Far Sidelobes of VLA & VLBA 25m Antennas at λ 18cm.

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NRAO [2]

[1]These measurements involved substantial NRAO resources, including effort from B. Brundage, B. Clark, P. Lilie, G. Petencin, B. Sahr, & telescope time. Contributions from D. Emerson, A. Thompson, and G. Moellenbrock are acknowledged.

[2]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under coopertive agreement by Associated Universities, Inc.

1. Introduction & Summary

Interference to Radio Astronomical observations with large reflector antennas enters the receiver mainly from the far sidelobes. The VLA and VLBA L-Bands cover about 1200-1800 MHz, and include many potential sources of interference, both terrestrial and in orbit. Detailed knowledge of the sidelobes is useful to evaluate present and future RFI levels, and build into systems some protection for Radio Astronomy.

The VLA and VLBA both use offset-Cassegrain optics, as described in references [1] & [2]. The VLA uses a lens-corrected horn, and the VLBA a corrugated horn feed. The feeds are sufficiently different that it was undertaken to measure the far sidelobes of both types of 25m antennas.

The main results are the measured sidelobe profiles, Fig-1, with supporting details of calibration and analysis. The main conclusion is that the CCIR model of ITU recommendation 509-1 [Ref.3] is an appropriate representation of the sidelobe envelope of radio astronomy antennas. The profile is well followed by the VLBA antennas, with their low-sidelobe feeds. The VLA sidelobes also follow the model, except in the range 20°-80° off axis, where they exceed the model by $\sim$6dB. This we ascribe to the high sidelobes, in this angular range, of the unusual horn-lens feed used on the VLA.

The VLA L-band horn is being re-designed to cover 1.2-2GHz, with low sidelobes, for the EVLA upgrade [Ref.4]. The reflector surfaces will remain unchanged, so the future sidelobe profile of EVLA antennas is expected to be close to the VLBA profile here.

2. Measurements and Calibration

2.1. Setup

The generic setup is in Fig-2. In each case the radio astronomy antenna received a narrow-band signal from a mountain-top transmitter about 40 km away. To minimize gain compression (but see Fig- 6), the high-gain astronomical signal path was interrupted after a single stage of low-noise amplification. The LNA output went to a spectrum analyser whose z-axis voltage (i.e., signal amplitude in dB) was logged, with the corresponding azimuth and elevation encoder readings, by the on-line computer driving the antenna.

The antennas were slewed in azimuth (the faster axis) and stepped in elevation over a wide range. Differences in the details between the VLA and VLBA setups are noted in each case. Full Nyquist sampling was not attempted over the whole sky due to time constraints, nevertheless in steradian coverage and density of samples, these data are among the most comprehensive available.

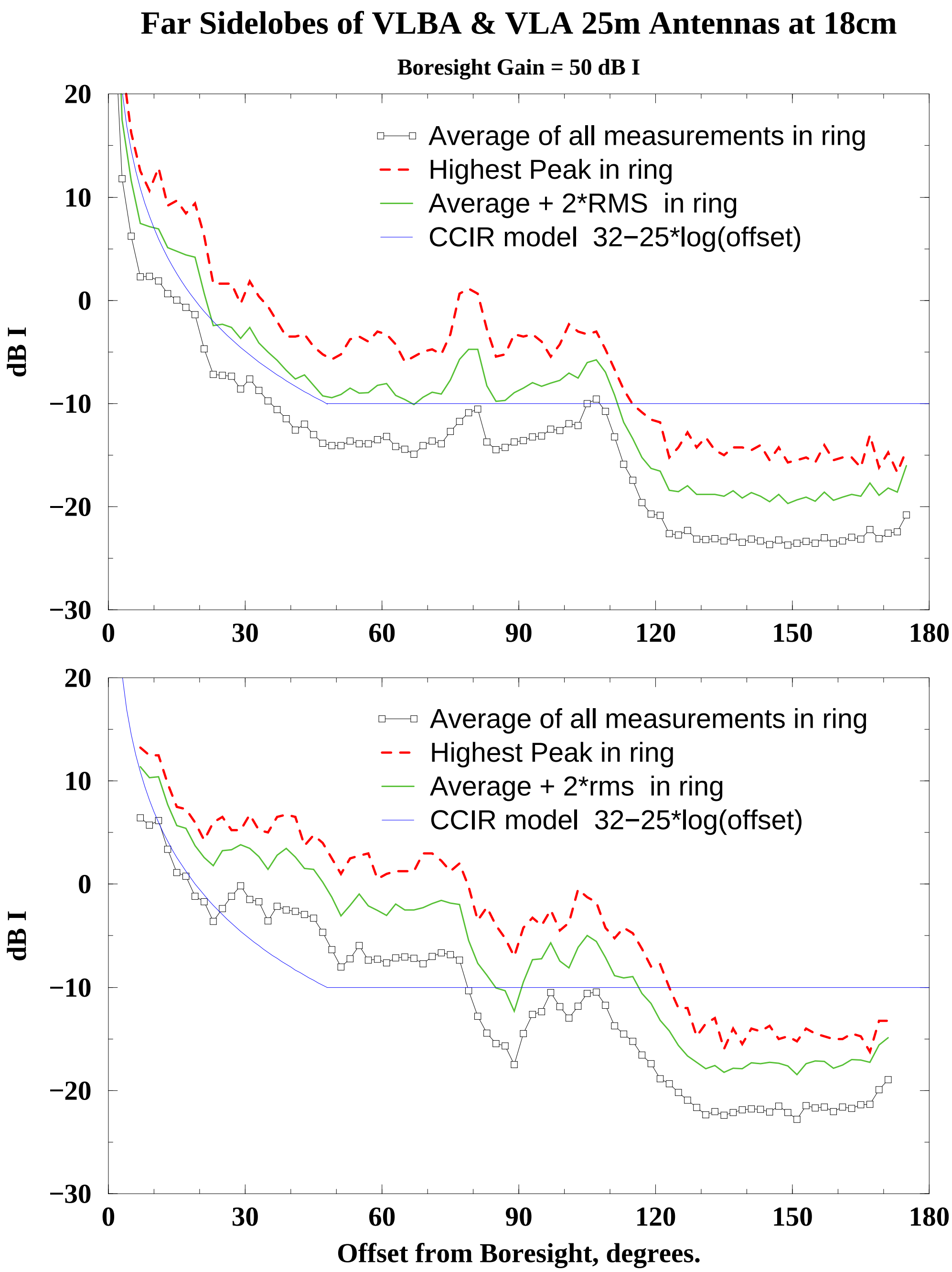

Fig. 1.— Sidelobe Profiles for VLBA and VLA antennas. The calibrated data are analyzed in 2° rings of offset from the boresight, to calculate: (A) the average of all significant measurements (above noise); (B) the highest peak in that ring; and (C) the [average + 2*RMS], below which 90% of values are expected to lie. The CCIR model is shown for comparison.

2.2. Source Location, Frequency, and Terrain Profile

2.2.1. VLA Antenna #17

The source was a low-power transmitter at 1612 MHz installed temporarily by NRAO on South Baldy, 39.4 Km from the VLA antenna #17, at azimuth 105.15°, elevation 1.2°. VLA Antenna 17 was selected because it was at the end of the east arm, giving the highest elevation angle to South Baldy and having no other VLA antennas nearer the transmitter to cause shadowing or multipath reflections. Spectrum analyzer bandwidth was 30 KHz.

See Fig-14 for the terrain profile and propagation calculation.

2.2.2. VLBA Los Alamos

The source was a Forest Service microwave link at 1717 MHz, 42 Km from the VLBA Los Alamos antenna, at azimuth 88.2°, elevation 2.0°. Spectrum analyzer bandwidth was 300 KHz.

See Fig-15 for the terrain profile and propagation.

2.3. Scanning Pattern

2.3.1. VLA

The antenna slews at 40° /min in azimuth, and was scanned 0-270° to get the front lobes and about half of the back lobes with respect to the transmitter at azimuth 105°. The data were logged at about 0.25° intervals in azimuth. At the end of an azimuth sweep, the antenna stepped in elevation by 1° and reversed azimuth direction for the next scan. The VLA elevation limit of 8°, allowed data to be taken to within 7° from the transmitter at 1.2°.

Several scans were made at 8° elevation, to check the stability of the setup. These scans show variations of about 1 dB at the peaks of the pattern. The variability in the nulls is somewhat greater, but since it is the peak sidelobe levels that are of most importance, this degree of repeatability is quite satisfactory.

2.3.2. VLBA

The antenna slew rate of 90° /min in azimuth permitted data points 11' apart. Scans were of two types, a 'boresight' pattern, 20° on either side of transmitter, with elevation going in 0.25° steps from 2° to 20°; and a 'survey' pattern in full azimuth circles, elevation from 3° to 90° in 0.5° steps. The different boresite runs showed excellent repeatability, within a fraction of a dB at the peaks.

2.4. Transformation of Coordinates

The data as taken is labelled with the antenna encoder coordinates, A, E (see Figure 2) The transmitter is at A_T, E_T in this frame. The sidelobes are best viewed in a coordinate system moving with the telescope, always having the main beam as the z-axis. To rotate this frame so that the main beam points to the zenith requires a rotation R_Y of (90-E)°, around the elevation axis. The transmitter has coordinates $(A\text{-}A_T)$, E_T in this frame, with cartesian components

$x = \cos E_T . \cos(A\text{-}A_T)$, $y = \cos E_T . \sin(A\text{-}A_T)$, $z = \sin E_T$

The corresponding coordinates in the Main Beam frame are:

$(x', y', z') = R_Y.(x, y, z)$, where the rotation matrix R_Y is:

$$\begin{matrix} \sin E, & 0, & -\cos E \\ 0, & 1, & 0 \\ \cos E, & 0, & \sin E \end{matrix}$$

Thus: $x' = \sin E . \cos E_T . \cos(A\text{-}A_T)$, $y' = \cos E_T . \sin(A\text{-}A_T)$,
$z' = \cos E . \cos E_T . \cos(A\text{-}A_T) + \sin E . \sin E_T$

Finally, the spherical coordinates with respect to the main beam are AZ_M, EL_M:

$AZ_M = \arctan(y'/x')$, $EL_M = \arcsin(z')$, $ZA_M = 90\text{-}EL_M$.

Naturally, the raw data has a maximum where the antenna true azimuth and elevation match the transmitter direction. The encoder coordinates in azimuth are offset 180° from the true azimuth, for both VLA and VLBA antennas, which changes the $(A\text{-}A_T)$ to $(A_T\text{-}A)$. The transformed coordinates show the peak at the center of a polar plot, where zenith distance=0°. The azimuth is wrapped around -180° to +180°. This display has the advantage of showing both hemispheres in a single page, at the expense of distorting the relatively unimportant back lobes (see Fig-7 & Fig-8)

2.5. Spectrum Analyser Calibration

A calibration of the spectrum analyser against a power meter showed an offset of 2 dB, with the power meter reading lower. This offset persisted over all ranges of the input signal, from +30 to -70 dBm. Since this is a constant offset, for all measurements made with the same instrument the relative scaling of sidelobes is unaffected.

The spectrum analyser dB-to-voltage scale, nominally 50 dB/volt, was measured to vary between 48.5 to 51 dB/V over the power range +30 to -70 dBm. Using the nominal figure leads to a maximum uncertainty <2 dB in the relative sidelobe level.

2.6. VLA Absolute calibration with Standard-Gain Horn

2.6.1. Equipment

1. (Transmitter) Wavetek 3250 Frequency Synthesizer S/N 4752235
2. Locus RF-660A Amplifier S/N 43
3. WJ AR7-18 horn (transmitter) S/N 097
4. Line-of-sight path length 39 Km
5. AEL H5001 S/N 167 horn (Calibration receiver)
6. Tektronix 2712 spectrum analyzer S/N B021588
7. VLA antenna # 17, with L-band horn (Antenna under test)
8. F103 # 33 Front end (RCP)
9. VLA Monitor & control system.

2.6.2. Power Density at VLA antenna

Preliminary measurements were made 1993 Aug 11:

Synthesizer output	+10 dBm
Cable loss	-2 dB
Tx Horn gain	+8 dB
E.R.P.	+16 dBm
1/Area of 39 Km radius sphere	-103 dB(m^2)
Expected power density at VLA#17	-87 dB(mW/m^2)
Measured power at analyzer	-99 dBm
Area of 14.8 dB Rx horn at 1.62 GHz	-11 dB(m^2)
Cable loss	-2 dB
Measured power density at VLA#17	-86 dB(mW/m^2)

For the final measurements made 1993 Aug 25, an amplifier was added to increase E.R.P. by 11 dB.

Expected power density at VLA#17	-76 dB(mW/m^2)
Measured power density at VLA#17	-77 db(mW/m^2)

A value of -76 dB(mW/m^2) was used in calculations.

2.6.3. VLA Front End (LNA) gain

Front-end gain was measured as follows: The receiver output power was measured when looking at the cold sky, and with ambient-temperature absorber over the feed. The change in output power divided by the change in input power is the receiver gain.

Load	Temp.	dBm/3KHz	mW
Sky	12 K	-99	126E-12
Absorber	297 K	-88	1580E-12

The change in output power is (1580-126)E-12 mW = -88.4 dBm.

The change in input power is (297-12) * (Boltzmann's constant) * 3KHz = -139.1 dBm.

Thus the LNA gain is -88.4 - (-139.1) = 51.2 dB.

Gain measured in the laboratory in Jan 1993 was 50.3 dB. A value of 51 dB was used for calculations.

2.6.4. Spectrum Analyzer Voltage to dB I conversion

Since the effective area of an isotropic (0 dB I) antenna is -26 db.(m^2) at 1612 MHz, the power received by such an antenna would be -76 db(mW./m^2) -26 db.(m^2) = -102 dBm. If the isotropic antenna were connected to this Front End which has 51 dB gain, the output would be -102 + 51 = -51 dBm. Thus the difference between the spectrum analyzer output and -51 dBm is the gain of the antenna relative to isotropic. The spectrum analyzer was set up with a reference level (maximum) of -30 dBm (corresponding to 0 volts video output) and a minimum level of -110 dBm (1.6V video, i.e. the scale is -50 dB per volt). Thus if the spectrum analyzer video output is V volts, it indicates a power of -30 -50*V dBm, with corresponding antenna gain of -30 -50*V - (-51) = 21 - 50* V dB I.

2.7. VLA Holography

Due to the VLA antenna elevation limit of 8°, the transmitter could get no closer to the main beam axis than 7°. As a cross-check of the VLA calibration, and to fill the gap near the main beam, a 7.5° x 7.5° raster was done on a broadband celestial source, at the interference-free band around 1385 MHz. Data was taken with one antenna (the reference) fixed on source, the other scanning over a raster. The amplitude and phase of the fringe on the (unresolved) source is the beam voltage pattern of the scanned antenna. This is the mode used for holographic diagnostics of the antennas.

Unfortunately, this 2-antenna subarray encountered an unforeseen interaction with another program, and the raster was disrupted and scrambled. This data was not merged with the larger sidelobe dataset, since it was not easy to extract the true coordinates from the scrambled file. However, as calibration check, the data is adequate - the sidelobe pattern was extracted along one coordinate, and is shown in figure-5 & 6, where it can be seen to mesh well with the wider survey data outside 7° off axis. The calibration of the sidelobe data in dB I is thus validated.

2.8. VLBA Absolute calibration with Standard horn

For tests of the VLBA antenna at Los Alamos, the USFS transmitter at 1717 MHz on Tesuque Peak made a convenient beacon.

2.8.1. *Power Density at VLBA antenna*

Using the same spectrum analyzer and calibration horn as were used at the VLA, tests were made on 1993 Sept 08.

Received power	-61 dBm
Horn effective area	-11 dB(m^2)
Power density at antenna	-50 dB(mW/m^2)

2.8.2. *VLBA Front End LNA Gain*

Only the RCP cooled stage of the low-noise front end was used. Laboratory test data on S/N 104, used at Los Alamos, indicated that it had 29.5 dB gain through the RCP cooled amplifier stage. 30 dB was used in calculations.

The VLBA antenna, with an effective area of about 25 dB .(m^2) on boresight should produce -50 dB(mW./m^2) + 25 dB.(m^2) +30 dB = +5 dBm at the LNA output. However, the LNA goes into compression at an output of about -4 dBm. Therefore, on-boresight data was compressed, see figure-8.

2.8.3. *Spectrum Analyzer Voltage to dB I conversion*

An isotropic antenna used with this Front End with the measured incident power density would produce -50 dB(mW./m^2) -26 dB.(m^2) + 30 dB = -46 dBm

For measurements far from boresight, the reference level of the spectrum analyzer was set to -30 dBm, as for the VLA. For a spectrum analyser output voltage V, the corresponding power was (-30 -50*V) dB. The gain relative to isotropic was then (-30 -50*V-(-46)) dB I or

Gain (over isotropic) = (16 - 50*V) dB I

For measurements near boresight, the reference level was set 40 dB higher, at +10 dBm. In this case Gain (over isotropic) = (56 - 50*V) dB I

2.9. VLBA Relative Calibration and Gain Compression

For the VLBA, the elevation limits allow the transmitter at 2° to be in the main beam. The relative sidelobe level is then measureable with no absolute power (horn calibration) necessary. Unfortunately, this is complicated by gain compression in the front end. Even with just the first amplifier alone, 1 dB compression is reached around -4 dBm output power. (Note: the VLA amplifier was not compressed, even at the closest approach to the transmitter of 8° where Pout = -30dBm). The horn calibration shows that +4 dBm is expected at the VLBA amplifier output, well into compression. Using measured compression data for this particular amplifier (Fig-6), the on-axis gain was corrected.

More than 1° off the main beam, the compression is negligible. For the designed antenna illumination, the first sidelobes are -17 dB down from the calculated peak gain of +50 dB I, i.e., at +33 dB I. The absolute horn calibration, the on-axis level after correction, and the first sidelobes, were all consistent to 1 dB. We thus can rely on the standard gain horn calibration for the far sidelobes.

3. Analysis of Sidelobes, and Discussion of observed features

Note: The recommended method of analysis of sidelobes is laid out in an ITU document, (see Appendix-2). These criteria were sufficiently ambiguous to confuse the author, and so their application awaits further effort. The average, peak, and rms sidelobe levels presented in this memo are straightforward.

The following features are observed in the sidelobe structure, and can be related to the geometry and the horn illumination pattern. A complicating feature is the offset angle of the feed, which makes the spillover asymetric in angle w.r.t the main axis. The geometry of the antenna optics is shown in Fig-10 & Fig-11 for the VLBA antenna. The VLA antenna is similar, but with a smaller subreflector (8° half angle). The profile plots, which are integrated over all azimuths, tend to broaden the features. Some of these can be seen more clearly as rings of islands around the beam in the contour plots.

The main beam shapes are compared with a canonical $J_1(x)/x$ diffraction pattern in Fig-4 & Fig-5. The VLBA beam is fit well, but the VLA beam shows higher first sidelobes by a few dB.

Referring again to the geometry in Fig-**??**, spillover of horn past subreflector at 8-12° for VLA, 10-15° for VLBA. The edge tapers are 11.5 dB for the VLA, 14 dB for the VLBA, and the horn peak gains are 27 dB and 24 dB, (Fig-9). The VLA horn has pronounced sidelobes at 30-45°, about 26 dB down from the peak at 0 dB I, clearly visible in the profiles.

The horn is shielded by the main reflector at about 80° for both VLA and VLBA, and the shielding of the subreflector by the main reflector is apparent as the transmitter enters the backlobes at about 110° off axis.

4. Sources of Systematic Error

Some possible systematic errors in the measurements are listed here:

Gain compression and calibration errors have already been discussed. The holography data is completely independent, and agrees with the calibration. The absolute calibration is uncertain by about 1.8 dB, a combination in quadrature of
a. power variation in the transmitter, and gain changes in the front end/spectrum analyser during the several hours of measurement. (about ± 1 dB)
b. The spectrum analyser power-to-analog voltage conversion factor variation across the dynamic range (about ± 1.5 dB)

Noise: The several repeated scans show the data to be reliable down to below -30 dB I. A cutoff at -30 dB I ensures that measurement noise is a negligible factor.

Multipath: Stray reflected radiation might affect the level in directions and elevations near the transmitter, but again seems unlikely to have a large effect over the hemisphere. Plotting the levels as a function of encoder az and el (Fig-4) & Fig-5) shows little asymmetry around the transmitter direction.

Interference: An interfering signal (second transmitter) from a different direction would raise levels but seems unlikely, given the narrow spectrum analyser bandpass (30KHz for VLA, 300KHz for VLBA).

Sampling Bias arises due to coarse sampling, compared to the beam with FWHM=0.5°and typical sidelobe with FWHM=0.25°.
VLBA: azimuth slew at 11arcmin/point, at 0.5° el steps from 3°-90° elevation; plus boresight $\pm 20°$ at 0.25° el steps from 2°-20° el.
VLA: azimuth slew at 16arcmin/point, at 1° el steps from 8°-90°.
Thus the data is Nyquist sampled only for the VLBA boresight data, and everything is smeared by the fast slew in azimuth. No interpolation was attempted.
For the VLA (VLBA), some values labelled as 'Highest Peak' could have missed the true peak by 8' (5') and be upto 3dB (1dB) lower than reality. On the other hand, the sharp nulls would be filled up by the integrating effect of the slew, and so the average level should be little affected.

Polarization: The transmitters were linearly polarized, as was the calibration horn. The radio astronomy antennas, however, received RCP in all cases. This reduces the received power by 3dB in the main beam, and in the near sidelobes with modest cross-polarization. Far sidelobes with random elliptical polarization may be (a) suppressed by 3dB, just like the main lobe, [if they are nearly RCP or LCP]; (b) unattenuated [if aligned with transmitter]; or, (c) rarely, suppressed by a large factor [if orthogonal to the transmitter]. Thus most of the peaks, and the average, are unaltered relative to the main beam.

5. Data Formats

5.1. Raw data

5.1.1. VLA

The bulk of the raw VLA data is in a single file, 'VLAraw1.dat'. A second run was done to fill some gaps in the first, and the scan at 8° elevation was repeated several times during the night of observation, 'VLAraw3.caldata'.

The data has 10 columns, with format:

date, IAT time, az, el, A/D converter counts, Voltage=counts/2000.

25 AUG 93 00:37:08.69 AZ: 24.29 EL: 8.17 130 0.650

5.1.2. VLBA

The raw data in files 'VLBrawx' has three columns, with the format

el, az, A/D converter counts (=voltage*3276.8)

The boresite runs are in files 'VLBrawborex.x', the wider survey data in files 'VLBsurvx.x'. The boresite data is then offset by the requisite amount, (see discussion of calibration), and combined with all the survey data into a single file, 'VLBraw.all.dat'

5.2. Processed Data

The coordinate transform and gridding are done in the program 'pbg2.f' It has already been run, to produce processed data of 2 types, with the output format common to VLA and VLBA.

5.2.1. Calibrated data, full resolution

Files 'VLAcalib.dat' and 'VLBcalib.dat' have the format:

AZ_M, ZA_M, dB I, az_{enc}, el_{enc},

where AZ_M, ZA_M, are the azimuth and zenith distance of the transmitter w.r.t. the main beam, dB I is the calibrated sidelobe measured at those coordinates, and az_{enc}, el_{enc}, are corresponding encoder readings. (i.e., the input coordinates are carried to the output file.)

5.2.2. Binned data, 1° bins.

Files VLx.grid have the format: [gx, gy, average, peak] where gx, gy are grid center points, average sidelobe level, and peak value for that cell.

The choice for data presentation was to use polar coordinates, radius (=zenith distance) & azimuth, centered on the main beam. The entire beam over 4π steradians would then occupy a circle. Since only half the sphere can be sampled, the data occupies the region seen in the contour plots. The output grid cell indices are then the rectangular components of the vector (zenith distance, azimuth), in units of the cellsize.

The data may be re-cast in any desired fashion, by starting with the complete, calibrated data. The gridded versions are smaller, and easier to work with.

6. Figures

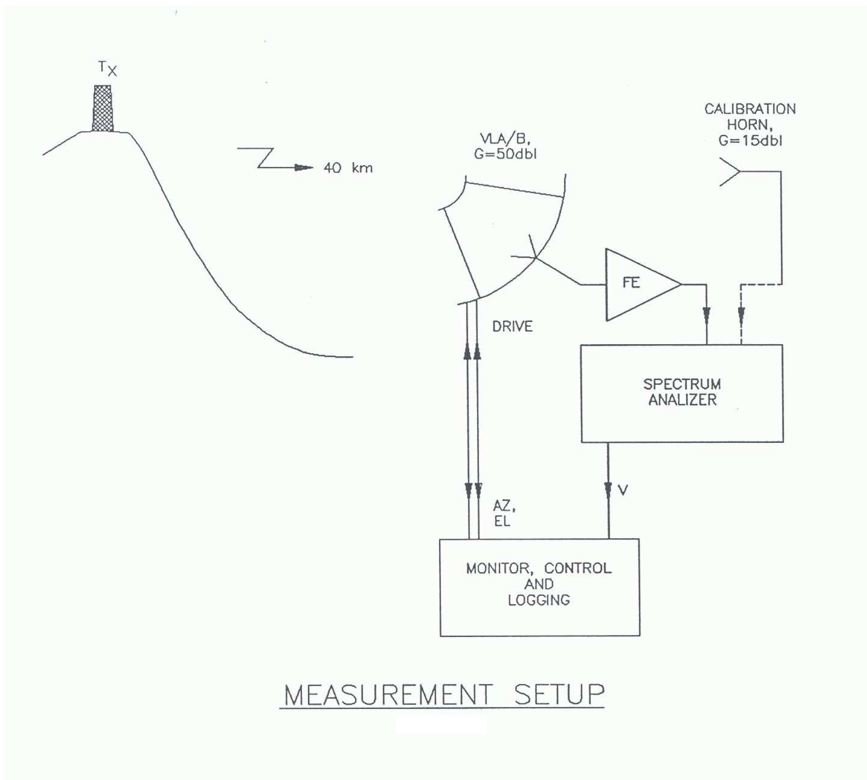

Fig. 2.— Measurement Setup

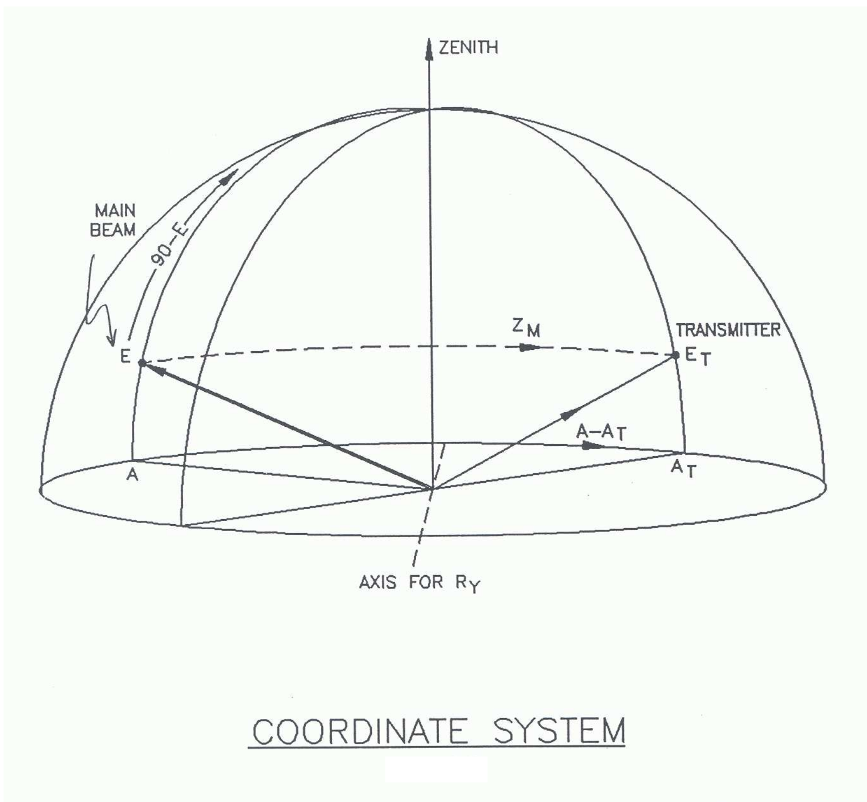

Fig. 3.— Transformation from Encoder coordinates to Main Beam coordinates.

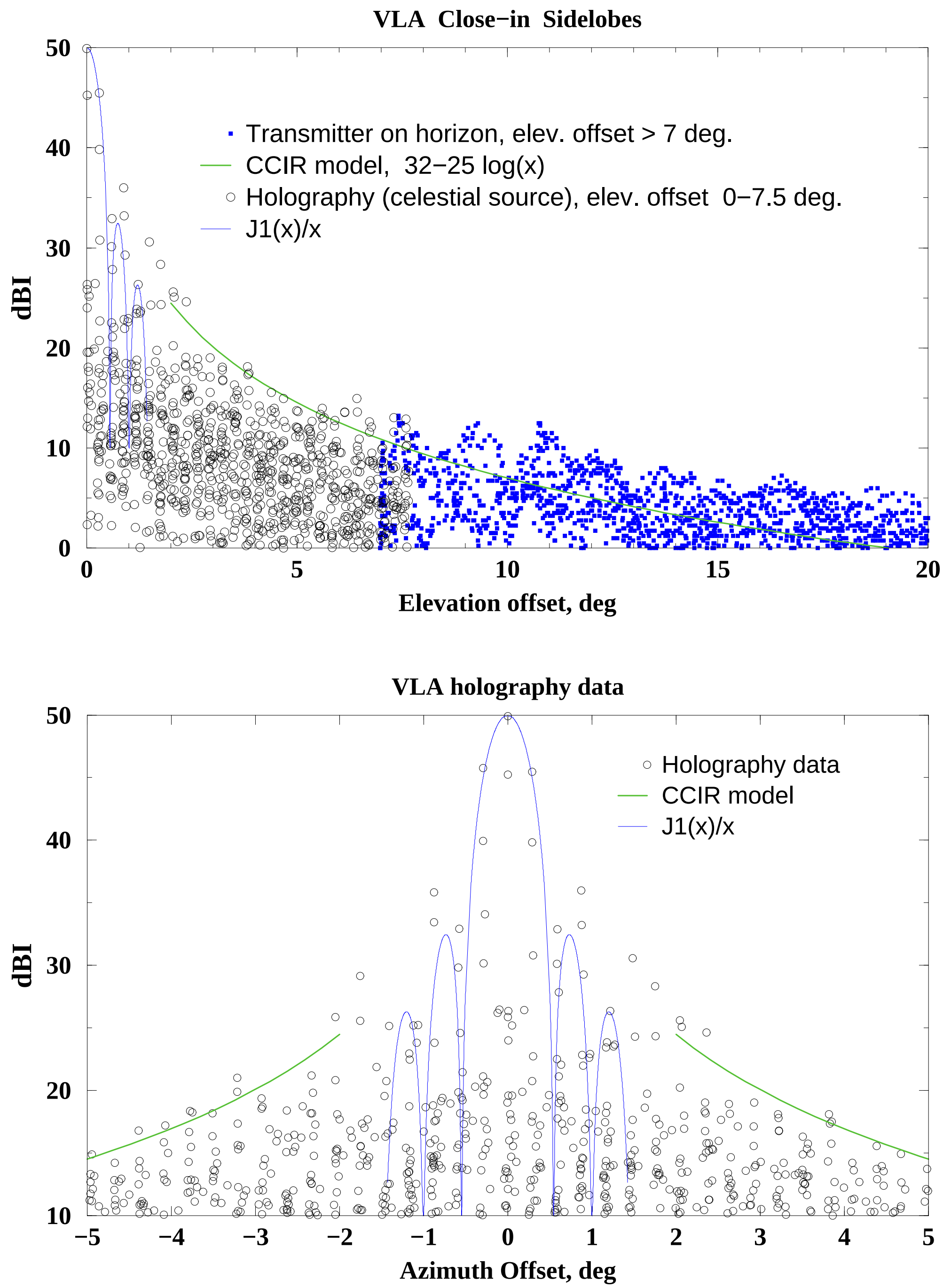

Fig. 4.— VLA close-in sidelobes, calibrated data at 1612 MHz plotted vs. offsets from transmitter. VLA holography data at 1385 MHz is overlaid on the 1612MHz data using the calculated on-axis gain of 50dB I. No relative shifts have been made and the match is good. A [J_1(x)/x] Airy pattern and CCIR model are shown for comparison.

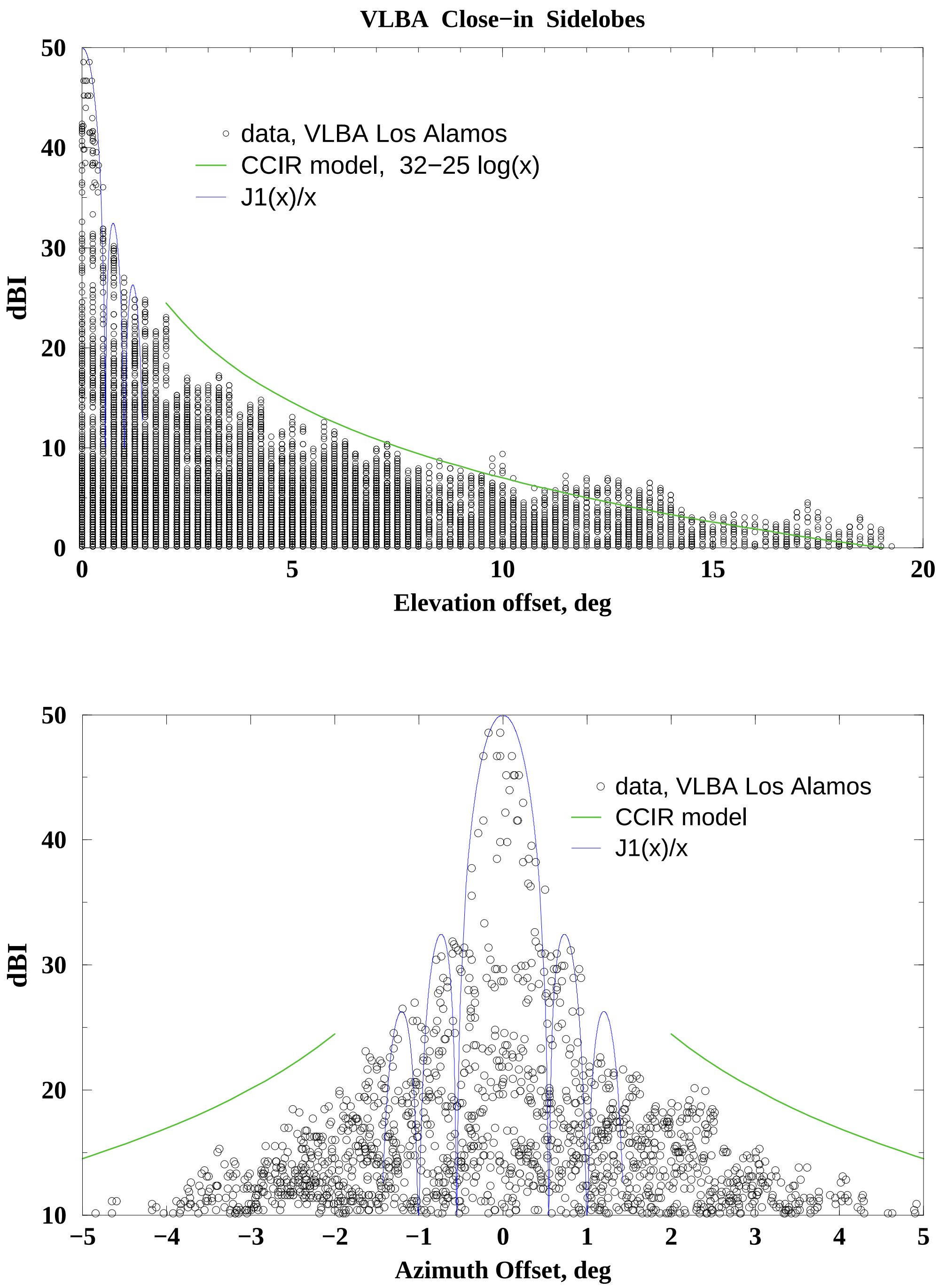

Fig. 5.— VLBA close-in sidelobes, plotted vs. offsets from transmitter. A correction (upto 8 dB on boresight) has been applied to the main beam for gain compression, (Fig-6) and the result is consistent with the expected, uncompressed, first sidelobe level as set by the calibration horn. A [J_1(x)/x] Airy pattern and CCIR model are shown for comparison.

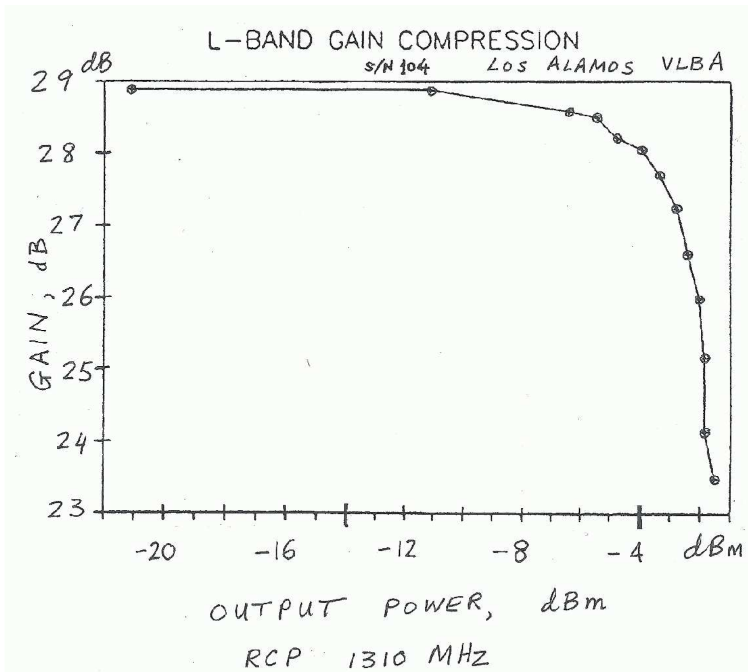

Fig. 6.— Gain compression measured for the VLBA Los Alamos RCP low-noise amplifier.

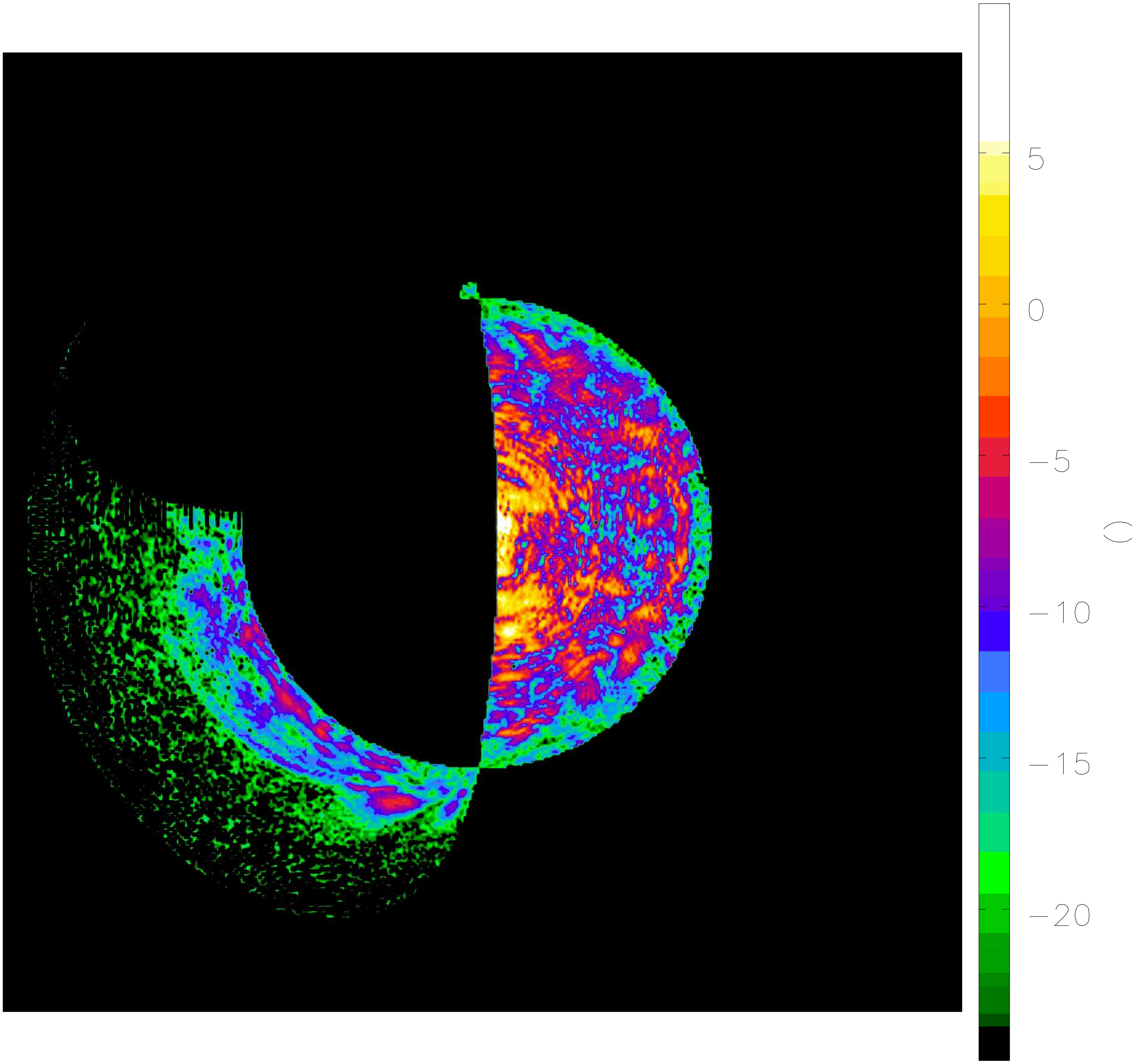

Fig. 7.— Contour plot of VLA sidelobes in 1° bins, in polar coordinates, with radius= zenith distance from boresight. The curved edge of the D-shape is 90° off axis, with the back lobes in the outskirts (partly unmeasured). Levels are in increments of 5 dB I, and the highest level is about 20 dB I (The on-axis gain is 50 dB I, but the antenna got no closer to the transmitter than 7°). Note the rings at about 80° and 110° off axis.

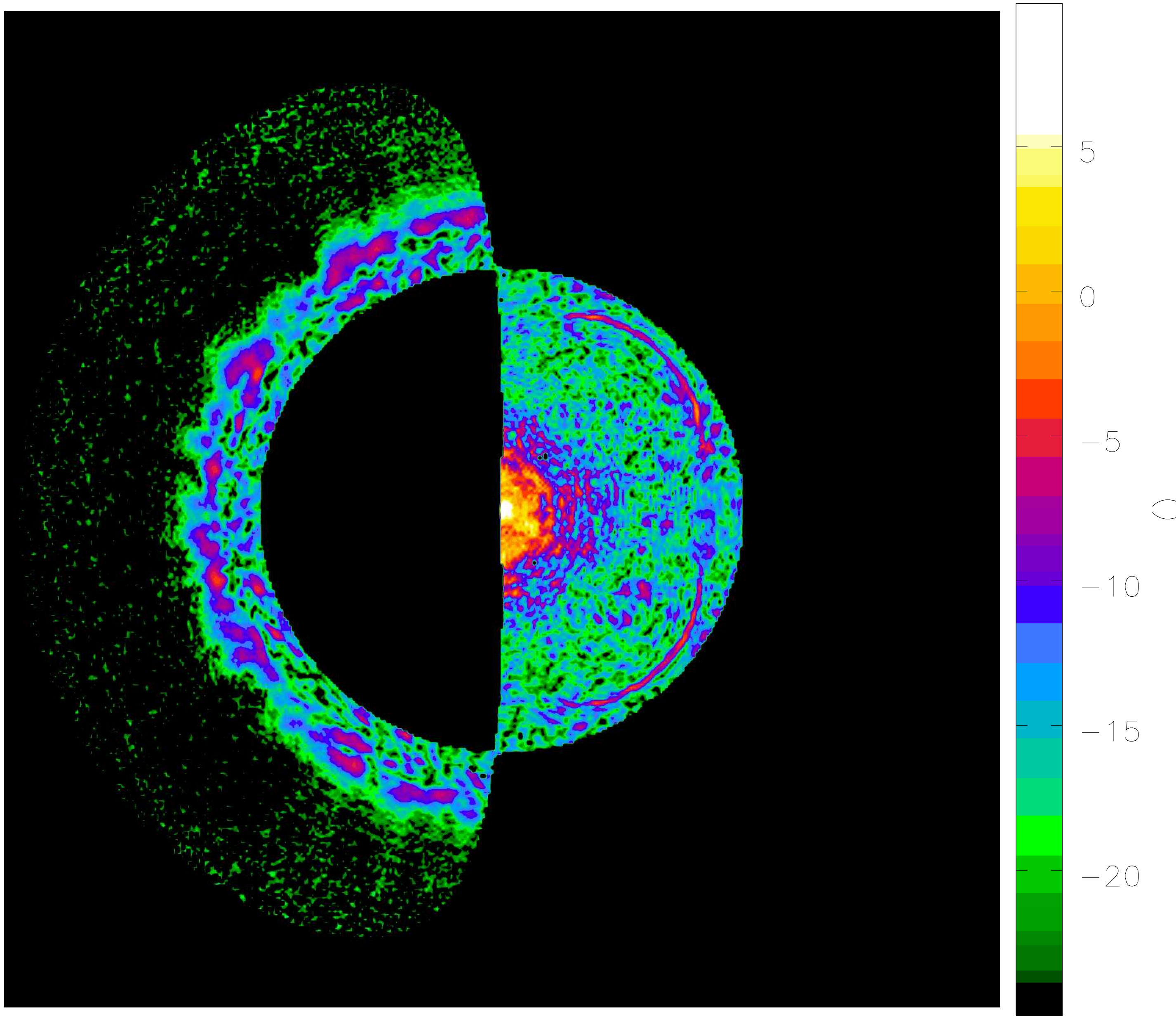

Fig. 8.— Contour plot of VLBA beam in 1° bins, in polar coordinates, with radius= zenith distance from boresight. The curved edge of the D-shape is 90° off axis, with the back lobes in the outskirts. Levels are in increments of 5 dB I, and the on-axis gain is 50 dB I. Note the rings at about 80° and 110° off axis.

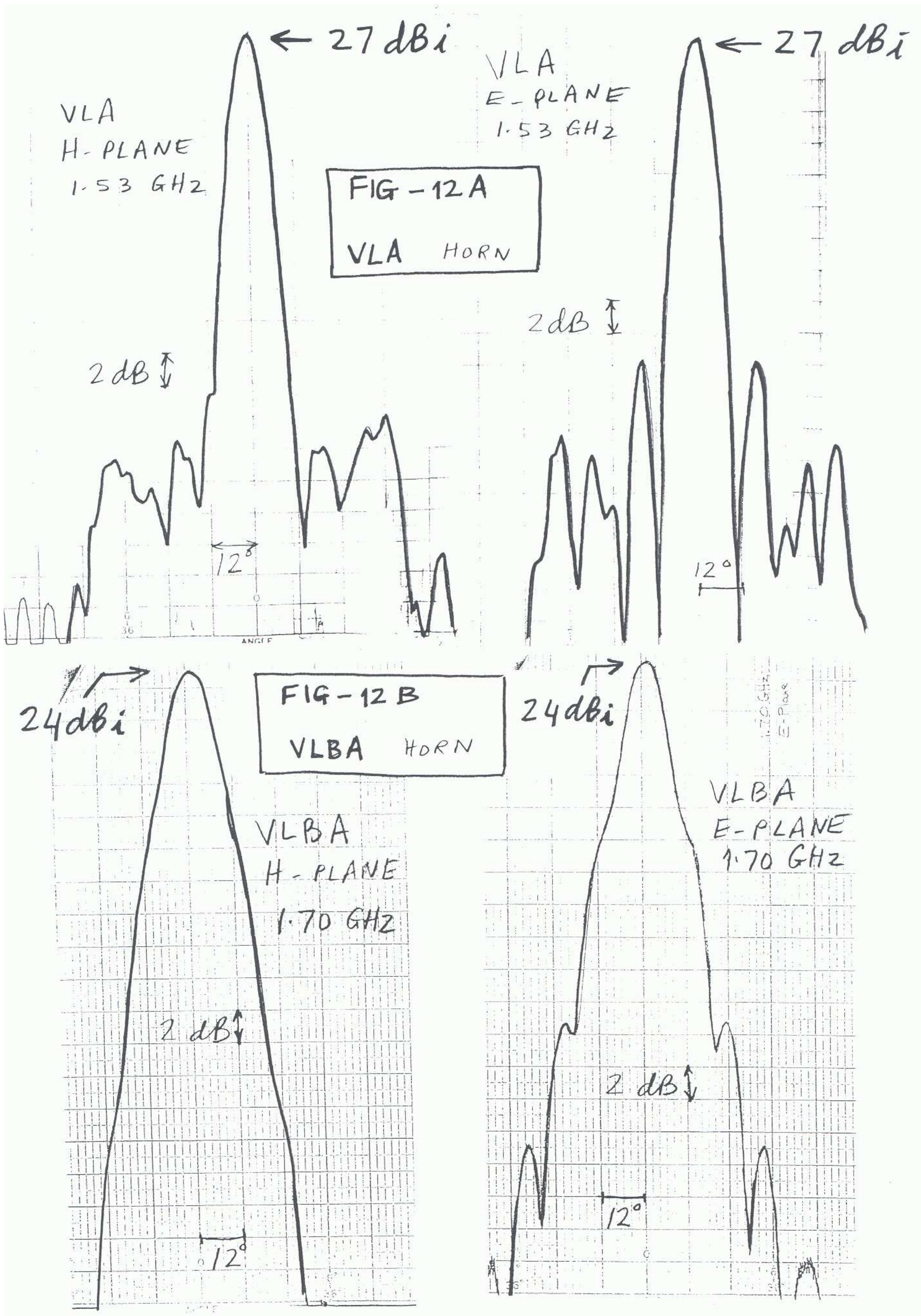

Fig. 9.— A: Feed patterns for VLA horn/lens at 1.53 GHz; note high sidelobes. B: Feed patterns for VLBA corrugated horn at 1.7 GHz; note low sidelobes. Horizontal scale is 12°/div, vertical scale 2dB/div.

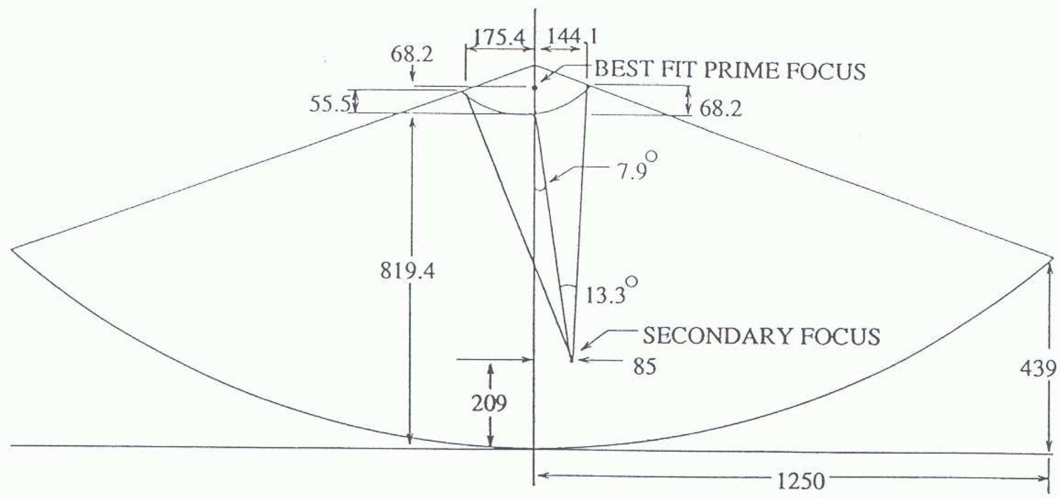

Figure a.

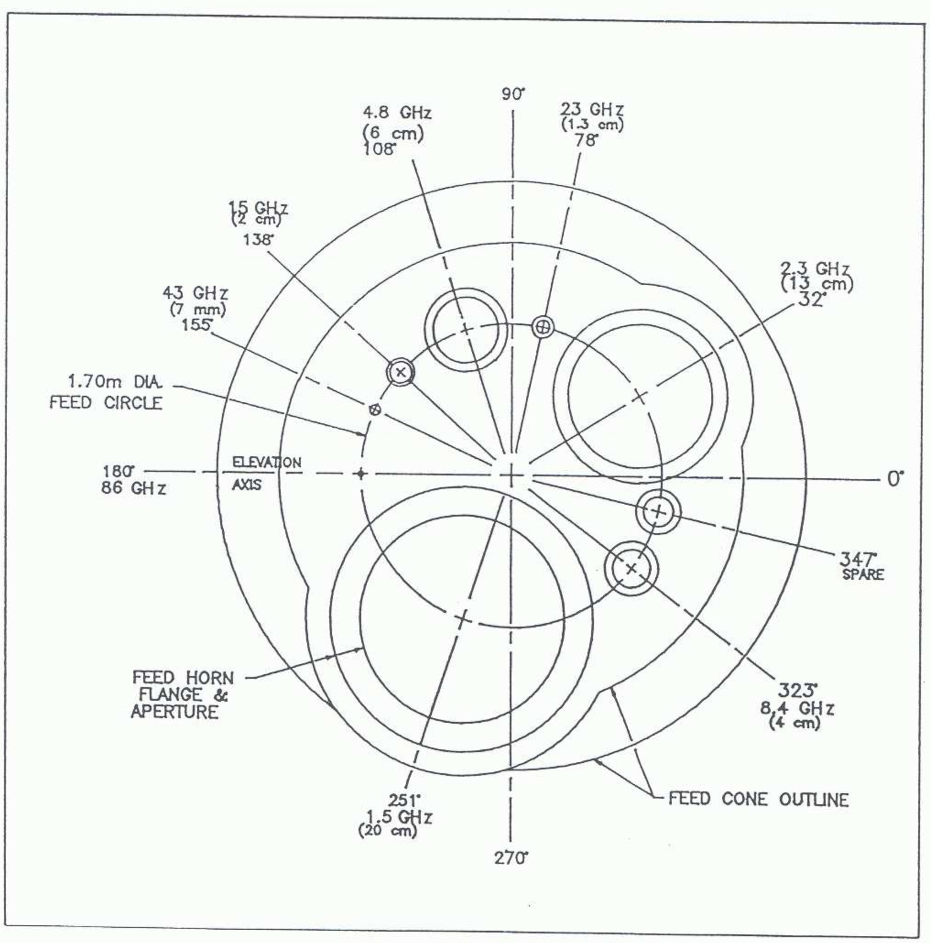

Figure b

Fig. 10.— Cassegrain Optics and Feed Circle Layout for VLBA.

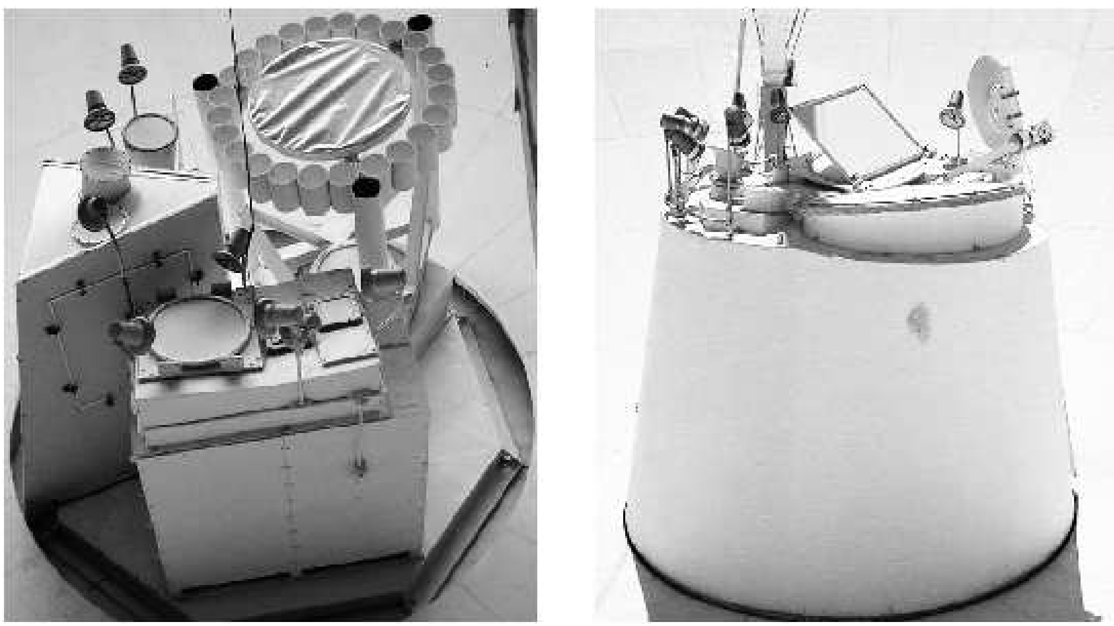

Fig. 11.— VLA and VLBA Feed Layout.

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RADIO-PROPAGATION PROGRAM

CHARACTERISTICS OF RECEIVING ANTENNA

NAME
vlaE18

LONGITUDE
107 36 07.0

LATITUDE
034 04 43.0

ELEVATION IN FEET
UNKNOWN

HEIGHT IN FEET
00050

CHARACTERISTICS OF TRANSMITTER

NAME
s baldy comet

LONGITUDE
107 11 21.0

LATITUDE
033 59 07.0

ELEVATION IN FEET
UNKNOWN

HEIGHT IN FEET
00005

CHARACTERISTICS OF DIGITAL-ELEVATION-MODEL DATA BASES

DEM DATA BASES TO BE USED
NGDC DATA

LONGITUDE AND LATITUDE OF SOUTHEAST CORNER
 60 00 00.0    23 00 00.0

LONGITUDE AND LATITUDE OF NORTHWEST CORNER
129 59 30.0    50 59 30.0

ANGULAR RESOLUTION
 00 00 30.0

FREQUENCY FOR CALCULATION IN MHz
      1612.0

EIRP FOR CALCULATION IN dBW
         0.0

ELEVATION OF RECEIVING ANTENNA CALCULATED FROM
DIGITAL-ELEVATION-MODEL DATA BASE IN FEET
 6980

ELEVATION OF TRANSMITTER CALCULATED FROM
DIGITAL-ELEVATION-MODEL DATA BASE IN FEET
10042

GREAT-CIRCLE DISTANCE IN DEGREES
  0.35

GREAT-CIRCLE DISTANCE IN KILOMETERS
   39.41

AZIMUTH OF TRANSMITTER AS SEEN FROM RECEIVING
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FIGURE 15A-1

Fig. 12.— Part 1 of 3: Propagation & Terrain, VLA ant #17 to South Baldy.

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ANTENNA IN DEGREES (N=>E)
 105.15

AZIMUTH OF RECEIVING ANTENNA AS SEEN FROM
TRANSMITTER IN DEGREES (N=>E)
 -74.62

GEOMETRIC-MEAN SCALING FACTOR FOR EFFECTIVE EARTH RADIUS
1.2108

GEOMETRIC-MEAN ATMOSPHERIC REFRACTIVITY
224.75

APPARENT ELEVATION OF RECEIVING ANTENNA AS SEEN
FROM TRANSMITTER IN DEGREES
 -1.48

APPARENT ELEVATION OF TRANSMITTER AS SEEN
FROM RECEIVING ANTENNA IN DEGREES
  1.19

OBSTACLES FOUND
```

	N	HORIZONTAL DISTANCE (KM)	VERTICAL DISTANCE (KM)	ELEVATION (KM)	RADIUS OF CURVATURE (KM)
TRANSMITTER	1	0.000	3.062	3.061	
RECEIVER	2	39.417	2.042	2.128	

```
REFERENCE POWER LEVEL FOR ONE WATT (E.I.R.P.) FOR THE DIRECT LINE OF SIGHT (dBW/m**2)
  -102.909
```

FIGURE 15A-2

Fig. 13.— Part 2 of 3: Propagation & Terrain, VLA ant #17 to South Baldy.

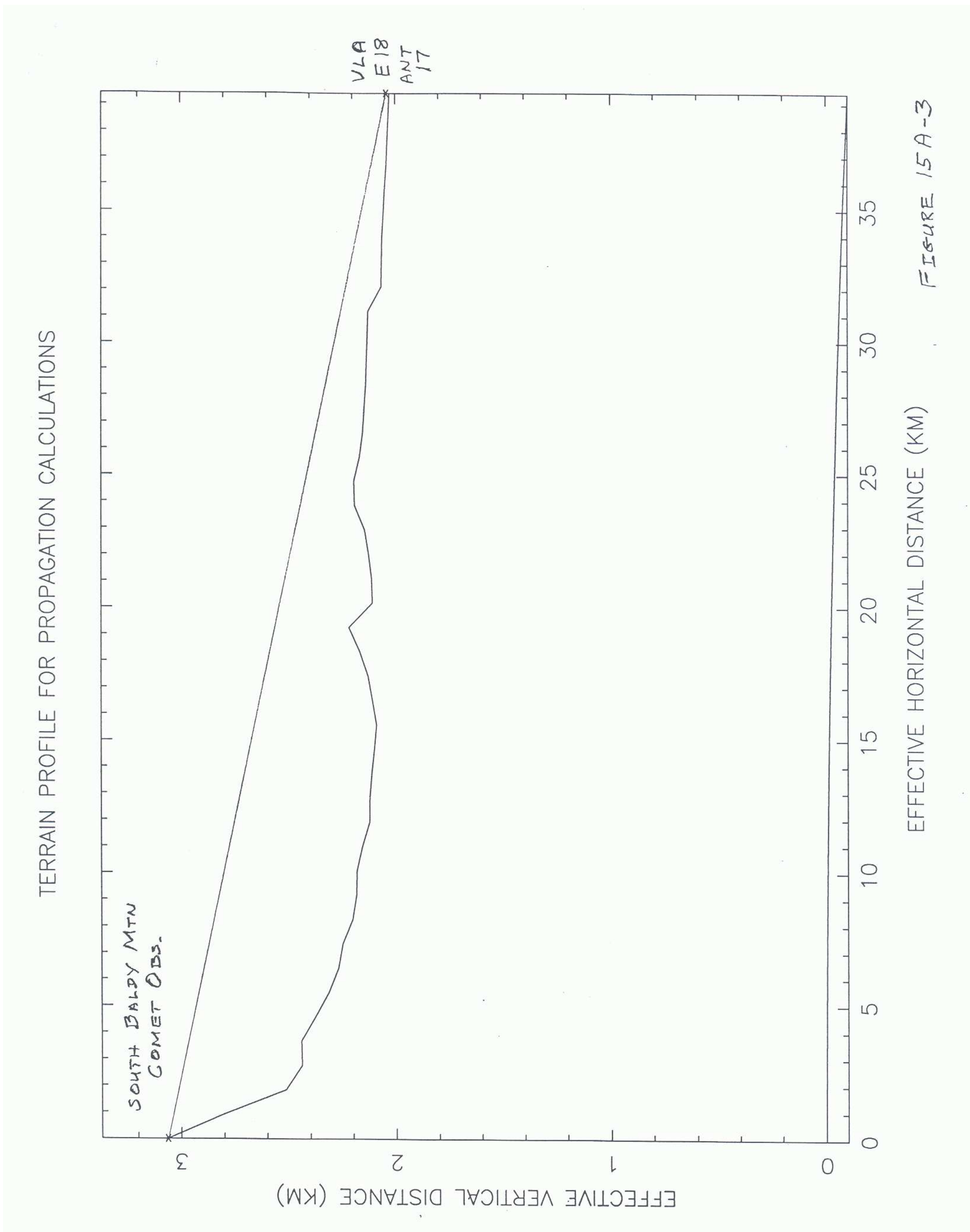

Fig. 14.— Part 3 of 3: Propagation & Terrain, VLA ant #17 to South Baldy.

7. References

[1] The Very Large Array, P. J. Napier, et al., IEEE Trans. MTT, April 1977, p. 244.

[2] The Very Long Baseline Array, P.J. Napier, et al., Proc. IEEE, November 1993. (Special Issue on the Design and Instrumentation of Antennas for Deep Space Communications and Radio Astronomy)

[3] ITU rec 509.... etc. see Appendix.1 (Draft!)

[4] For EVLA description, see http://www.aoc.nrao.edu/evla

8. Appendix 1: (Draft) Fact Sheet for ITU WP7D, D. Emerson & V. Dhawan

http://www.aoc.nrao.edu/ vdhawan/ and follow link to Appendix-1

9. Appendix 2: Recommendation 732 on Processing of Sidelobes

http://www.aoc.nrao.edu/ vdhawan/ and follow link to Appendix-2

```
RADIO-PROPAGATION PROGRAM

CHARACTERISTICS OF RECEIVING ANTENNA

NAME
LOS ALAMOS

LONGITUDE
106 14 42.01

LATITUDE
 35 46 30.33

ELEVATION IN FEET
 6453

HEIGHT IN FEET
  100

CHARACTERISTICS OF TRANSMITTER

NAME
tesuquepeak

LONGITUDE
105 46 54.0

LATITUDE
035 47 09.0

ELEVATION IN FEET
UNKNOWN

HEIGHT IN FEET
00100

CHARACTERISTICS OF DIGITAL-ELEVATION-MODEL DATA BASES

DEM DATA BASES TO BE USED
NGDC DATA

LONGITUDE AND LATITUDE OF SOUTHEAST CORNER
 60 00 00.0     23 00 00.0

LONGITUDE AND LATITUDE OF NORTHWEST CORNER
129 59 30.0     50 59 30.0

ANGULAR RESOLUTION
 00 00 30.0

FREQUENCY FOR CALCULATION IN MHz
      1720.0

EIRP FOR CALCULATION IN dBW
         0.0

ELEVATION OF TRANSMITTER CALCULATED FROM
DIGITAL-ELEVATION-MODEL DATA BASE IN FEET
11699

GREAT-CIRCLE DISTANCE IN DEGREES
  0.38

GREAT-CIRCLE DISTANCE IN KILOMETERS
   41.79

AZIMUTH OF TRANSMITTER AS SEEN FROM RECEIVING
ANTENNA IN DEGREES (N=>E)
  88.23

AZIMUTH OF RECEIVING ANTENNA AS SEEN FROM
```

FIGURE 15B-1

Fig. 15.— Part 1 of 3: Propagation & Terrain, VLBA Los Alamos to Tesuque Peak.

```
TRANSMITTER IN DEGREES (N=>E)
 -91.50

GEOMETRIC-MEAN SCALING FACTOR FOR EFFECTIVE EARTH RADIUS
1.1993

GEOMETRIC-MEAN ATMOSPHERIC REFRACTIVITY
215.16

APPARENT ELEVATION OF RECEIVING ANTENNA AS SEEN
FROM TRANSMITTER IN DEGREES
 -2.35

APPARENT ELEVATION OF TRANSMITTER AS SEEN
FROM RECEIVING ANTENNA IN DEGREES
  2.03

OBSTACLES FOUND
```

	N	HORIZONTAL DISTANCE (KM)	VERTICAL DISTANCE (KM)	ELEVATION (KM)	RADIUS OF CURVATURE (KM)
TRANSMITTER	1	0.000	3.596	3.566	
RECEIVER	2	41.801	1.883	1.967	

```
REFERENCE POWER LEVEL FOR ONE WATT (E.I.R.P.) FOR THE DIRECT LINE OF SIGHT (dBW/m**2)
  -103.423
```

FIGURE 15B-2

Fig. 16.— Part 2 of 3: Propagation & Terrain, VLBA Los Alamos to Tesuque Peak.

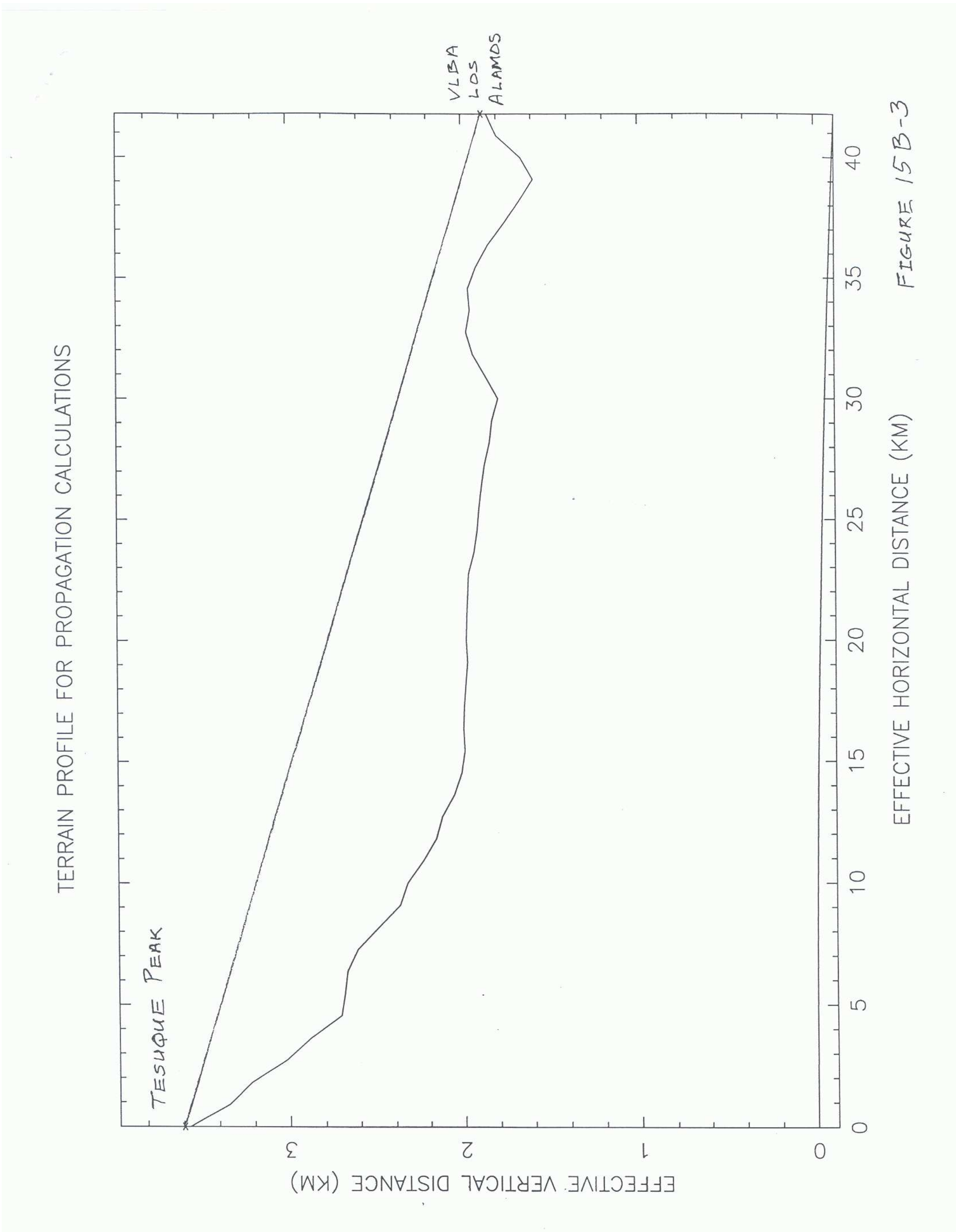

Fig. 17.— Part 3 of 3: Propagation & Terrain, VLBA Los Alamos to Tesuque Peak.