

## **EVLA Memo No. 89**

# **The EVLA Outdoor Antenna Test Range Project: Fourth Quarter 2004, Progress Report**

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### **Abstract**

The EVLA will require a reliable quality assurance program for testing the numerous antenna feeds that will be fabricated over the duration of the project. An integral component of this test plan is an Outdoor Antenna Test Range (OATR). This report describes the accomplishments and problems encountered in the development of the OATR during the last quarter of 2004. Proof of concept test results and budgetary information are also provided.

### **Introduction**

The EVLA project represents many complex engineering challenges coupled with budgetary limits that push the design envelope to new extremes. One particular task is to implement a Quality Assurance Program (QA) to monitor the manufacturing of corrugated feed horns by various internal and external production facilities. Two plans were simultaneously developed; the first was to send a statistical sampling of the new feed horns to an outside testing facility. The radiation pattern and VSWR data taken would be the core mechanism of the QA program. The second plan involved the same technique in data acquisition except the testing would be performed locally at a new NRAO facility.

The plan to use an external testing center proved to be impractical. The shipping costs and testing fees incurred during the EVLA program could approach the range of \$100,000. Whereas building and maintaining a test facility locally would cost a fraction of the external testing plan. It would also allow for the quick testing cycle of a few days versus a few weeks. Therefore, building a test range locally became the more viable option.

In this update, the building phase of the OATR is characterized by identifying the budget and by describing specific topics of interest. Detailed subjects include; the development of a flexible software package, the physical properties of the range, and the testing environment for the Antenna Under Test (AUT). Proof of concept tests are shown and the results of identifying and correcting problems encountered are presented by example.

## The Budget

With a limited budget, building an antenna range capable of producing accurate and repeatable data comparable to that generated by a commercial facility is a non-trivial task. Brand new test equipment can easily drain a small budget and prevent the project from becoming operational. However, extensive research into vendors selling liquidated equipment and having access to government surplus has been advantageous to this project.

Tables I and II represent a breakdown of actual versus estimated costs in constructing an antenna test range. The items listed are described as either already purchased (actual costs) or items still required (future costs). The third column is an estimated cost breakdown of new equipment. The involvement of New Mexico Tech (NMT) in constructing the final location will offset the costs substantially as indicated by the blue highlighted items.

Antenna range Costs Comparison					
Shipping/Testing Costs @ External Testing Facility (Estimate)	Total Projected Costs if new range equipment were purchased	Total Material and Equipment costs (to date) for building test range:	Funds required to complete project	Total NRAO Costs (estimate) without NMT involvement	Total NRAO Costs (estimate) with NMT involvement
\$93,000	\$149,510	\$13,629	\$11,940	\$25,569	\$18,729

**Table I. Cost comparison of building a functional antenna range with/without NMT involvement versus a cost estimation if new equipment was purchased.**

NRAO Antenna Range Cost Breakdown				
Item Description	Estimated	Actual Costs	Future Costs	Notes
Azimuth Positioner	\$20,000	\$6,200		Commercial Surplus
Source Positioner	\$10,000	\$0		Govt. Surplus
Receiver, Phase/Amplitude (HP 8510B)	\$80,000	\$0		Govt. Surplus
Source Generator (HP 8340A)	\$10,000	\$0		Govt. Surplus
Laptop Computer	\$2,500	\$1,218		Shared costs with EM Chamber
Positioner Controller	\$5,000	\$2,760		Commercial Vendor
Optical Encoders	\$2,500	\$1,541		Commercial Vendor
Foam Tower Material (Azimuth Tower)	\$600	\$500		Commercial Vendor
Source Tower, adjustable	\$2,000	\$0		VLA Surplus
Optical Fiber HP1B Bus Extender (x2)	\$600	\$500		Commercial Vendor
Krytar 10dB Directional Coupler	\$510	\$510		Commercial Vendor
2 - 18GHz Standard Gain Horn (Pairs)	\$2,500	\$0		Semi-permanent Loan
Rotary Joint, DC - 26.5GHz, Weatherized	\$1,000	\$400	\$400	1 purchased, 1 future
Azimuth Tower Support Structure	\$1500		\$1500	Dependant on final design
Scalar Network Analyzer Extension Cables	\$500		\$500	For Polarization Measurements
Source Positioner Optical Encoder	\$1,500		\$1,500	Remote positioning control
Laser Level System (Mechanical Alignment)	\$250		\$250	Two beam system (carpentry)
Ladder, Articulating, 17' A-Frame	\$950		\$950	Vendor search underway
Site preparation	\$2,500		\$2,500	Ground leveling / utilities
Storage Shed, 8' x 14' (Tuff Shed)	\$2,500		\$1,740	Basic Kit, Accessories extra
Concrete Pad 4' x 4' (x2)	\$600		\$600	\$86/cu.yard with anchors
Power, Electrical (For storage shed/equip)	\$2,000		\$2,000	50amp Service with two 25amp outlets.
	\$149,510	\$13,629	\$11,940	

**Table II. An itemized list of the costs in building the OATR. Identifying the distinction between actual costs versus an estimation of the costs if purchasing brand new equipment.**

There is a significant difference in what has been spent to date compared to building a brand new test range from scratch ("Estimated" Column). Furthermore this breakdown identifies the differential costs of building and operating an internal testing platform versus the utilization of an external testing facility.

## OATR Requirements

To perform the function of QA, the test range must adhere to a well-defined set of requirements. The functionality is driven by the design parameters of the EVLA feed horns. Tables III and IV represent the requirements necessary for the antenna range and the progress in reaching these goals.

**Primary Antenna Range Requirements Summary**

Req. ID	Requirement Description	Requirement	Goals
	System Automation	Manual	Computer Controlled
1	Tunable Frequency Range	1 to 8 GHz	1 to 12 GHz min.
2	Receiver Type	Scalar (amp)	Vector (amp & phase)
3	Amplitude Accuracy	< 1 dB	< 1 dB
4	Phase Accuracy	n/a	TBD
5	Sensitivity (1 KHz BW)	< 60 dBm	< 60 dBm
6	Source Output Power	< +10 dBm	< +10 dBm
7	Nominal Tx Beamwidth	~ 40 deg.	~ 40 deg.
8	Nominal Tx Gain	>12 dBi	>12 dBi
9	Range Type	Elevated (10 ft)	Elevated (22 ft.)
10	Range Length (R)	22 ft (fixed)	Up to 200 ft (variable)
11	Clutter Free Range	> (3*R)^2 sq. ft	> (3*R)^2 sq. ft
12	AUT Vertical Load	1000 lbs.	1000 lbs.
13	AUT Moment	1000 ft. lbs.	1000 ft. lbs.
14	Angular Accuracy	< 0.1 deg.	< 0.1 deg.
15	Location	See detailed req.	See detailed req.
16	Logistics	See detailed req.	See detailed req.

**Table III. Established Requirements.**<sup>1</sup>

Req. ID	Requirement Description	Status of reaching Goals	Current Capabilities
	System Automation	<b>Complete</b>	Computer Controlled
1	Tunable Frequency Range	<b>Exceeded</b>	45MHz to 26 GHz Possible
2	Receiver Type	<b>Complete</b>	Vector (HP8510B)
3	Amplitude Accuracy	In Progress	Initial results <1dBm with response calibration. Testing in progress.
4	Phase Accuracy	In Progress	Has not been tested
5	Sensitivity (1 KHz BW)	In Progress	Testing in progress. Location Dependant Item.
6	Source Output Power	<b>Complete</b>	Stable output at various levels
7	Nominal Tx Beamwidth	In Progress	New Horn Antennas require testing
8	Nominal Tx Gain	<b>Complete</b>	11.5 to 17 dBi typical for Gain Horns
9	Range Type	In Progress	See Req. ID # 15
10	Range Length (R)	<b>Complete</b>	Established 22ft Separation
11	Clutter Free Range	In Progress	See Req. ID # 15
12	AUT Vertical Load	<b>Exceeded</b>	Greater than 1100lbs achieved with High Density Foam Column Tower.
13	AUT Moment	<b>Complete</b>	1000lbs
14	Angular Accuracy	In Progress	See Req. ID # 15
15	Location	In Progress	Final location TBD
16	Logistics	In Progress	See Req. ID # 15

**Table IV. Status of OATR goals.**

## Achievements

The project has entered a rudimentary testing phase with simple construction materials. This setup is very limited in simulating the final range configuration. For example, the towers for supporting the AUT and source have been constructed with Sono-tube™ and wood as displayed in figure 1. These towers are very susceptible to wind and mechanical vibration. The actual tower design will use a more rigid foam material capable of supporting ~1700lbs as seen in figure 2.

Despite the fundamental flaws with using this setup, success in reaching many of the established requirements has been achieved. These are summarized below:

- A computer-controlled interface has been created using MATLAB® v7.0 as the programming environment. MATLAB was chosen over other data acquisition software packages for several reasons:
  - a) The ease of scripting the code (similar to the C programming language).
  - b) Proprietary hardware drivers not required. Other DAQ programs, LabVIEW™ for example, has limitations regarding the type and brand name of equipment available to interface with.
  - c) Built in algorithm and graphing libraries.
- A tunable frequency range from 45MHz to 26.5GHz with amplitude and phase information has been established using a HP8510B S-Parameter test set and a HP8340A Synthesized Sweeper (Source).
- Output power levels of the source generator have been tested at 0 and -10dBm with similar results. Further testing will be done to identify the affects that different output levels have on dynamic range and sensitivity with respect to cable and component losses not accounted for using the response calibration.
- The recent acquisition of standard gain horns covering the 2 - 18GHz spectrum, with nominal gains ranging from 10 to 20dBi, will allow for future testing capability above the 12GHz threshold. Although the current plan does not stipulate any testing below 1GHz or above 12GHz, future initiatives for such testing can be accommodated with minimal modification.
- Range separation is Twenty-Two feet. NMT's involvement in providing a final site for the range, could allow for several other separation baselines. This is with the understanding that NMT would utilize the range for an independent curriculum.
- The vertical loading capacity for the Azimuth Tower was increased from 1100lbs to ~1700lbs by employing a higher density foam material. This is to satisfy a safety concern regarding the catastrophic compression threshold of the foam material. This would also accommodate any changes to the weight of the L-Band Feed Horn, should the current design be modified.

<p><b>Note: Tests with the higher density foam column have not been performed. Testing with this tower configuration is not practical until a final site is chosen. Therefore, RF properties attributed to this material have yet to be characterized.</b></p>
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- The higher density of the foam column also satisfies the AUT Moment of 1000lbs. Since the feed horn's center of gravity is the desired reference point for mounting on top of the foam tower, the AUT moment should be equally distributed.

## Goals

The limitations of the current test setup are identified by the requirements that still need to be addressed. These items have a synergistic relationship with each other. Once a permanent location is established, most issues concerning the functionality of the OATR will be resolved at an accelerated rate.

## Location

This is a critical factor. Final testing and characterization of the range will be on hold until a permanent location is established. The current location being used for the initial testing is behind the Shipping/Receiving Dock at the AOC. It is not clutter free! The AOC building and concrete wall surfaces do not generate ideal conditions for an outdoor test range. The four fundamental requirements to establish a permanent location are:

- An area encompassing three times the baseline separation in radius.
- A 4ft x 4ft concrete pad with the means to properly anchor the azimuth positioner. See figure 3 for a conceptual drawing of the pad design.
- A means to provide power to the equipment (50amp Single Phase 110VAC service with 2 breaker service nodes of 25amps each)
- Accessibility for a mobile crane (capable of lifting a 17ft tall, 1500lbs load at least 10ft above ground level) to assist in the assembly and disassembly of the AUT tower.

With respect to these requirements, two sites have been identified: (1) The VLA and (2) At the NMT Campus (near the Etscorn Observatory). A comparison of advantages and disadvantages are indicated in Table V.

		Pros	Cons
VLA SITE	1	RF Quiet zone	Limited Time for usage. Maintenance days only, with restrictions imposed!
	2	Heavy Equipment Support (Crane and Crew)	Weather is a prominent factor! VLA Site is open space, more frequent weather changes possible.
	3	Close proximity to EVLA work	VSWR Testing is currently performed at the AAB. Also restricted to Maintenance Days.
NMT Campus	1	No restrictions for radiating RF! A more reasonable dynamic scheduling environment exists.	Must rely on NMT for Heavy Equipment Logistics.
	2	Better wind protection provided by "M" Mountain!	Possible RFI Environment from "M" Mountain Antenna Farm. (Although non-coherent signal rejection is very good with the HP8510B Phase Lock)
	3	VSWR Testing can be done at same location	Extra logistics is required in transporting feed horn to/from the VLA Site.

Table V. Pros and Cons for the two possible sites.

Both sites have good arguments towards the positive. However, the non-restrictive scheduling that the NMT Campus would provide is more feasible when considering the budget and the data acquisition environment. Scheduling conflicts at the VLA Site have already produced additional costs in man-hours while testing new EVLA feed horns.

A specific example is given; the acquisition of VSWR data for an EVLA feed horn was plagued with logistical conflicts the day the testing was to be conducted. When the issues were finally resolved, the actual testing was restricted by VLA

Operations to a twenty minute window due to an upcoming observation in the same frequency band. This generated an undesirable testing environment by rushing the scheduled tests. The validity of the measured data was compromised and the tests had to be conducted again two days later. This particular scenario should be considered an isolated incident due to its occurrence in the early stages of EVLA production. However, the possibility of similar conflicts reoccurring cannot be ruled out.

Configuring the range to generate reliable and repeatable data requires meticulous attention to detail and patience. Conducting tests in a hurried manor will generate questionable results. It is understood that logistical issues could hamper scheduled operations no matter what site is used. The proposed NMT site could effectively reduce the number of these conflicts, ultimately providing a safer and more flexible testing environment.

An antenna test range is hazardous by nature. Working in a rushed environment can produce a haphazard test setup, which can expose the equipment and personnel to a potentially dangerous situation. There is no room for error. All persons involved in the setup and/or testing on the antenna range will be properly trained and qualified prior to gaining access to the area. Safety is paramount! Strict safety guidelines will be in place and no exceptions will be allowed.

### **Clutter Free Range**

The goal is to have a clutter free test range with a perimeter three time the baseline separation:  $22\text{ft} \times 3 = 66\text{ft}$  radius. A good argument supporting this is provided in Figure 4. A test with 64 integrations, no time gating and an angular resolution of  $0.5\text{deg}$  was in progress, when a FEDEX delivery truck arrived at the shipping/receiving dock. The location of the vehicle produced a  $\sim 10\text{dB}$  artifact in the side-lobe energy when the AUT was pointing directly at the intruder. This artifact was present in two of the eleven frequencies being measured. Other effects to the measured data can be seen as well.

### **Amplitude Accuracy**

Initial results show repeatable measurement accuracy below  $1\text{dBm}$  (Normalized). The tests performed to date have focused mainly on radiation pattern issues including the identification and removal of specular and transient reflections from the testing environment. The only calibration type currently available for the antenna range is called a "response" calibration. This is essentially the signal path frequency response error correction. The HP8510 Operations and Programming Manual (OPM) recommends a "Full 2-Port" calibration in-order-to provide the best magnitude and phase measurement accuracy.<sup>2</sup> Further investigation is needed to identify whether or not a full 2-port calibration routine can be implemented.

### **Phase Accuracy**

There are very few commercial testing facilities capable of measuring phase with less than one degree of error in both accuracy and repeatability. That list is reduced even further when considering the facilities that can achieve  $0.5\text{deg}$  or better. The level of phase accuracy achieved on an antenna range depends on how well the testing environment is characterized and the calibration techniques employed by the persons conducting the test. Before the phase accuracy can be determined for the OATR, several tasks require completion:

- A permanent location established.
- Integrate a "Full 2-Port Calibration" including a precision calibration kit.
- Integrate a rotary joint on the Source Positioner. Polarization setting accuracy and phase stability with respect to cable movement at the source can be improved with the use of a rotary joint.

- Investigate the phase characteristics of all components involved. Including all coaxial adapters and cables used in the setup.
- Accurate mechanical alignment and characterization of the test setup.

A coaxial rotary joint has been installed at the Azimuth Positioner to remove errors associated with cable movement. The initial test setup used a "cable wrap" technique at the AUT. As the antenna rotated, a portion of the cable would circumnavigate the tower. With the rotary joint in place, the resulting radiation pattern data shows an improvement in amplitude repeatability. It can be postulated that repeatability in phase has improved as well. Testing and refining the level of phase accuracy will be directly associated with the improvements identified here.

### **Boresight Accuracy**

Integrated into the software is a function to locate the electrical boresight of the AUT in the azimuth plane. This is accomplished by measuring either the co-polarization peak-of-beam or the cross-polarization null if located at zenith. The attempts to measure boresight accuracy have been hindered by several issues. The current setup is very susceptible to wind. Both the source and AUT towers oscillate in the slightest breeze, which warrants concern regarding the repeatability of the measured data. Another concern is the cross-polarization isolation (linearity) of our current source antenna, a 1 - 10GHz double-ridged pyramidal horn.

The data in figure 5 portrays the measured radiation pattern peak-of-beams for eleven frequencies. Changing the time gating and data integration affects the measured data. For comparison, the "O" symbol represents a "worst case" scenario. This was one of the first attempts to identify the boresight accuracy. The most recent experiment is represented by the diamond symbols. This boresight test was done with time gating and 64 integrations, which identifies the best-case scenario to date. The current level of accuracy does not satisfy the established requirement of less than one degree. Further investigation and refinement of this routine will be performed after the final test location is established.

### **Sensitivity**

Sensitivity can be approached two ways: Theoretical and Real World. In theory, the HP8510B has the ability to reach a sensitivity level of -134dBm with 4,096 integrations per data point and a very accurate calibration (Full 2-Port). Averaging with 64 integrations would provide -116dBm in sensitivity.<sup>3</sup>

In the real world, a single 360 degree radiation pattern with 4,096 integrations and 0.5deg angular resolution measuring eleven frequencies would require nearly 48 hours to complete! This is very impractical. The same test with just 64 integrations per data point requires only 33 minutes. Measuring the actual system sensitivity will be the final characterization performed.

### **Nominal Transmit (Tx) Beamwidth**

Pairs of pyramidal gain horns covering 2 - 18GHz were recently acquired. However, the testing of these units cannot be completed until the appropriate waveguide-to-coax adapters are obtained. The adaptors are currently being researched.

The tests that have been conducted to date used pairs of horn antennas covering the 1.0 - 2.5 and 2.0 - 5.0 GHz bands. As expected, the beamwidth for these horns vary as a function of frequency. The lower frequencies exhibit beamwidths of 40 - 46 degrees at -3dB. The higher frequency beam-widths are around 23 - 27 degrees. Figure 6 represents the measured beam-widths of a L-Band standard gain horn.

### **Range Type**

The final OATR design will be an elevated type with both the AUT and source approximately fourteen feet above ground level. This will be accomplished by supporting the AUT with a 2ft x 2ft x 12ft column of high-density polystyrene foam. Two columns were delivered on December 9<sup>th</sup>, 2004. The source will be mounted on a telescoping tower currently located at the VLA. This tower will be relocated if required to the final range test site when established. The design of a support structure to mount the foam column on top of the Azimuth Positioner is underway. Actual building of the structure will be dependent on final design approval and acquisition of needed materials.

### **Angular Accuracy**

The azimuth positioner with the optical encoders installed has the angular resolution of 0.03deg. The manufacturer states the backlash of the positioner does not exceed 0.05deg. Based on this information, angular accuracy can be narrowed down to <0.1deg resolution. The intention is to build a Pointing Error Model in the software to monitor the positional accuracy and systematic drift.

### **Logistics**

VSWR and range testing of a feed horn, including setup and teardown, could be accomplished in one day (8 - 10hrs). Several variables can impact the actual testing time:

- a) The experience of the crane crew.
- b) Dynamic changes in the weather.
- c) Equipment malfunctions.

Profiling the logistics involved can only be accomplished with real-time testing.

### **A Steep Learning Curve**

It is beyond the scope of this update to describe the many aspects of setting up an outdoor range of this magnitude. Every range has its quirks, and no two are alike. This especially holds true for outdoor ranges. Specular and incidental reflections can affect the testing environment drastically. This is where time gating comes into the picture. As a function of Time of Arrival, time gating can effectively remove reflections from the measured data. However it does have its limitations.

A specific example of this regards small amounts of broadband noise that has plagued the back-lobe portion of all radiation pattern tests to date. The effort in identifying the source of this noise has been significant. On the surface it seemed to be a failure in time gating, due to its presence with the time gating function turned on or off. The probable cause of this was attributed to reflections off of the coax connected to the AUT, which cannot be effectively removed by time gating due to the proximity to the antenna. Tests were performed to investigate this theory by changing the position and angle to which the cable was being connected. The changes in cable orientation did not reduce the noise level.

The keen observation of a team member changed the focus of the troubleshooting effort entirely. It was noted that the noise was mainly present in the data when the aperture of the AUT is in line of sight with the equipment rack. Subsequent tests taken with the rack in two different locations have proved this theory true, as shown in Figure 7. Further investigation has identified the DC Motor of the azimuth positioner as the noise source. The lack of shielded wiring in the



azimuth positioner has provided a convenient signal path for the noise to travel from the positioner to the equipment rack. Correcting this manufacturing oversight is currently underway.

## Comments

Significant progress has been made in just a few months of testing. Actual testing of the setup was not possible until after the arrival of the Azimuth Positioner and Positioner Controller in late September and the acquisition of the optical encoders in early October. Before these key components arrived, most of the effort was focused in the development and testing of the software interface to the receiver and source.

Many tasks still require thorough attention prior to reaching a fully operational status. As emphasized throughout this update, the test range location is the key. Once established, the final characterization of the range will rapidly coalesce within a few weeks of testing. When it becomes fully operational, a detailed report regarding the capabilities and limitations of the antenna test range will be forthcoming.

## References

- [1] E. Szpindor, "Requirements for the Antenna Range", NRAO Internal Correspondence, *Req\_for\_Antenna\_Range8-26-03.doc*, pp. 1, August 2003.
- [2] Hewlett Packard, "Types of calibrations and their uses", HP 8510 Operating and Programming Manual, Ch. 8, p. 6, June 1991.
- [3] Hewlett Packard, "Manual Pattern Measurements Using the HP 8510B", Product Note 8510-11, Table 1, p. 8, December 1987.

## Figures



Figure 1. Basic AUT Tower using Sono-tube<sup>™</sup> and wood. (Source Tower is of similar construction)



Figure 2. L-Band test setup conducted at Composite Optics, Inc. in San Diego, CA. The foam tower depicted here represents the type of construction that will be used on the OATR.

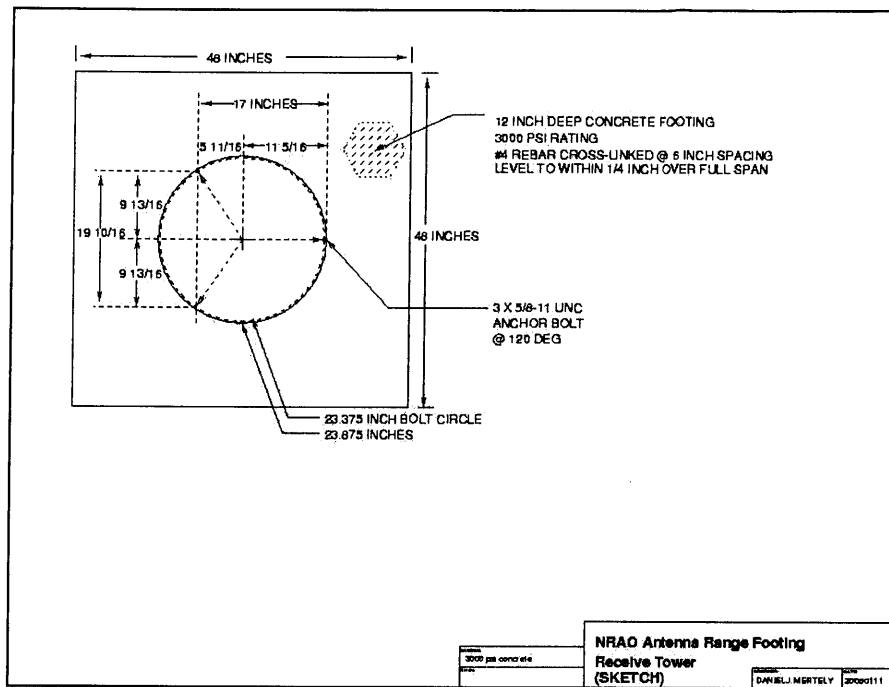


Figure 3. A conceptual sketch for the Azimuth positioner concrete pad.

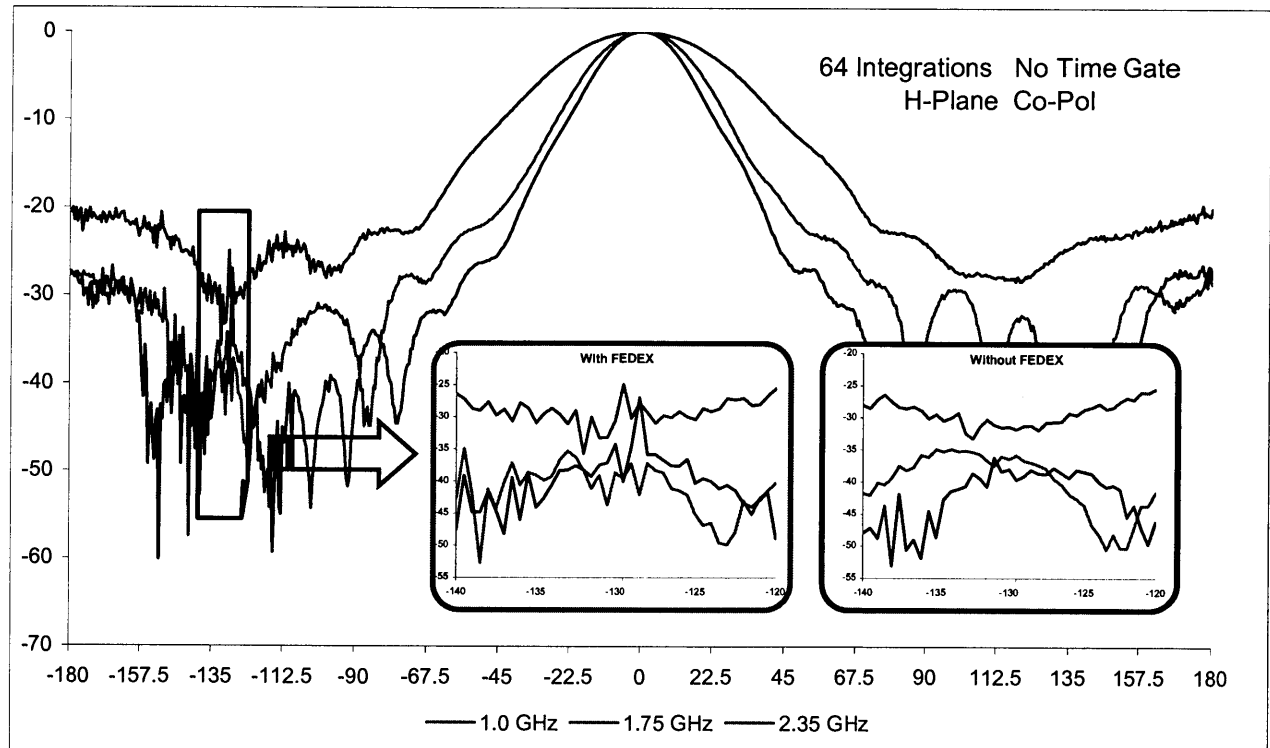


Figure 4. The intrusion of a FEDEX Delivery Truck generated a ~10dB side-lobe artifact without time gating turned on. A follow-up test (in blue frame) shows the results without the delivery truck present.

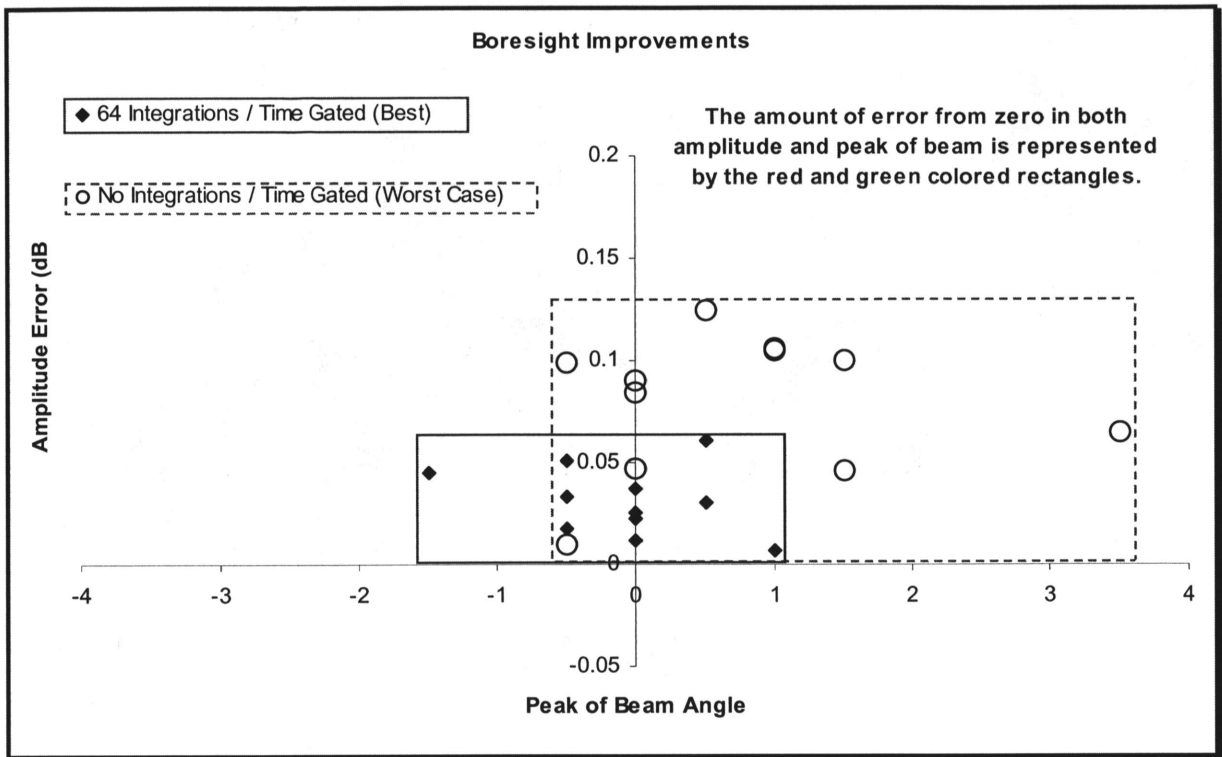


Figure 5. Boresight tests using 2.5GHz Peak of Beam as the reference. The data represents errors from nominal.

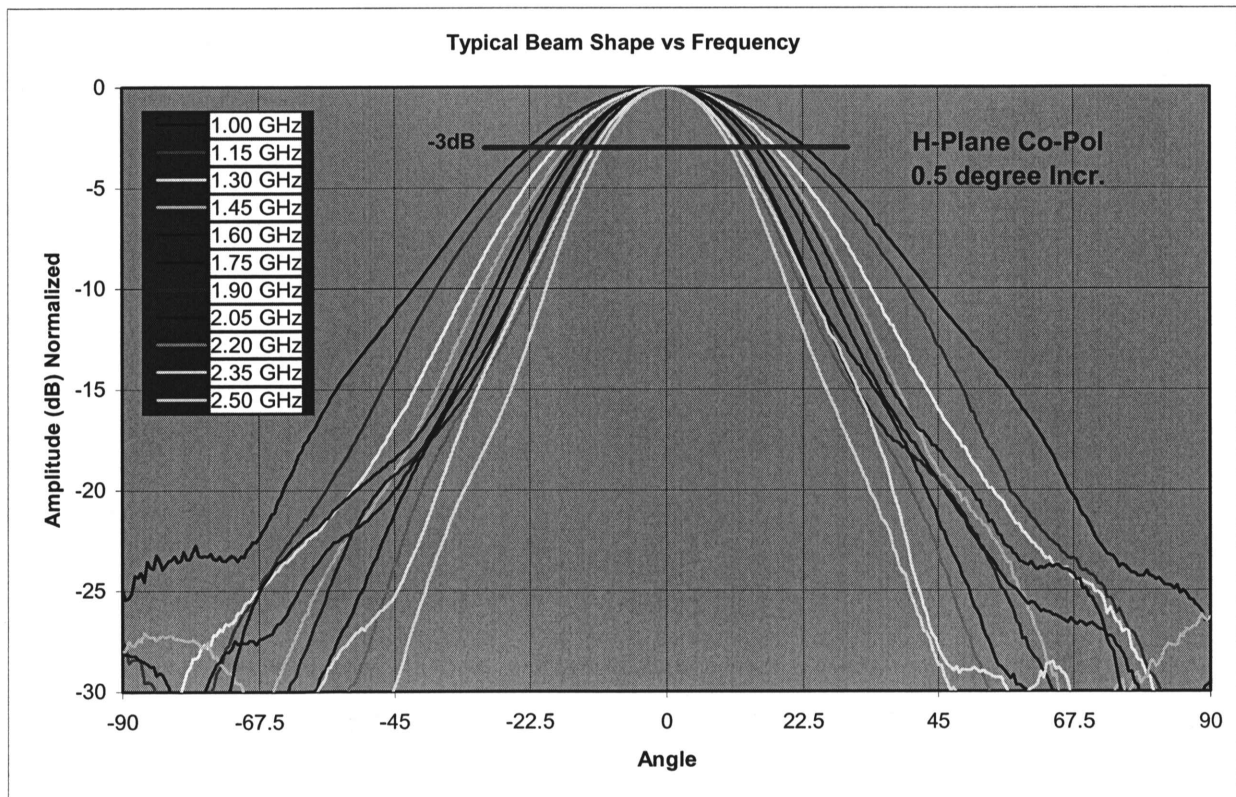
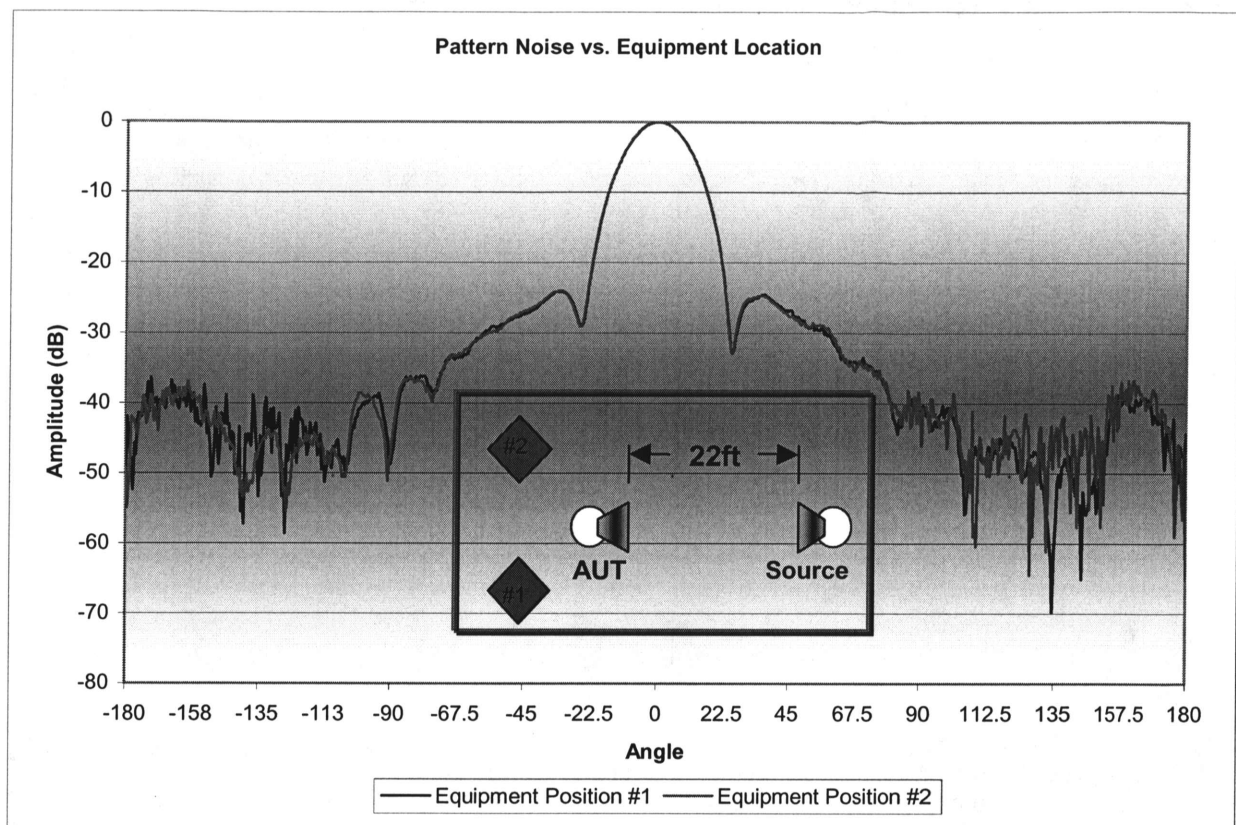


Figure 6. The typical beam widths with respect to frequency.



**Figure 7.** Moving the location of the equipment rack stimulated a change in the noise position on the pattern data. Inset diagram is looking at the setup from above.

## **Team Members:**

### **Colton Dunlap**

Mr. Dunlap has been the EM Coordination COOP student at the VLA for the past six months. His woodworking skills, strong mechanical aptitude, and good problem solving discipline have been instrumental in solving key issues regarding the initial testing of the antenna range. Noteworthy are the test fixtures and towers he built using wood and Sono-tube<sup>™</sup> in-order-to conduct initial tests of the standard gain horns. When he assumes the Student Work Study position in January 2005, his already proficient programming skills will be honed to a sharper level. A sophomore at New Mexico Tech, his intentions are to pursue a double major in EE and CS.

### **Tanner Oakes**

Mr. Oakes has held the Student Work Study position here at the AOC since May 2004. The task of building the antenna range became his primary duty after completing several other projects. The majority of his time has been to develop and refine the software interface using MATLAB<sup>®</sup> v7.0. The dauntless effort of creating this unique program has given him the opportunity to develop an in-depth knowledge regarding positioner control and data acquisition. A strong insight to the basics of antenna testing has paralleled the software development. With the assistance from other team members, he successfully tackled the challenge of integrating the optical encoders both mechanically and electrically in the azimuth positioner providing better angular resolution capability to the setup. He will be assuming the EM Coordination COOP position beginning in January 2005. A junior at New Mexico Tech, he is currently pursuing a double major in EE and CS.

### **Troy Jensen**

Mr. Jensen is a senior electronics technician with the Front End Group at the AOC. With eighteen years in the RF industry, both military and commercial, he has logged over 6200 hours in the operation and maintenance of various antenna test ranges. This includes two tapered anechoic chambers (48ft and 75ft), a 22ft rectangular RCS chamber, 12ft engineering range and a 200ft outdoor test range. A notable accomplishment was the successful testing of the NASA/JPL JMR (Jason-1 Microwave Radiometer). Meticulous mechanical alignment was necessary to accurately measure the 0.5deg beamwidth at 18.7, 23.8, and 34GHz, providing phase delay certification for this space-borne subsystem. The experience gained from testing various levels of antenna design provides a good fit in his capacity as the team leader for building and operating the OATR. Mr. Jensen holds an Associates Degree in Occupational Sciences (AOS) from the Westwood College of Aviation, formerly Colorado AeroTech, 1997.

### **Robert Ridgeway**

Mr. Ridgeway held the RFI/EMC Engineer position at the VLA/VLBA until the beginning of December 2004 when he assumed the position of RF Systems Integration Engineer with the ALMA Project. During the later part of his tenure as the RFI Engineer, the building phase of the OATR was placed under his direct supervision. Over 25 years of experience as an RF design engineer and his direct involvement in the construction of an outdoor test range for an entity funded by the Australian Government, demonstrated to be a capable resource for the other team members to utilize in solving issues as they appeared. A repertoire including several signature antenna designs has allowed him to approach engineering challenges with a unique and disciplined perspective. Mr. Ridgeway holds a Bachelor of Sciences in Electrical Engineering and Physics from Arizona State University, 1979.