30.8) | 8.51 (21.6) | 6.30 (16.0) | 12 (30.5) | 4 (10.2) |
| −5.8 | aluminum | RG-106/U | 1.37 (3.5) x 0.62 (1.6) | UG-441/U | rd. | 20.00 (50.8) | 11.30 (28.9) | 8.42 (21.4) | 11.0 (29.4) | 4 (10.2) |
| −8.2 | aluminum | RG-67/U | 0.90 (2.3) x 0.40 (1.0) | UG-135/U | sq. | 14.00 (35.6) | 7.65 (19.4) | 5.67 (14.4) | 8 (20.3) | 4 (10.2) |
| −12 | aluminum | RG-349/U | 0.62 (1.6) x 0.31 (0.8) | UG-1665/U | sq. | 14.00 (35.6) | 5.98 (15.2) | 4.91 (12.5) | 6 (15.2) | 4 (10.2) |
| A-18 | brass | RG-53/U | 0.42 (1.1) x 0.17 (0.4) | UG-595/U | sq. | 10.65 (27.1) | 4.00 (10.2) | 3.28 (8.3) | 16.50 (41.9) | 8 (20.3) |
| A-26 | brass | RG-** 96/U | 0.28 (0.7) x 0.14 (0.4) | UG-** 599/U | sq. | 6.82 (17.3) | 2.72 (6.9) | 2.23 (5.7) | 16.50 (41.9) | 8 (20.3) |
| −33 | brass | RG-** 97/U | 0.22 (0.6) x 0.11 (0.3) | UG-** 383/U | rd. | 5.77 (14.7) | 2.18 (5.5) | 1.79 (4.5) | 16.50 (41.9) | 8 (20.3) |
| −50 | brass | RG-** 98/U | 0.15 (0.4) x 0.07 (0.2) | UG-** 385/U | rd. | 3.85 (9.8) | 1.45 (3.7) | 1.19 (3.0) | 16.50 (41.9) | 8 (20.3) |
| −60 | brass | RG-** 99/U | 0.12 (0.3) x 0.06 (0.2) | UG-** 387/U | rd. | 3.21 (8.2) | 1.21 (3.1) | 0.99 (2.5) | 16.50 (41.9) | 8 (20.3) |

*Does not have preferred military designation, but is compatible with mating Series 11 Coax-to-Waveguide Adapter

**Waveguide Dimensions per Jan. spec. but brass instead of silver.

# APPENDIX D

## Description of Chaparral Style

## APPENDIX D: Description of Chaparral Style

### Description

CHAPARRAL COMMUNICATIONS

The Chaparral Dual Feed horn is an orthomode transducer for simultaneous reception of horizontal and vertical C-Band polarities. Due to its reliable performance with virtually no signal loss, Chaparral's Dual Feed is the most trusted feed horn for commercial applications.

### Applications

- SMATV
- Cable TV operators
- Multiple receiver systems
- Commercial satellite systems

### Features

- 100% tested
- Adjustable scalar ring
- Cast-in f/D gauge
- Mounts to all standard satellite dishes
- Cast aluminum construction
- Chip-resistant polyurethane powder coating
- Two-year warranty
- Made in the USA

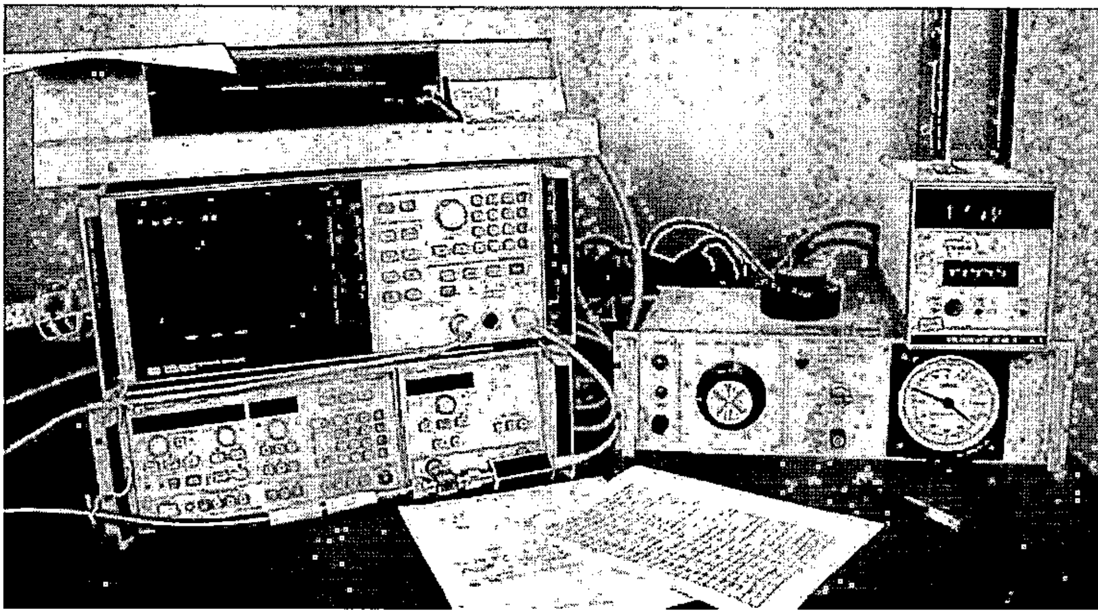
### Specifications

| | |
|---|---|
| Part Number | 11-1329-1 |
| Frequency Range | 3.7-4.2 GHz |
| VSWR | 1.5:1 Max |
| f/D Range | .33 to .45 |
| Cross Pol. Isolation | 35 dB Min |
| Output Ports WR | 229 Compatible |
| Temperature Range | -40° C to +60° C |
| Size | 8.0" x 6.5" x 5.0" |
| Weight | 2.23 lbs. |

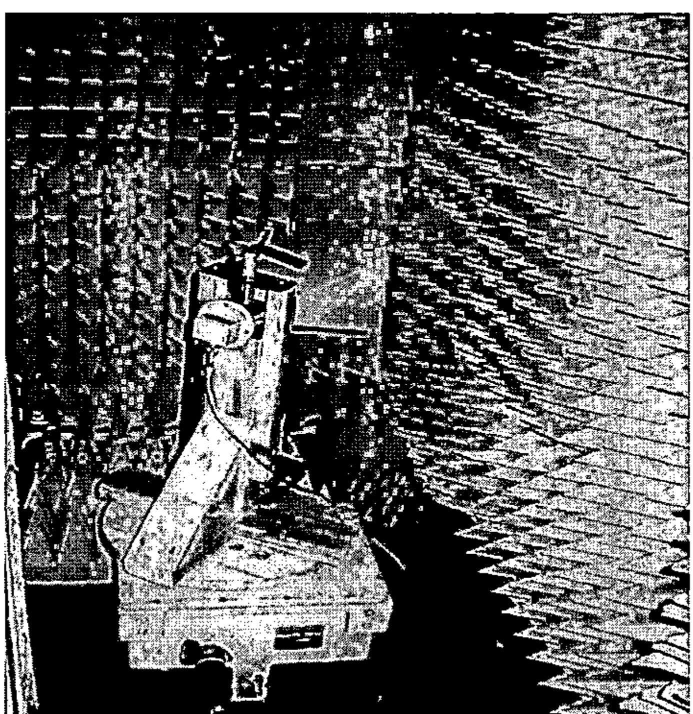
# APPENDIX E

# Test Equipment Photos

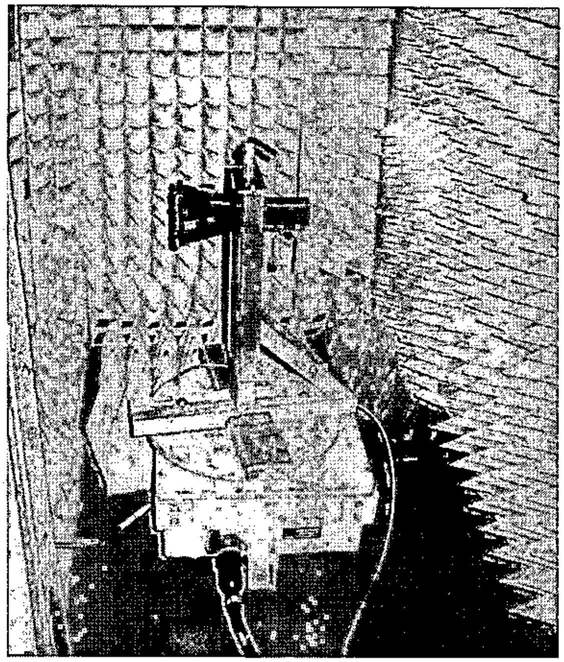
## APPENDIX D: Test Equipment Photos



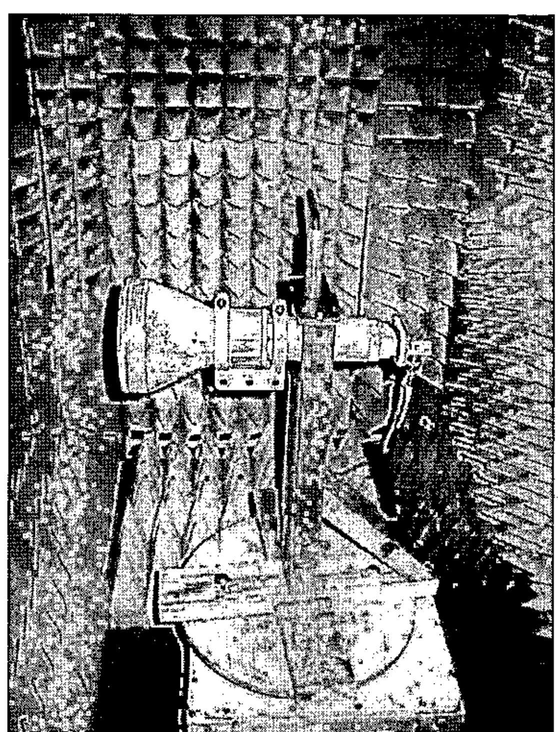
Equipment Setup for Anechoic Chamber Test



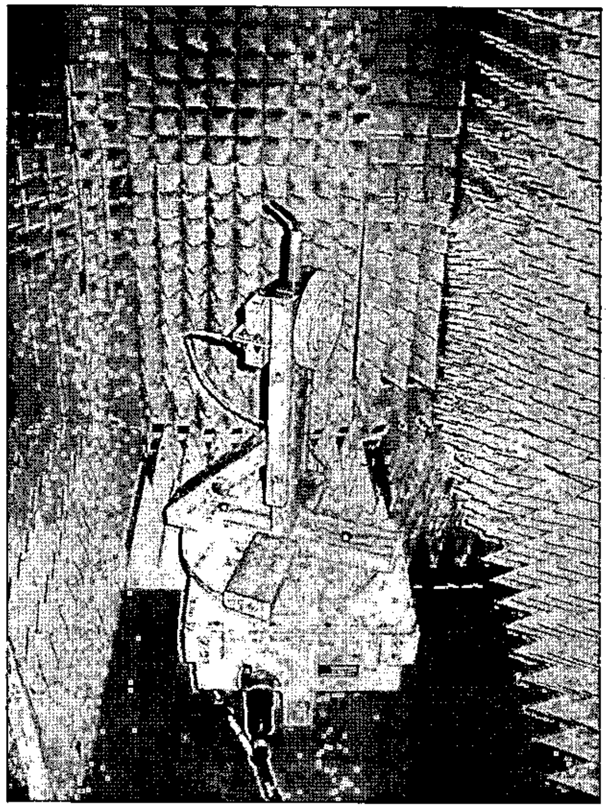
Scientific Atlanta Standard Gain Horn under Anechoic Chamber Test



Square Green Rectangular Military Horn under Chamber Test



Equatorial Antenna under Chamber Test



Chaparral Style Antenna under Chamber Test

The Researcher Recording the Data from Anechoic Chamber