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POINTING CALIBRATION OF THE ESSCO 45-FT ANTENNA AT GREEN BANK

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Pointing Calibration of the ESSCO 45-ft Antenna at Green Bank

by

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Summary.

A conservative estimate of the rms pointing accuracy of the 45-ft antenna is measured to be 30"/cosE in azimuth, and 40" in elevation, similar to the conclusions of a study by Fomalont in 1973, who found 30" and 50".

Nighttime measurements during clear weather achieve somewhat better accuracy: about 20"/cosE in azimuth and 26" in elevation.

The antenna efficiency appears to fall off slightly at elevations below 30°. At 10° elevation, the efficiency drops to about 90% of the maximum.

The 1973 memo on 45-ft pointing by Fomalont is reproduced in Appendix A.

I. Introduction.

This report describes measurements of the pointing accuracy of the 45-foot (13.7 m) ESSCO antenna at Green Bank. This antenna was moved to Green Bank in 1988 from a site near Huntersville, WV, where it had been for about 15 years. Measurements of efficiency (D'Addario, Feb.1990) and pointing accuracy were undertaken to evaluate the suitability of the antenna as a communication link with orbiting VLBI antennas.

Observations of celestial radio sources made on January 31, February 1, and Feb. 6 were used to make preliminary estimates of the pointing model parameters. This model was used for a 24-hour observing run on February 8-9, 1990. Eight strong sources (see Table 1) were observed over a wide distribution in azimuth and elevation. Figure 1 shows the sky distribution of these observations.

The receiver used was a dual X- and S-band and dual polarization (right and left circular) receiver, formerly used on antenna 85-2. Only the X-band data was used for this pointing calibration.

Readjustments of the antenna reflector panels and re-leveling of the antenna will probably be done in the next few months. Thus the values of the pointing coefficients presented here will undoubtedly become obsolete in the near future. But the estimates of the rms pointing errors should remain valid.

II. Model

The pointing model was derived by Fomalont (March 1973 memo; see Appendix A). His terms for the feed offset are not used here, leaving 5 terms each in azimuth (A) and elevation (E). Let W1 through W10 be the coefficients, and ΔA and ΔE the corrections in azimuth and elevation, in the sense "Indicated minus True".

The elevation correction is given by

$$\Delta E = W1 + W2 \cos A + W3 \sin A + W4 \cos E + W5 \cot E$$

and in azimuth by

$$\Delta A \cos E = W6 \cos E + [W7 \cos A + W8 \sin A + W9] \sin E + W10$$

Two terms are related as follows:

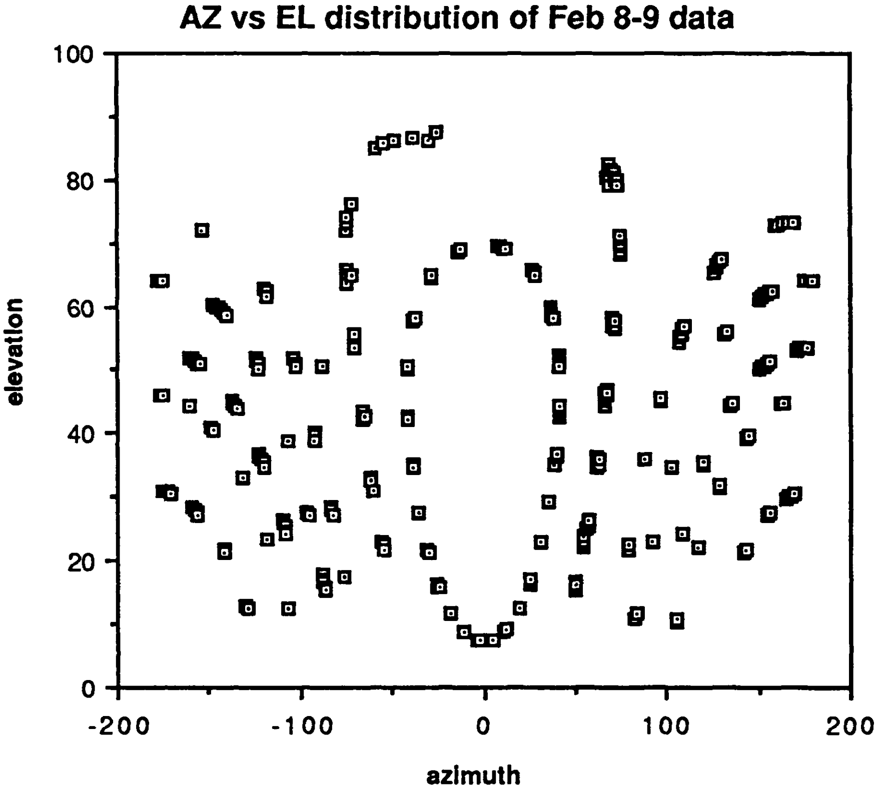
$W2 = W8$ (the elevation axis pointing error), and

$W3 = -W7$ (the azimuth axis pointing error).

Table 1. Calibration Sources

Source	RA(1950)	DEC(1950)	points used in fit A
3C84	03:16:29.6	41:19:52	22
Taurus A	05:31:31.0	21:59:00	34
Orion A	05:32:49.0	-05:25:15	19
3C273	12:26:33.3	02:19:43	29
Virgo A (3C274)	12:28:17.6	12:40:02	34
W31	18:06:25.6	-20:19:36	27
Cygnus A	19:57:44.4	40:35:46	53
Cass A	23:21:09.0	58:32:30	64

Figure 1. Sky Distribution of Observations.



III. Pointing Results

Pointing errors were measured separately for the XL and XR data. These two measurements were averaged together for each source, and the results used in a fit for the W parameters ("Fit A"). Fitting was done for the XR and XL data separately ("Fit B" and "Fit C"). Fits were also done to the averaged data, selecting only daytime observations ("Fit D"), and only nighttime observations ("Fit E").

The fitting program (written by Harry Payne) allows deviant data points to be filtered out, first if they exceed 4 times the mean absolute deviation from a least absolute deviation fit, and second, if they exceed 3 times the rms deviation to a least squares fit. A final least squares fit uses only the filtered data. This procedure might give improved accuracies for the Ws, but probably underestimates the actual pointing errors. Thus a fit was also done ("Fit F") in which all points were used. Fit F, with unfiltered residuals, probably gives a more realistic idea of the average size of pointing errors that would be found in practice. Thus a conservative estimate of the pointing errors is about 30" in azimuth and 40" in elevation.

No significant differences were found in the W parameters derived from fits A, B, C, and F.

Table 2 compares the rms deviations from the fit for the 6 cases. Table 3 lists the W parameters for Fit A. Results of Fit A are further presented in graphical form in Figures 2 and 3. Figure 2 shows the total pointing errors (ΔAcosE and ΔE) plotted against E and A. Figure 3 shows plots of the residuals to the fit.

Table 2. RMS Pointing Residuals

fit	data	no.points	rms in ΔA cosE	rms in ΔE
A	XR and XL averaged, all data	285	23"	38"
B	XR data only	276	23"	35"
C	XL data only	279	28"	43"
D	Daytime data, (averaged R,L)	142	24"	40"
E	Nighttime data, (" " ")	115	18"	26"
F	like fit A, but no filtering of residuals	302	31"	41"

Table 3. Model Parameters (arcminutes)

coefficient	value	std.err.	term	description
W1	-1.88	0.15	1.0	elevation encoder offset.
W2	-0.17	0.07	cosA	elevation axis misalignment = W8.
W3	-1.54	0.06	sinA	azimuth axis misalignment = -W7.
W4	-2.16	0.29	cosE	gravitational sag.
W5	0.80	0.05	cotE	refraction.
W6	12.24	0.55	cosE	azimuth encoder offset.
W7	1.62	0.10	cosA sinE	azimuth axis misalignment =-W3.
W8	-0.35	0.09	sinA sinE	elevation axis misalignment =W2.
W9	-3.35	0.54	sinE	non-perpendicularity of azimuth and elevation axes.
W10	-1.79	0.71	1.0	non-perpendicularity of beam center and elevation axes.

IV. Discussion of Pointing Results.

The rms elevation residuals to Fit A, as listed in Table 2, are about twice that of the residuals in azimuth, a result previously noticed by Fomalont (1973). The disparity in the two coordinates is considerably less for the nighttime data (Fit E), which show smaller residuals in both coordinates, but especially in elevation.

The separate fits to the daytime and nighttime data suggest that daytime differential thermal effects are a major cause of elevation pointing errors. It should be noted that the weather was quite clear during most of the 24-hour observing run, so direct sunlight was on the antenna during the entire day. Temperature records from the Interferometer weather station show daytime temperatures on Feb.8th ranging from 0° to 15° C. The nighttime range was from -4° to 3° C. Wind speeds were less than 10 MPH during the entire run. The larger temperature changes during the day, combined with heating effects of direct sunlight, can probably explain the larger daytime pointing residuals.

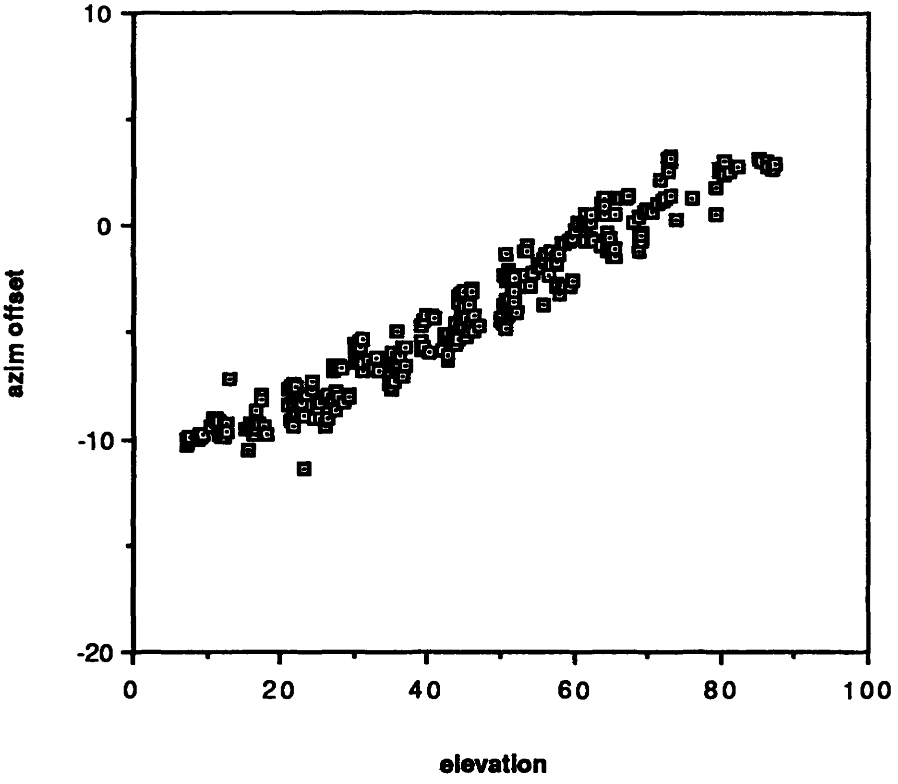
The XL data gives larger rms residuals than the XR, perhaps because the XL system temperature is about 15% larger than that of XR (D'Addario, 1990, 45-ft report).

There is a large azimuth encoder offset (W6) of 12 arcmin. This is probably why Figure 2a shows a strong dependance of azimuth error with elevation.

Although the antenna leveling was not checked after it was recently moved to Green Bank, the azimuth axis is only 1.6 arcminutes from the vertical (parameters W3 and W7).

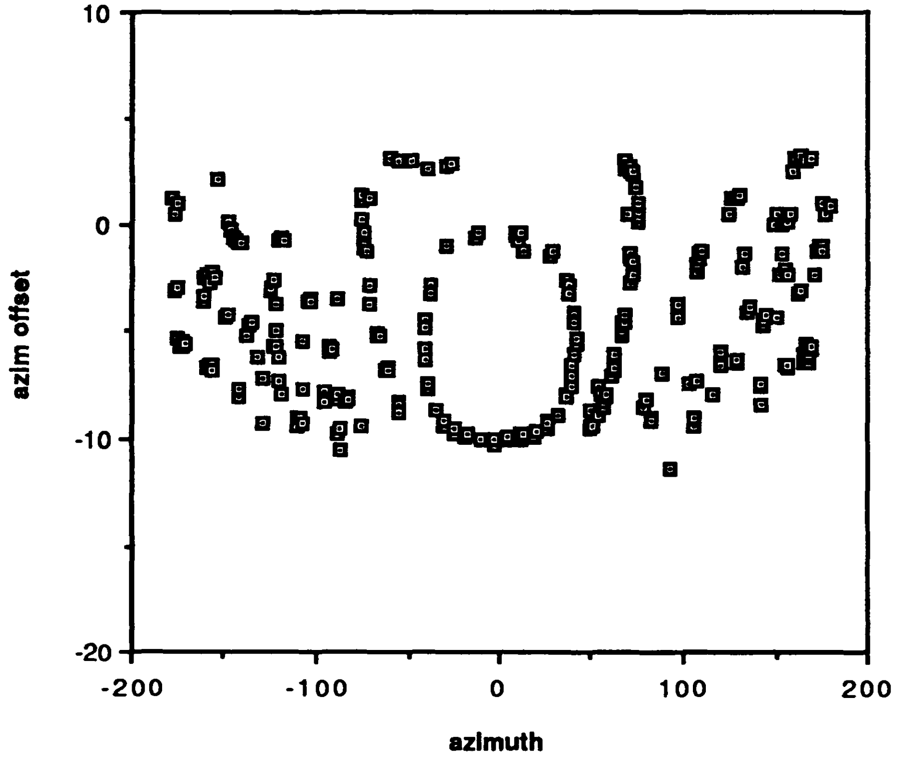
Fomalont (1973) reported the sag of the focus position due to gravity was fairly large, given by W4=-7 arcmin, but we find a much smaller value of -2.2 arcmin.

The residual plots, Figures 3a-d, do not show any serious, un-corrected-for, systematic effects.


45-ft feb 8 data

azimuth offset vs elevation

Fig. 2a


45-ft Feb 8 data

azimuth offset vs azimuth

Fig. 2b

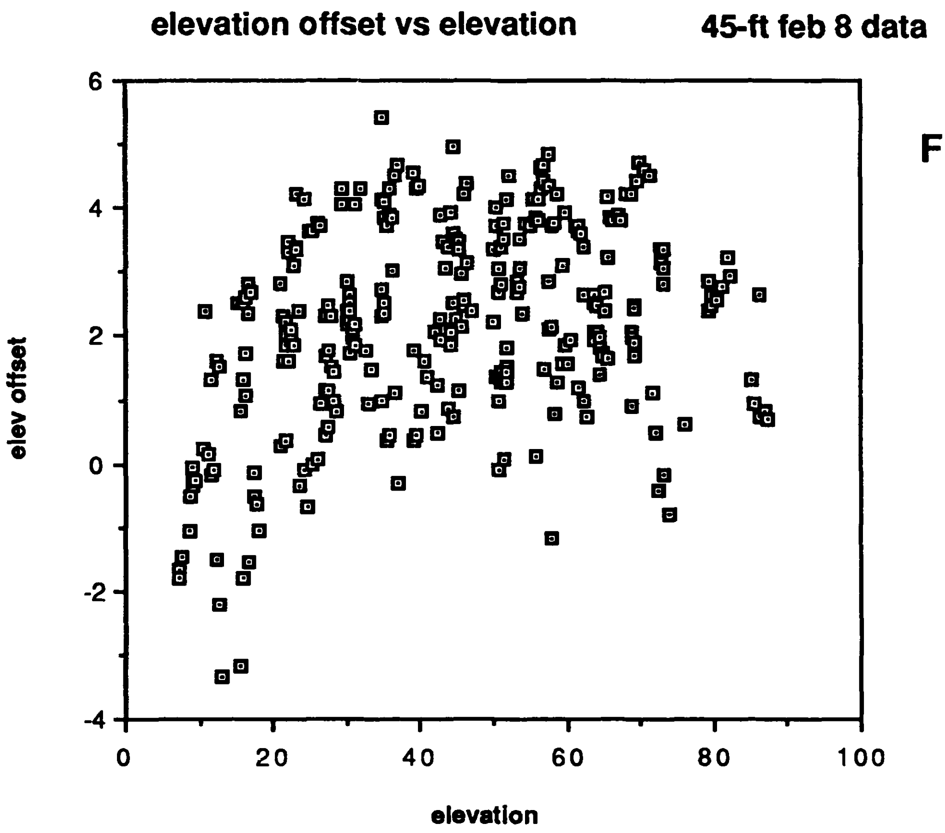

elevation offset vs elevation
45-ft feb 8 data
6
4
2
0
-2
-4
elev offset
0
20
40
60
80
100
elevation

Fig. 2c

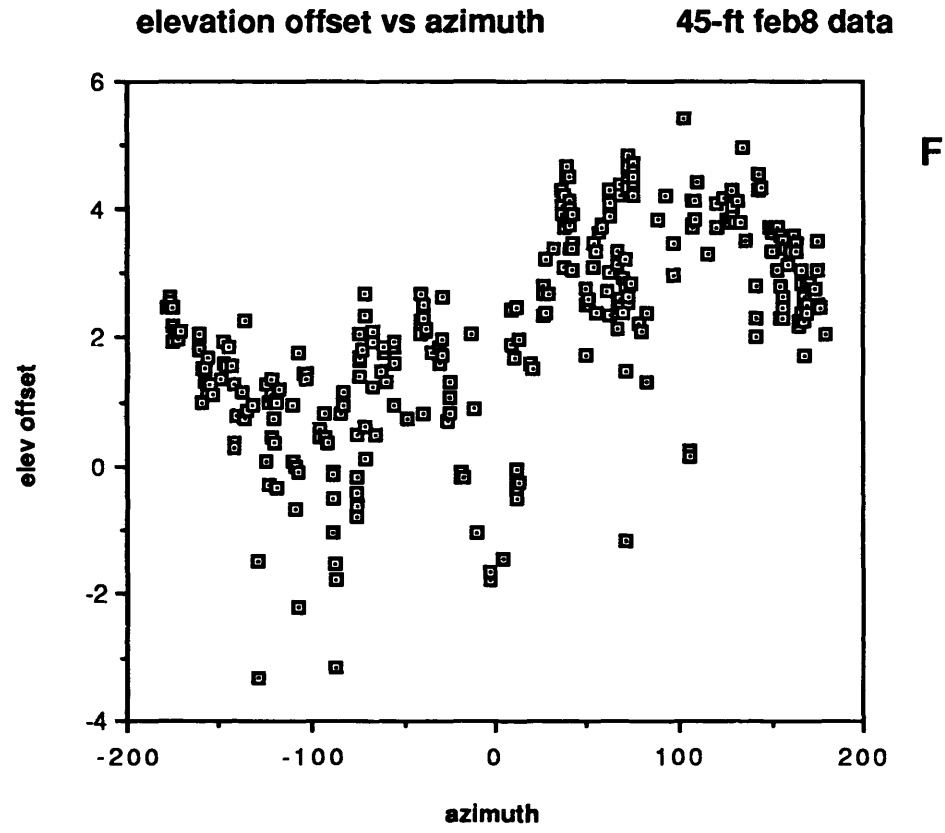

elevation offset vs azimuth
45-ft feb8 data
6
4
2
0
-2
-4
elev offset
-200
-100
0
100
200
azimuth

Fig. 2d

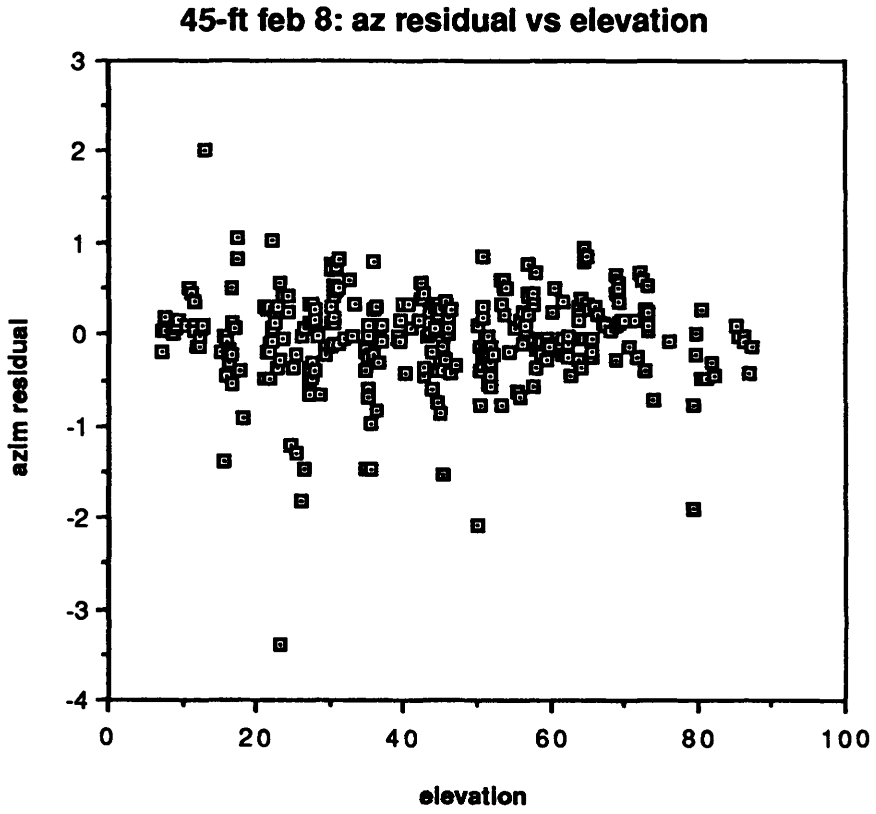

45-ft feb 8: az residual vs elevation
azim residual
3
2
1
0
-1
-2
-3
-4
0
20
40
60
80
100
elevation

Fig. 3a

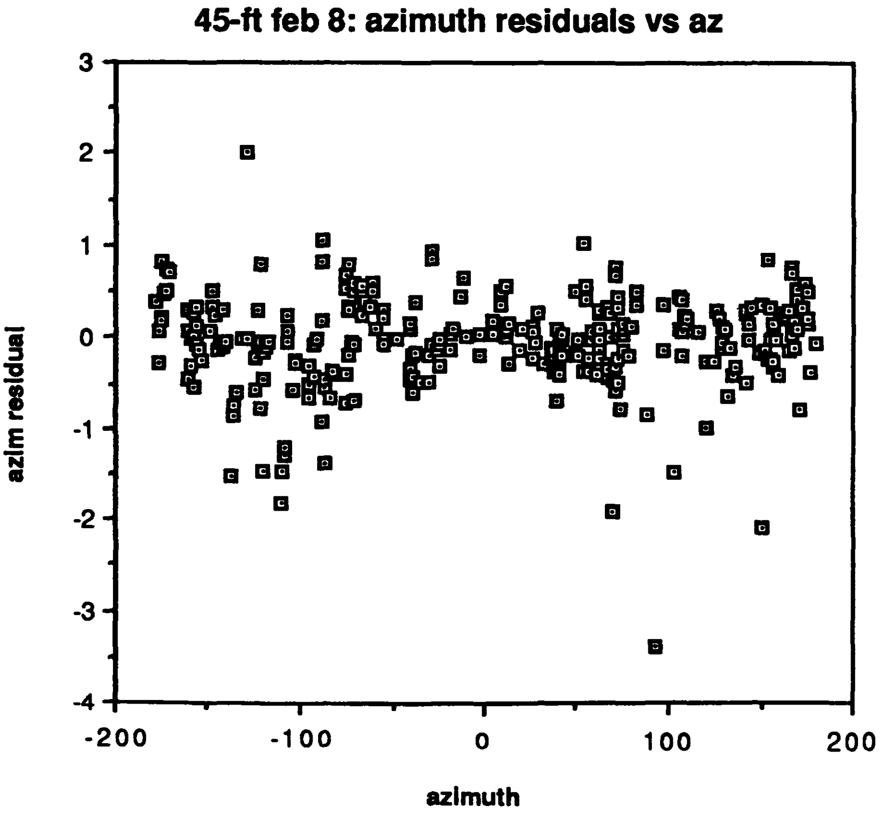

45-ft feb 8: azimuth residuals vs az
azim residual
3
2
1
0
-1
-2
-3
-4
-200
-100
0
100
200
azimuth

Fig. 3b

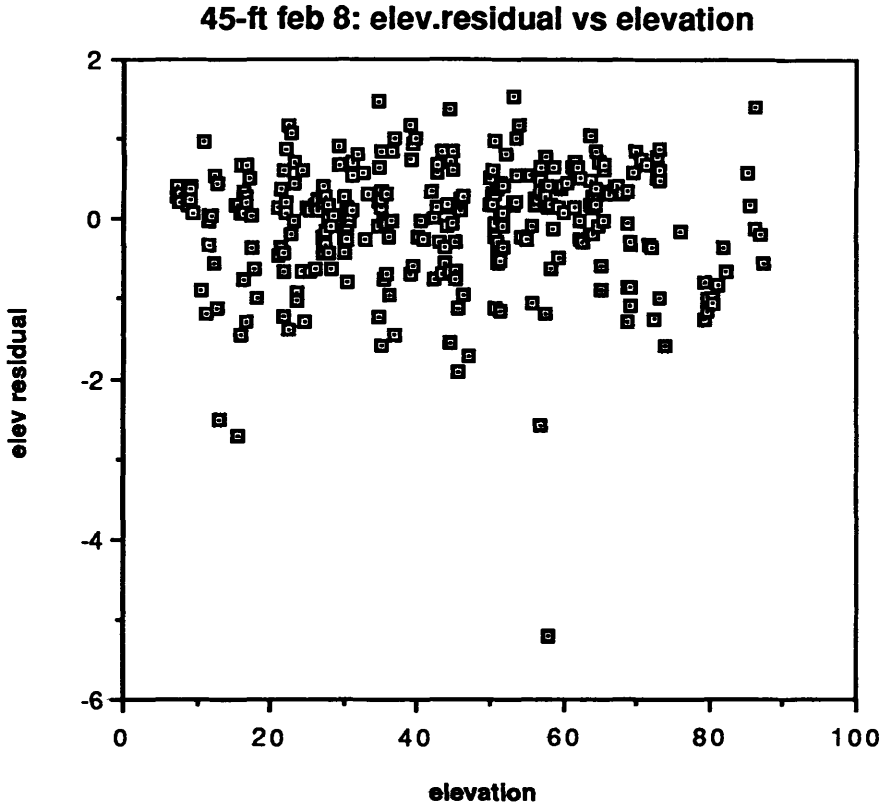

45-ft feb 8: elev.residual vs elevation
elev residual
2
0
-2
-4
-6
0
20
40
60
80
100
elevation

Fig. 3c

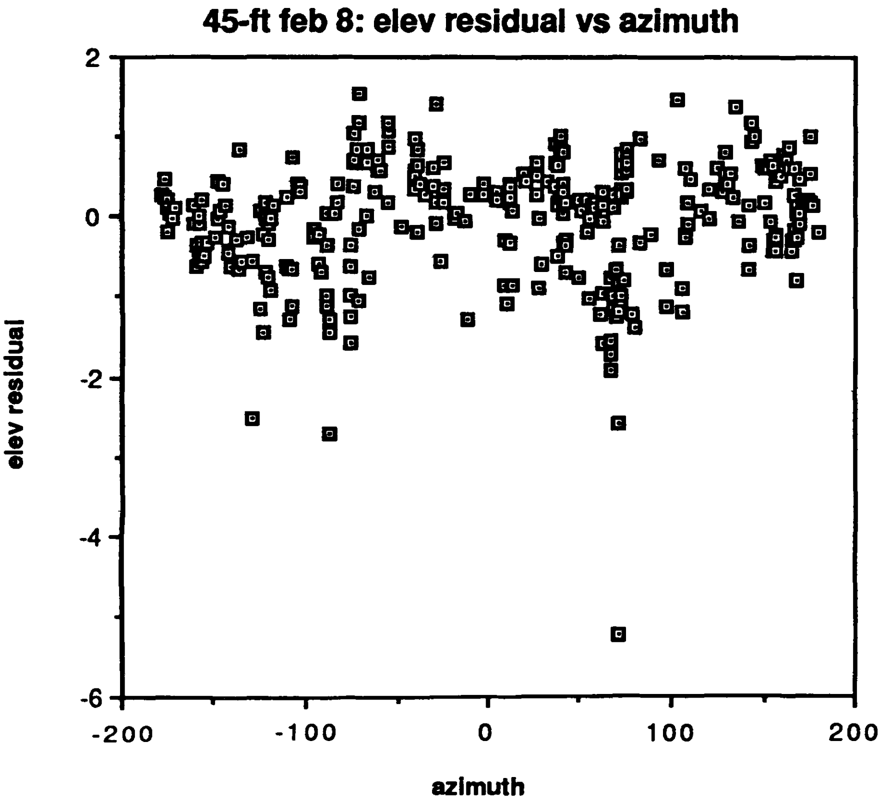

45-ft feb 8: elev residual vs azimuth
elev residual
2
0
-2
-4
-6
-200
-100
0
100
200
azimuth

Fig. 3d

V. Elevation dependence of Efficiency.

D'Addario (1990) found an aperture efficiency of about 40% from observations of strong sources at high elevations. The pointing observations yield estimates of the peak amplitude of each source, as described in section VI. No gain calibrations were done during the pointing observations, but if we assume that the receiver gain was constant, then changes in amplitude for a given source should be proportional to changes in antenna efficiency. Figures 4a and 4b show amplitudes for Cass A and Cyg A plotted versus elevation. These amplitudes are simply voltages from the detector. There is evidently very little change in amplitude for elevations above 30°. At 20°, the efficiency has fallen to about 95% of the maximum; at 10° it is down to about 90%.

VI. Measurement Method

Each source is observed with a cross-shaped pattern consisting of five positions each in azimuth and elevation centered on the calculated position of each calibration source. For step size D, each azimuth sequence consists of positioning the antenna at the following offsets:

$$x_a(n) = nD/\cos E$$

and in elevation at offsets

$$x_e(n) = nD, \qquad \text{where } n = -4, -1, 0, 1, 4$$

(We used D=7 arcmin for the Feb 8-9 observations.)

Let P(n) be proportional to the measured total power at step n of a scan, whether in azimuth or elevation. Let H be the HPBW of the antenna. The measured pointing error is derived from the 5-point series separately in each coordinate. The method is adapted from Clark (1968).

First remove the baseline:

$$B(-1) = P(-1) - [5P(-4) + 3P(4)]/8$$

$$B(0) = P(0) - [P(-4) + P(4)]/2$$

$$B(1) = P(1) - [3P(-4) + 5P(4)]/8$$

The assumed beam shape is gaussian:

$$B = A \exp(-(x-a)^2/2s^2)$$

where A is the source strength (or amplitude), and a is the pointing error.

The HPBW is related to s by: $2.3548s = H$

(we used H=11 arcmin for the 45-ft at X-band)

Then the unknowns A and a are given by

$$a = (s^2/2D) \ln[B(1)/B(-1)]$$

and $A = B(0) \exp(a^2/2s^2)$

After the 45-ft control program performs each 5-point sequence, the above calculation is done and the resulting values of a and A are written to an output file.

The P(n)s are the result of averaging the total power measurements over a specified interval, which,for these runs, was about 15 seconds. The standard deviation of each total power measurement was also written to the output file. These are used by the off line processing program to reject data with too low a S/N ratio (=A/stddev(P)). For these data, a minimum S/N of 4 was used. After this filtering, the data were given to the fitting program mentioned above.

References

L.R. D'Addario, "Performance of the NRAO 45-foot Antenna as an Earth Station for Orbiting VLBI", Feb.1990 (report sent to NASA).

B.G.Clark, "Programs for the Interferometer DDP-116 Computer", 1968 (manual written for the NRAO Interferometer).

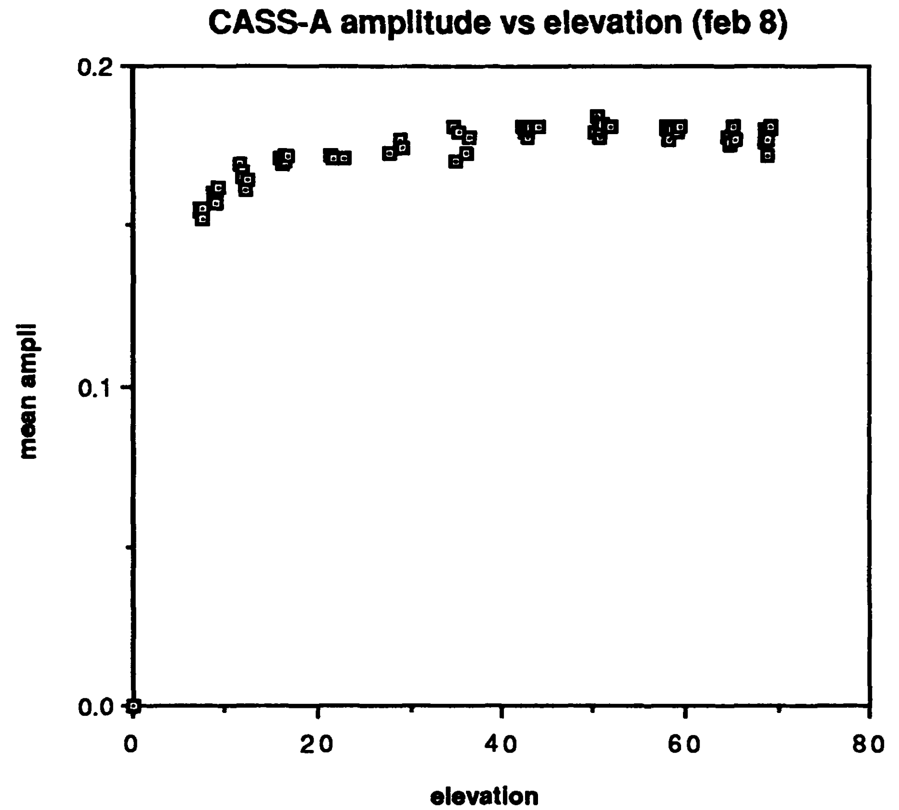

CASS-A amplitude vs elevation (feb 8)
0.2
0.1
0.0
mean ampli
0
20
40
60
80
elevation

Fig. 4a

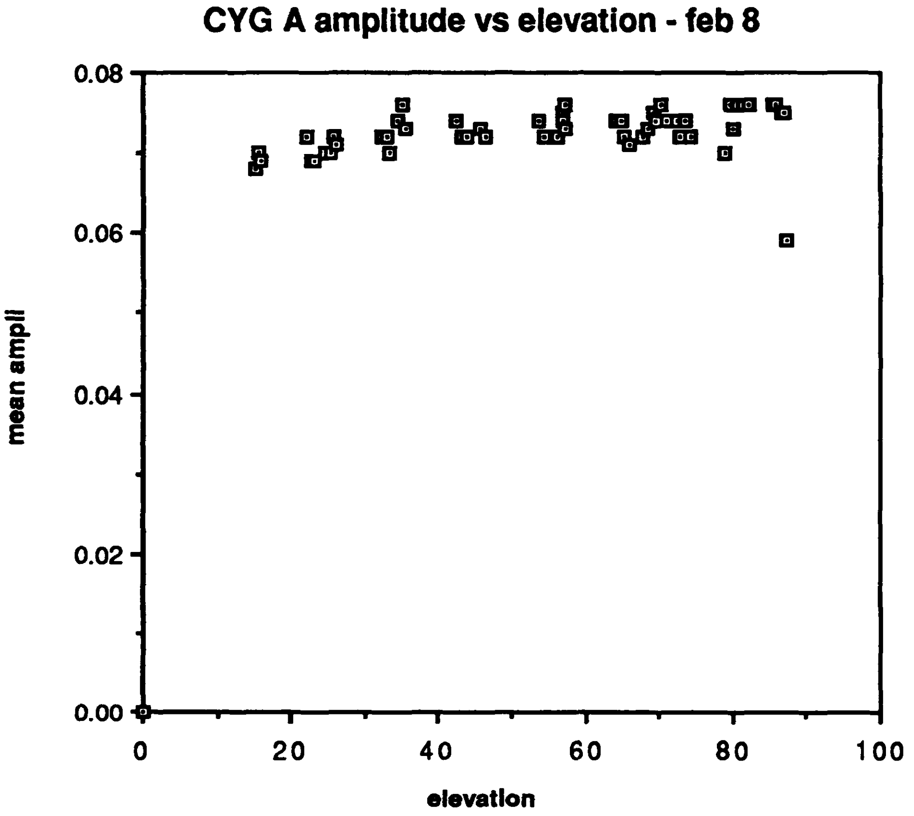

CYG A amplitude vs elevation - feb 8
0.08
0.06
0.04
0.02
0.00
mean ampli
0
20
40
60
80
100
elevation

Fig. 4b

APPENDIX A
Copy of memo by E. Fomalont

March 8, 1973

To: D. Hogg, F. Crews, G. Conant, R. Weimer, R. Hallman, R. Hjellming,
J. Coe, L. Howell, B. Vance, J. Ralston, J. Payne, W. Brundage, B Horne

From: E. B. Fomalont

Subject: 45-Foot Pointing and Efficiency

Summary: The pointing properties of the 45-ft antenna are astronomically acceptable with no additional adjustments. The efficiency, although not as large as anticipated, does not significantly decrease with elevation.

The results of an initial survey of the 45-ft pointing were reported in a memo of January 29, 1973, from which large azimuth and elevation encoder offsets were found and corrected. However, the data was too sparse for an accurate determination of the other pointing parameters. Furthermore, recent changes of the antenna surface panels may have affected the pointing.

A more complete survey of the pointing properties and efficiency of the 45-ft antenna was made between February 28 and March 2, 1973. Eight strong sources (Tau A, 3C147.1, 3C274, Cen A, Sgr A, W31, Cyg A and Cas A) were observed at a wide range of elevation and azimuth at both S-Band and X-Band. The observations were taken with the feed box in various orientations to check for non-alignment of the feeds and numerous efficiency measurements were made to check on the elevation dependence of the efficiency.

I. Pointing Results

The pointing errors as a function of azimuth (a) and elevation (e) were fit to the following functional form:

Δa cos e =		(Indicated-True) Azimuth
C1 cos(e)	1!03	Azimuth encoder offset
+C2 cos(a) sin(e)	-0!40	Azimuth axis pointing error
+C3 sin(a) sin(e)	0!94	Elevation axis pointing error
+C4 sin(e)	2!32	Collimation of axes (non-perpendicularity of azimuth and elevation axes)
+C5	-5!24	Telescope collimation (non perpendicularity of beam center and elevation axes)
+C6 cos(f-C7)	{0!71 {152°	Feed offset (f = feed angle)

Δe =		(Indicated-True) Elevation
D1	2!34	Elevation encoder offset
+D2 cos(a)	0!68	Elevation axis pointing error = C3
+D3 sin(a)	0!61	Azimuth axis pointing error = -C2
+D4 cos(e)	-7!00	Bending or sag
+D5 cot(e)	1!10	Refraction
+D6 cos(f-D7)	{0!76 {250°	Feed offset (f = feed angle)

The rms deviation in azimuth of a data point from the best fit is 0!49; for elevation the rms deviation is 0!84. Specific comments concerning the pointing errors are:

1) The encoder offsets are now small. Part of the original large offsets may have been due to components of the axes collimation terms which are indistinguishable from encoder offsets.

2) The solutions of the antenna axis alignment from the azimuth and elevation solutions are consistent. The axis orientation is 0!8 north and 0!5 east of zenith.

3) The collimation of axes determined here agrees well with the earlier determination. This parameter should remain fixed.

4) Telescope collimation is a measure of the beam center position from the perpendicular of the elevation axis. This parameter also remains fixed.

5) The bending of the focus position due to gravitational force is large but the value of -7!0 is consistent with that measured by J. Ralston.

6) Refraction of 1!1 was assumed in the solution.

7) The feed offset terms, independently derived from the elevation and azimuth solutions, are in good agreement. The amplitudes are the same and the offset angles are ~90° apart in azimuth and elevation. The offset of 0!73 radius corresponds to a displacement of 3/32 inch which is that measured by J. Ralston. The zero offset of the feed angle encoder must not be changed to insure this pointing term is added properly.

Other problems or comments:

1) Good agreement between X-Band And S-Band pointing.

2) Low elevation points were difficult to fit to the elevation data. Pointing residuals of 1 to 2 arc minutes were common.

3) For a period of 4 hours after sunset on February 28, the elevation appeared to change systematically by 1!0 at both S and X-Band.

II. Efficiency Measurements

Efficiency measurements were made of selected sources at various elevations at S-Band and X-Band. The results are:

Source	Elevation	Azimuth	Efficiency	
			SR-Band (cal = 23°.1)	XL-Band (cal = 15°.5)
Cas A	13°	338°	36	41
Tau A	23	280	38	37
Cyg A	33	61	38	41
Cas A	38	41	43	39
Cyg A	59	73	-	34
Tau A	65	235	38	34
			$<\eta>$=38.6	37.6, (38.9 w/o 59°)

There is no systematic changes of efficiency with elevation. The low efficiency at S-Band is (hopefully) due to a drift in the assumed cal noise temperature.