VLA/VLBA Interference Memo No. 33

A Frequency Independent Conical Logarithmic Spiral Antenna for Observation of the Atacama Large Millimeter Array (ALMA) Test Site

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Abstract

A two-armed conical logarithmic spiral antenna capable of receiving circularly polarized radio signals from 300MHz to 5GHz is designed, built, and tested. The antenna design is modeled and evaluated using NEC4 simulation software. The antenna is manufactured in two sections. Semi-rigid cable is used near the apex in which the turn's density is altered to improve the broadband impedance match to 50 Ohms. Then 3/8" heliax coaxial cable is used for the large end of the antenna. The step increase in wire diameter has the potential to cause unwanted reflections. Hence the two sections are joined at a spiral radius that corresponds to 475MHz, as we are least interested in receiving near this frequency. The antenna is fed via one spiral arm (the 3/8" heliax coax cable) at the large end of the truncated cone; this active cables' outer shield also acts as one of the spiral arms. An other cable carries no currents inside but the outer shield serves as the second spiral arm. The two-spiraled outer shields are shorted in a place where the currents traveling down from the apex feed will cancel at all frequencies. This cable configuration acts as a wide band frequency independent balun from ~100Mhz-5Ghz. Parameters tested include the gain, impedance, and radiation pattern with respect to frequency. The antenna is now used to monitor the ALMA radio-telescope test site at the Very Large Array, NM. The 24 Hour records can be viewed on the intranet at this address in near real time:
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1 Introduction

The Extended Very Large Array (EVLA) is an ongoing project to increase the utility of the Very Large Array (VLA). One of the key improvements to the existing radio telescope is the digitization of its received signal just after the cryogenic front end. The Atacama Large Millimeter Array (ALMA) is a similar radio telescope slated to be built in the Atacama Desert, Chile. Three test dish antennas are currently being evaluated to determine which will be best suited for ALMA. Each of these antennas will be used with digitization equipment, much like the EVLA. The ALMA engineers are not worried about RFI below 30Ghz and thus need to be informed if their development work is interfering with the VLA / EVLA which operates in the 1-50Ghz frequency range .It is now possible for ALMA engineers to check in near real time (10 min. update) for any unwanted RFI that could conflict with the VLA operation.

While digitization of the signal provides many benefits to the scientists and astronomers, it also presents new EMC challenges for the interference protection group (IPG). The typical digitization equipment radiates RF at frequencies from hundreds of kilohertz to >5 gigahertz. In order to minimize the RFI noise due to such digital equipment, the IPG performs tests to characterize the radiation of each piece of equipment in an RF Echo chamber at the VLA site. Then we design appropriate shielding to enclose the equipment and attenuate the radiated fields.

The antenna discussed in this paper is capable of giving the desirable radiation pattern, and gain with minimal frequency variation. Most importantly, there is a –40db null in the radiation pattern that keeps the control building RFI out of the ALMA site pickup region.

2 Formulations

A log-spiral (**Figure 1**) has the property that the angle between a radial line to the spiral and a tangent line to the spiral is a constant value for all points on the spiral.

A log-spiral antenna can be excited along its arms by a signal of a given wavelength to a point that corresponds to the radius of the circle whose circumference is approximately equal to that wavelength. That is to say that a 300 MHz ($\lambda = 1m$) radio wave will excite a log-spiral antenna, along its arm, to a radius of $1m/2\pi = 0.1591m$. Likewise, a 5 GHz ($\lambda = .06$m) radio wave will excite a log-spiral antenna to a radius of $0.06m/2\pi = .0096m$. The equation of a log-spiral is given by $R = R_o e^{A\theta}$, where R_o is the minimum value of the radius, and A is the expansion coefficient. In order for the antenna to operate properly at a given wavelength, at least one and a half turns of the spiral need to be within the radius to be excited. Therefore, if we an expansion coefficient A equal to 0.0312 is used, and the spiral extends one and a half turns in from the 5 GHz radiuses, the equation for the log-spiral can be solved to find a suitable minimum radius R_o.

$$0.0096m = R_o e^{(0.0312*3\pi)}, R_o = 0.0072m$$

It will also be necessary to continue the spiral beyond the maximum radius of RF radiation for the antenna to operate properly at the low frequency range. The magnitude of currents reflecting from the truncated low frequency end of the spiral arms must be small fraction of that allowed to radiate into space. The spiral can be continued with an appropriate expansion coefficient, and a suitable outer radius can be found to allow good impedance matching to 50 Ohms.

For this particular antenna we decided to construct two conic segments. One segment, the smaller one, will be constructed from .141 inches semi-rigid cable with a wire radius of $0.0017907m$. The other segment will be constructed from 3/8" heliax coaxial cable with a wire radius of $0.0047625m$. To minimize the disruption caused by the stepped wire radius junction of the segments, the junction will be placed where the radius corresponds to a frequency of 475 MHz. This is not in a radio astronomy band of interest.

3 Design Process

Numerical Electromagnetic Code (NEC) –Method of Moments is a computer program for analyzing the electromagnetic response of antennas. The code is based on the numerical solution of integral equations by the method of moments, and combines an electric-field integral equation for modeling thin wires with a magnetic-field integral equation for closed perfectly conducting surfaces. NEC-4 (which is the software that was used to design this antenna) is the latest series of NEC-MoM program, other versions of NEC include NEC-2, which can model wire structure in free space or over finitely conducting ground, and NEC-3 which is the same as NEC-2 but can also model wires buried in the ground or penetrating from air into ground.

NEC-4 offers number of features for modeling antennas and their environments, including excitation by voltage sources or plane waves, distributed loading, and networks and transmission lines. The code output includes current distributions, impedances, power input, dissipation and efficiency, radiation patterns and gains.

Following is the NEC-4 code used to simulate this antenna:

```
CM SPIRAL ANTENNA USING WIRE ARMS .3-4.8GHZ, connecting at 475MHz
GH 1 250 13. .6 .1005 .005 .002 .002 0
GM 0 0 0 0 0. 0 0 1.3
GH 5 150 11 1.3 .4 .1005 .005 .005 0
GM 1 1 0. 0. 180. 0. .0 .0
GW 850 3 .005 0. 1.9 -.005 0. 1.9 .002
CM GW 851 3 .4 0. 0. -.4 0. 0. .005
GE
PT -2
PT 0
FR 0 0 0 0 48. 1.17
LD 5 0 0 0 5.98E7
LD 4 851 2 2 50. 0.
EX 0 850 2 1 1. 0. 1.
RP 0 181 181 0001 0. 0. 3. 3.
EN
```

Each line specifies certain information about the structure, orientation, and excitation input of the antenna. For instance:

The GH card specifies- the number of wire segments used to approximate the curve: 250
- the number of turns: 13
- the height of the cone segment: 0.6m
- the radius at the base of the cone segment: 0.1005m
- the radius at the apex of the cone segment: 0.005m
- the radius of the wire: 0.002m

3.1 Procedure Used in implementing the Antenna

- First find the angle ϕ for the cone segment.
- Then use this triangle to determine the height of the wire at a given radius (or after a given number of turns).

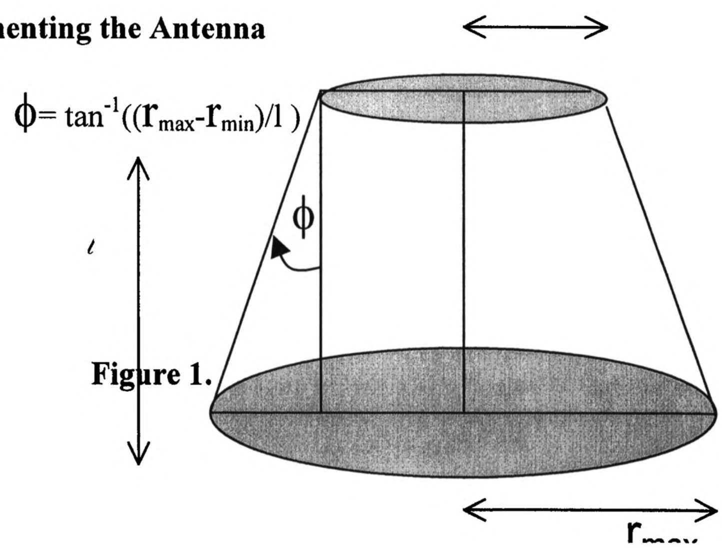


Figure 1.

The three radii in **Figure 2** can be determined from the equation $R = R_o e^{A\theta}$, where R_0 is

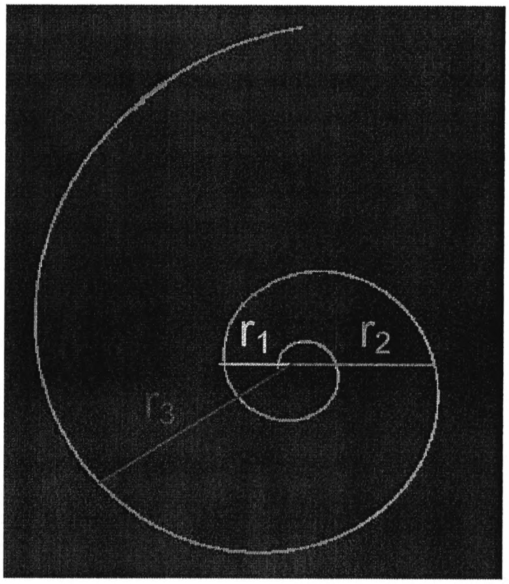


Figure 2

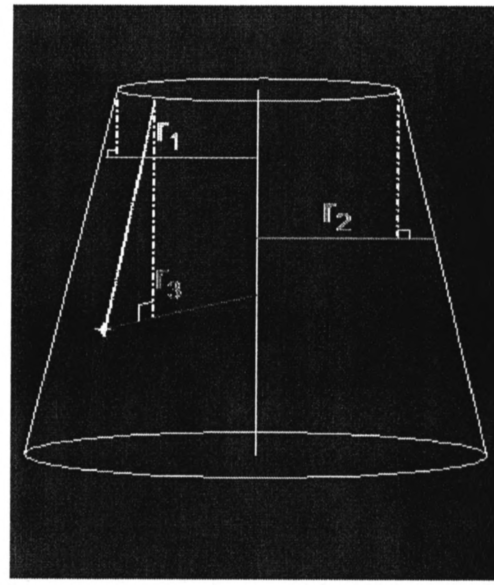
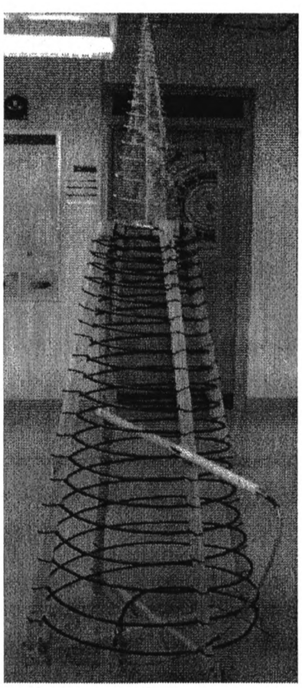


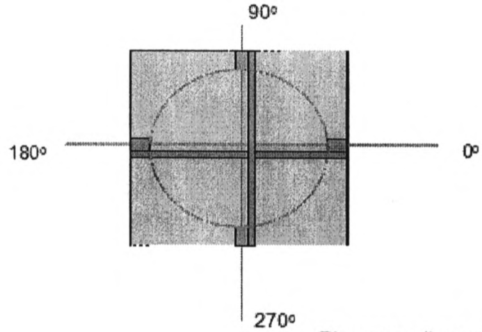
Figure 3

the radius at the apex, R is the radius to be determined, and $\theta/2\pi$ is the number of turns the spiral has made at from R_0 to R. Once r_1, r_2, and r_3 are known, trigonometry yields the length down the side of the cone that has each radius. Using this method, guide markings were made every quarter turn around the cone to show where to affix the wire.



The antenna was constructed in two segments, each with a distinct angle ϕ and expansion coefficient A. The base segment is supported on a wooden frame, while the top segment is supported by a plastic frame.

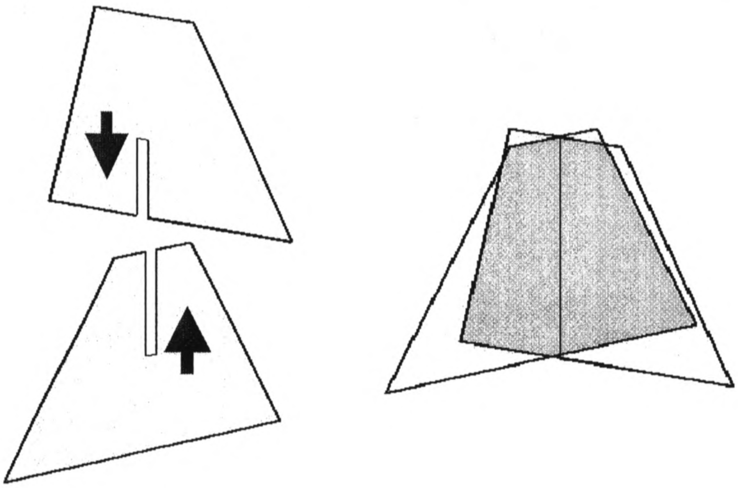
The base section is a wooden structure with four legs whose

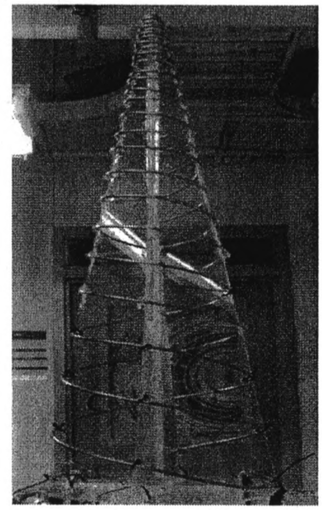


The orange lines show the shape of the cone and its center. Brpwn boxes are the wood. Notice that the orange lines go through the center of the legs.

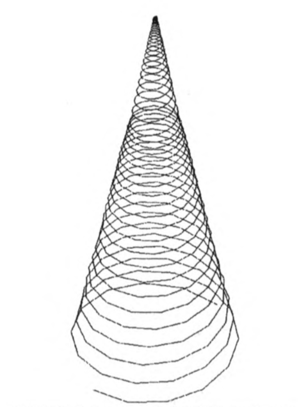
exteriors lie on the inner surface of the cone. Heliax (LDF2-50) coaxial cable is wrapped inside the leg as seen below.

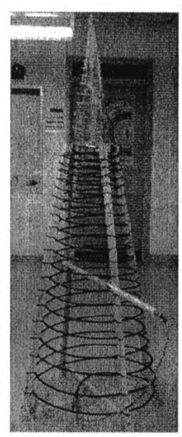
The apex section is made of two pieces of plastic fitted together. The (0.141") semi-rigid cable is wrapped around the exterior of this section as seen below.





The diagram below is the computer simulated spiral cone on the left in which the viewing angle is 45 degrees, adjacent that on the right is the constructed spiral cone with a viewing angle of ~30 degrees.





4 COST

Product	Amount ($)
2 packs of Epoxy	9.78
4 paint brushes	5.56
1 piece plastic glass	17.98
8 sqr. ft. fiber glass mat	4.99
10 ft 141 cable (2X)	In house

46 ft 3/8" heliax cable (2X)	In house
Wooden Leg	15.00
Total cost	53.31

5 Results

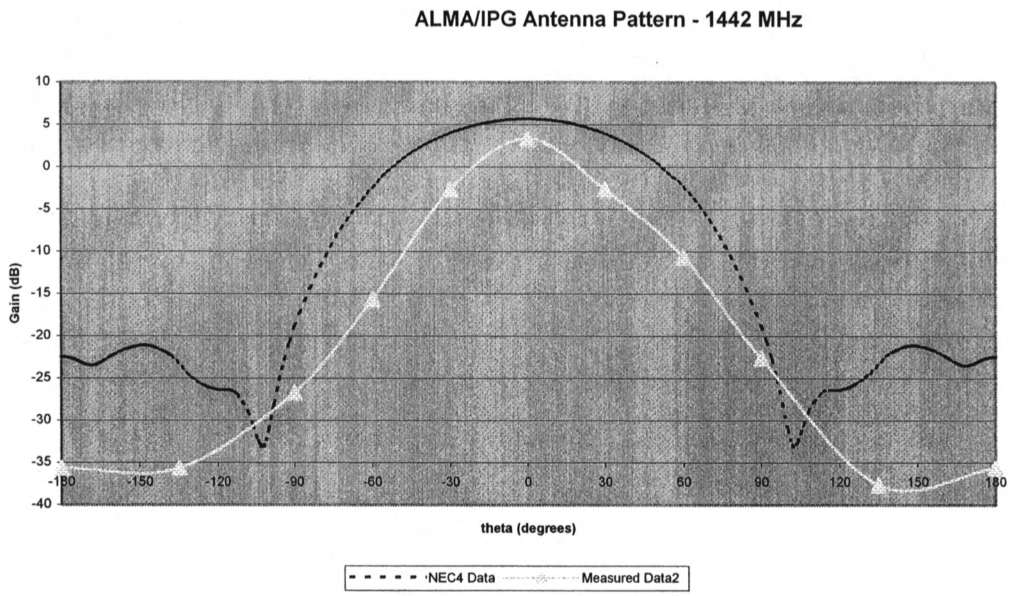
Gain: The gain of the antenna is defined as "the ratio of the power in a given axial direction to the power of an isotropic reference antenna. The reference antenna in this case was a liner polarized horn antenna with a known gain and this gain is accounted for.

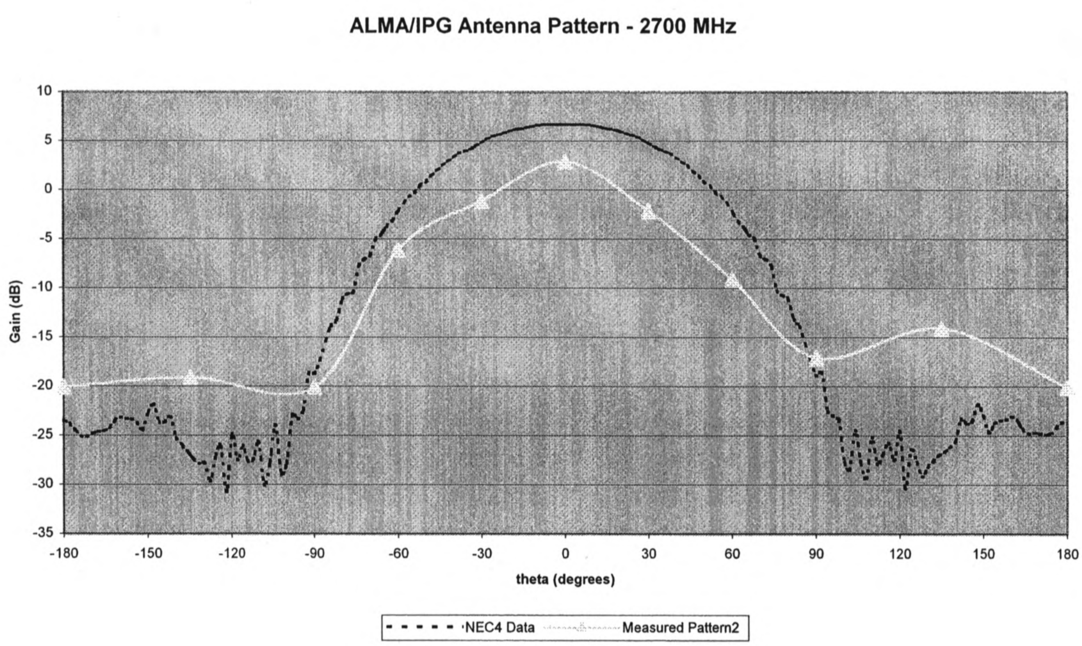
A far field antenna test measurement was performed to obtain the antenna's characteristics over the frequency range of interest. The procedure for Open Area Test Site (OATS) was closely followed while the measurements were performed.
The Friis Transmission Equation,

$$P_r/P_t = (\text{losses})(\lambda/4\pi R)^2 G_t G_r,$$

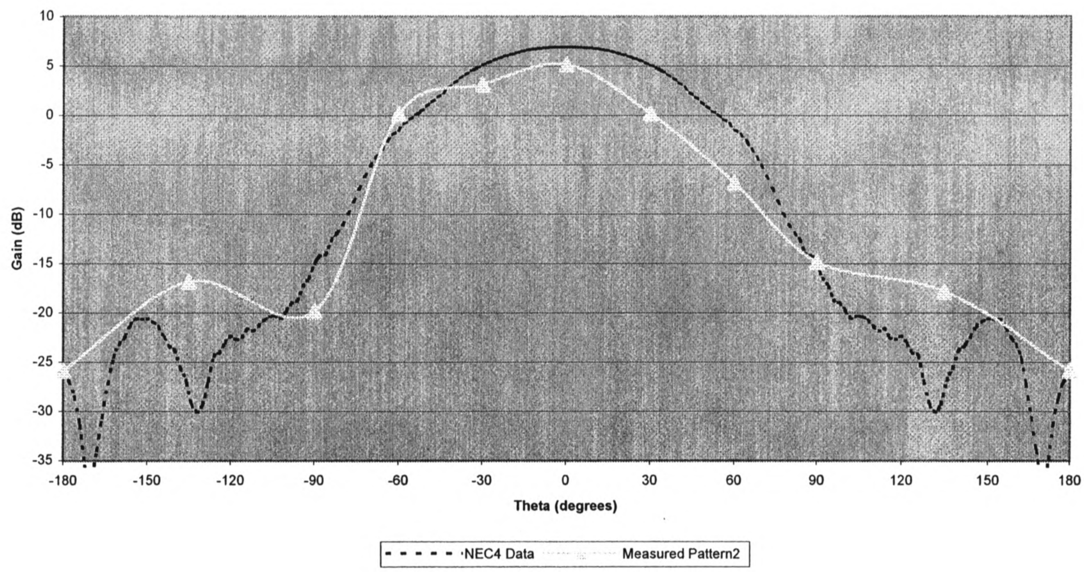
relates the power received to power transmitted between two antennas separated by the far field distance $R>2D^2/\lambda$, where D is the largest dimension of either antenna. The term $(\lambda/4\pi R)$ is called free-space loss factor, and it takes into account the loss due to the spherical spreading of the energy by the antenna. A 3dB polarization loss was used to account for the polarization mismatch between the antennas. The horn antenna is linearly polarized while the antenna under test is circularly polarized. The coaxial balun cable loss becomes significant at higher frequencies. Therefore a cable loss factor was included on the right hand side of the Friis Equation as well.

The gain was measured on axis and radiation pattern was measured every 30 degrees. The OATS ranges were subject to bad ground reflections. The expected gain from the NEC simulation is included as a dotted line for comparison's sake. Even the best antenna test site on the roof of the AOC, Socorro was not characterized thus the gains are not corrected and are presented here only for a quick look at how it compares with the NEC4 simulation.

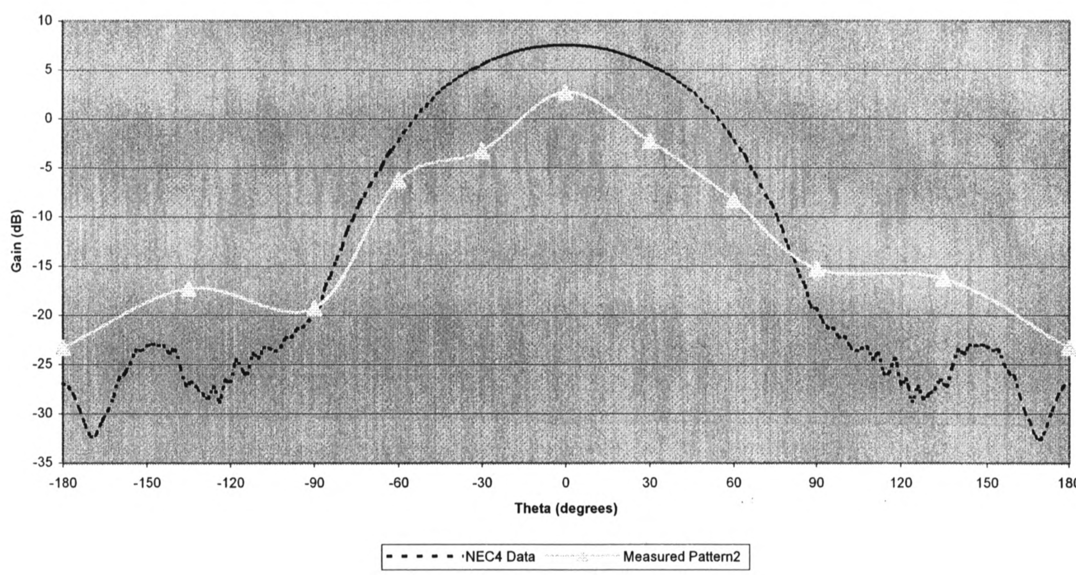

ALMA/IPG Antenna Pattern - 1442 MHz
Gain (dB)
theta (degrees)
NEC4 Data
Measured Data2

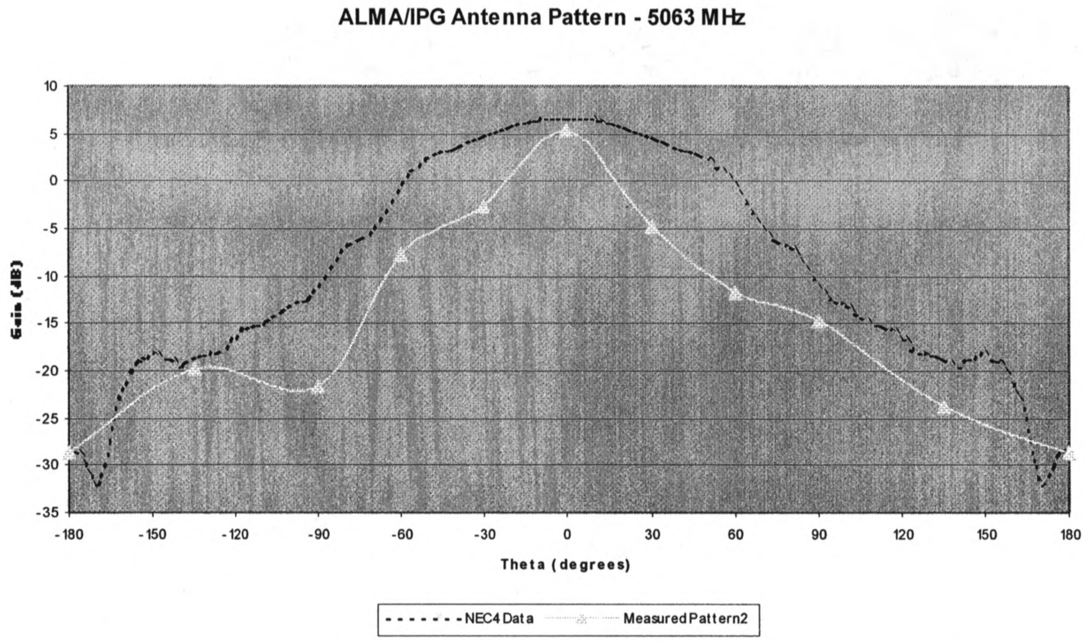

ALMA/IPG Antenna Pattern - 2700 MHz
Gain (dB)
theta (degrees)
NEC4 Data
Measured Pattern2

ALMA/IPG Antenna Pattern - 3700 MHz



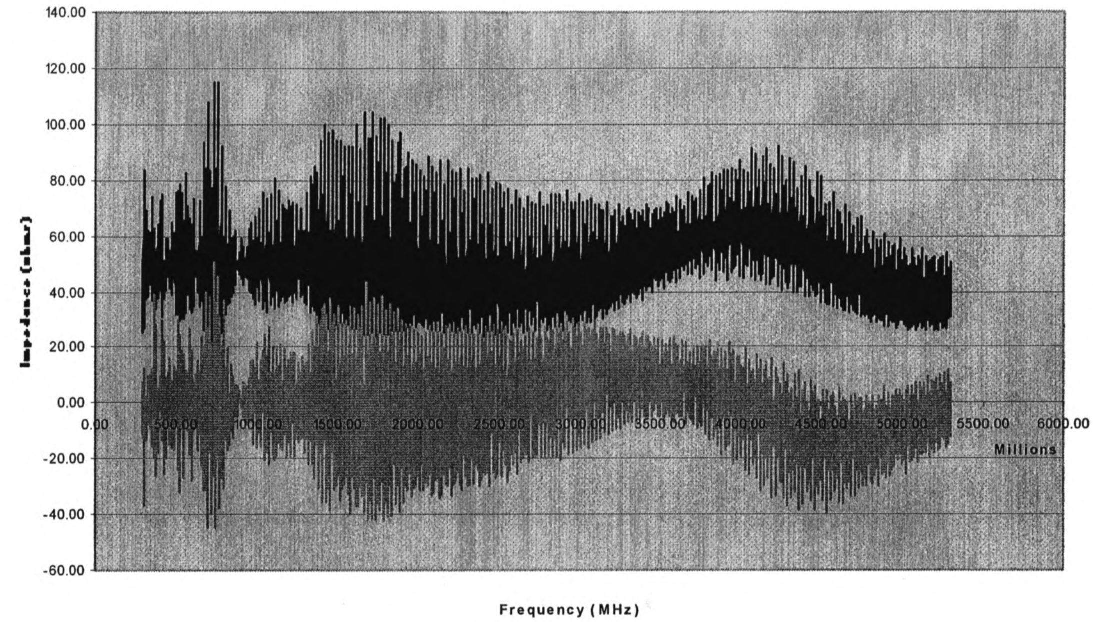
ALMA/IPG Antenna Pattern - 4330 MHz





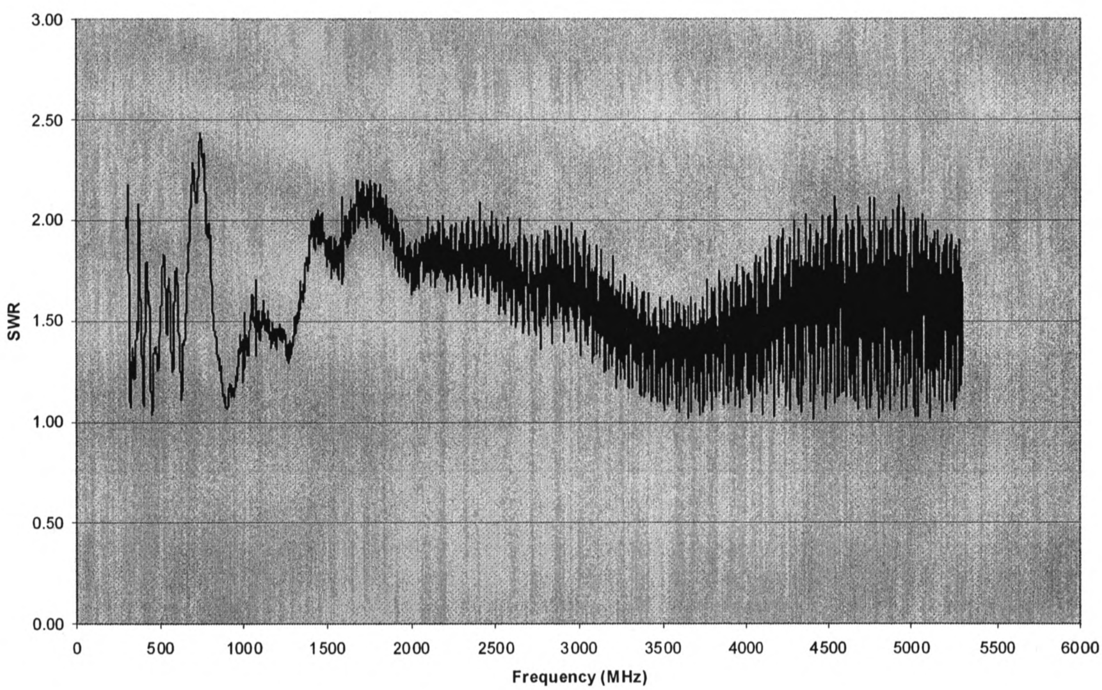
Impedance: The antenna's impedance was the issue of primary concern. It is difficult to perform impedance matching over (.3-5Ghz) a broad band of frequencies. Therefore it was very important to choose a design that had the desired impedance characteristics to begin with. The majority of the work in simulation was directed towards obtaining a model that is very well impedance matched to the feed lines over the whole range of frequencies.

We were pleased to see that the antenna's measured impedance through a frequency sweep actually outperformed the computer simulation. The measurements were taken using a network analyzer. The first graph below shows the impedance through the frequency range with resistance in blue and reactance in magenta. The second graph shows the VSWR as a function of frequency. The aim was a resistance very close to fifty ohms and a reactance close to zero for the entire frequency range. A VSWR of less than two was desired. The antenna performance was very favorable, as is seen in the graphs.

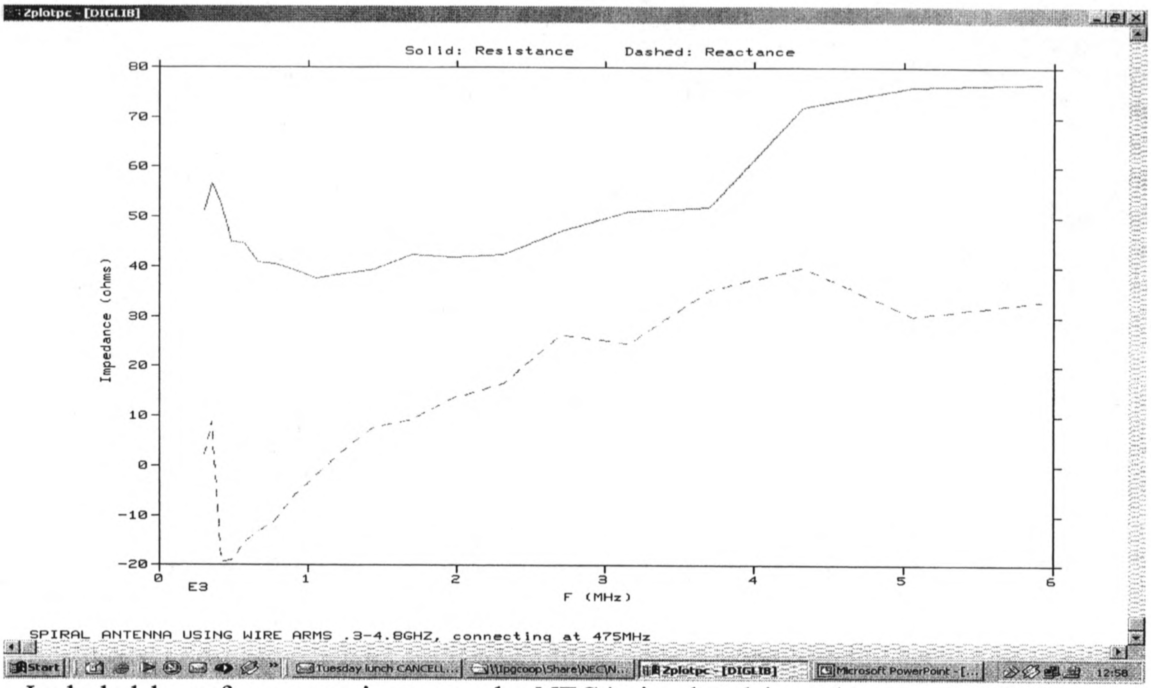


140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
Impedance (ohms)
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
5500.00
6000.00
Millions
Frequency (MHz)

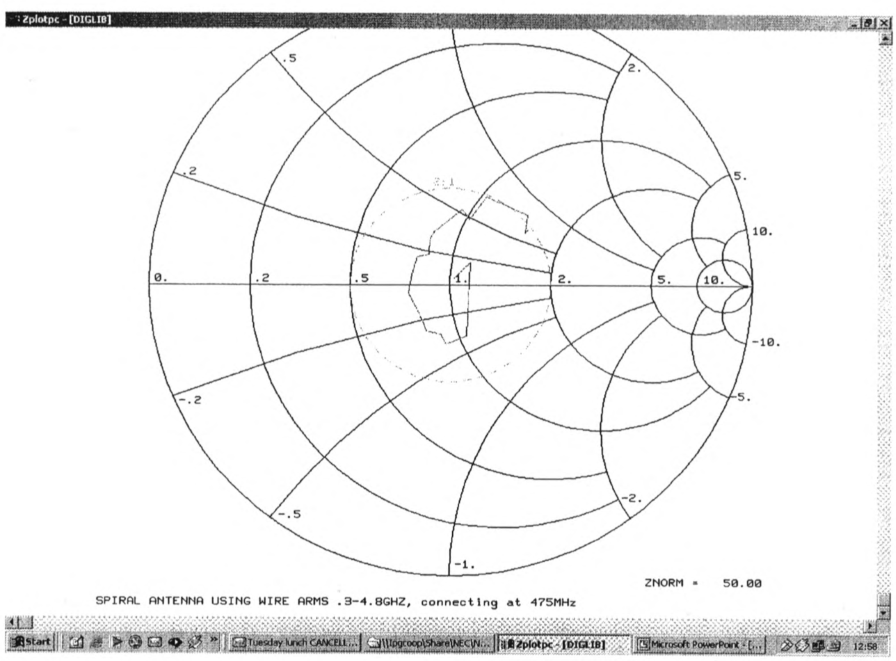
S11 SWR U



3.00
2.50
2.00
1.50
1.00
0.50
0.00
SWR
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Frequency (MHz)



Included here for comparison are, the NEC4 simulated impedance and VSWR graphs. The simulated Smith chart was very similar to the results obtained through measurement of the antenna. One of the key features of our antenna impedance matching efforts is that at the low frequency end the impedance goes toward the 50 Ohm center of the smith chart.

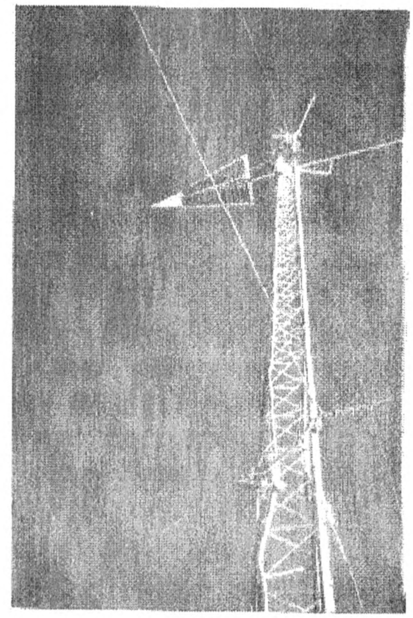


5 Conclusion

The NEC 4 simulation software was able to provide a good “free space” indication of the characteristics of an antenna with a fairly complicated geometry. Following careful software modeling, the antenna was constructed and tested. The test results show that the frequency independent conical log-spiral antenna, comprised of two distinct conical arms, performs well through the frequency range of interest. Semi-rigid cable is used near the apex in which the turn’s density is changed to impedance match to 50 Ohms even below 300 Mhz.

The antenna specifications called for the material costs to stay reasonably low. Using surplus materials available at the AOC, and constructing an inexpensive wooden frame for the base section of the antenna minimized expenditures.

Future improvements on the antenna include replacing the skeleton of the antenna with a more rugged fiberglass structure. It should be noted however, that there would be a tradeoff between increased durability and increased wind resistance. The antenna has been mounted on the EMS tower and aimed at the ALMA test site. The -40db null NEC4 had predicted was measured to be only –20db (which rejects most CB RFI) in the direction of the VLA control building. This was later found to be due to the 3 guy wires near the antenna mounting on the EMS tower. We will be experimenting with NEC4 to find a more suitable position with less RF scattering.



Alma Antenna sitting on EMS Tower

Software has been written to acquire data from the antenna every 10 minutes. The initial data collected from the antenna over several days does reflect the RFI that is believed to be radiating from the ALMA test site. However some RFI is coming from behind the ALMA site and is well known to us (IPG). It appears that this new ALMA antenna will be a useful tool for real time monitoring of the RFI noise by ALMA engineers. We now have the means to protect the EVLA from unwanted local ALMA RFI.

References

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[3] J.D Kraus and R.J. Marhefka, *Antennas For All Applications,* McGraw-Hill, New York, 2002.
[4] G.J. Burke, *Numerical Electromagnetics Code-NEC-4: User's Manual,* LLNL, California, 1992.

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