NATIONAL RADIO ASTRONOMY OBSERVATORY

VERY LARGE ARRAY PROGRAM

SOCORRO, NEW MEXICO

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VLA PRIMARY BEAM PARAMETERS

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In February, 1981, the primary beams of the VLA antennas were measured at all bands using a special version of the MODCOMP computer program G10, written by Gareth Hunt. This special program, which can be initiated by specifying G10 to be run from ALT, allows a full, two dimensional, measurement of the main beam out to the first null to be made by changing the pointing of the antenna while it is tracking a strong point source. During the measurement, the phase center of all interferometers is located at all times on the point source. The pointing of each antenna is changed so as to provide a raster scan of the main beam. Azimuth and elevation collimation pointing offsets are introduced according to

$$\Delta Az = m\Delta\theta, \quad m = 0, \pm1, \pm2, \pm3, \pm4 \tag{1}$$

$$\Delta El = n\Delta\theta, \quad n = 0, \pm1, \pm2, \pm3, \pm4 \tag{2}$$

where ΔAz is the azimuth collimation offset, ΔEl is the elevation collimation offset and $\Delta\theta = \frac{9.72}{F}$ arc.min., where F is the signed sum of LO frequencies in Ghz. Note that since ΔAz and ΔEl are collimation offsets, they represent actual displacements of the beam on the sky. The azimuth offset is not reduced by a cos(El) factor. All combinations of n and m are provided so a 9 by 9 raster of the main beam is obtained. At any time all scanning antennas have the same value of m and n. During the measurement, a reference antenna is kept pointing at the point source. Fringe strength on a baseline containing the reference antenna and a scanning antenna gives a measure of the antenna voltage pattern, whilst baselines containing two scanning antennas give a measure of the antenna power pattern.

The measurements were made using 20 sec integrations on 3C84. The two-dimensional beam data was calibrated using observations for which m = n = 0 at the beginning, middle and end of the raster scan. No effort was made to peak up the pointing of the antennas.

We define the "array primary beam", B, at angle (ΔAz, ΔEl) as the power pattern averaged over all baselines:

$$B(\Delta Az;\Delta El) = \frac{1}{N} \sum_{i=1}^{N} V_i \; (\Delta Az,\Delta El) \tag{3}$$

where $V_i(\Delta Az,\Delta El)$ is the calibrated fringe amplitude measured on the i^{th} baseline when both antennas have their pointing offset by (ΔAz, ΔEl). N is the total number of baselines participating in the measurement. Both AA and CC correlators are included in the summation in (3), so B is the primary beam appropriate for a total intensity map.

The measurements of B for the four bands (L, C, U, K; respectively at 1465, 4885, 15035 and 22485) are shown in Figures 1a-d. Azimuth and elevation cuts (n = 0 and m = 0 respectively) are shown. The error bars indicate the standard deviation of the V_i divided by the square root of the number of antennas. The curves in the figures are only hand-drawn smooth curves. No attempt was made to fit the data. The array primary beam appeared to scale well with frequency, and only at U band there seemed to be an indication that the array beam was notably wider than an individual antenna beam.

We now present polynomial fits for the primary beam. This beam will be supposed to be frequency independent and, of course, axisymmetric. The radial coordinate will be denoted by R and expressed in units of arcmin * GHz.

From Figures 1a-d we extracted nine uniformly spaced sample points which are shown in each graph as large black squares, and listed in Table 1.

Table 1

SAMPLE POINTS

R (arcmin * GHz)	P(R)
0.0	1.00
5.0	0.98
10.0	0.89
15.0	0.73
20.0	0.57
25.0	0.41
30.0	0.27
35.0	0.14
40.0	0.06

Least squares fits to these points were made with polynomials of the form:

$a_0 + a_2 * R{**}2 + a_4 * R{**}4 + \ldots + a_n * R{**}n$

Note that ONLY EVEN POWERS of R are used!

A polynomial of degree 6 was adopted. We also made a similar fit to the inverse primary beam (after all, that is the function one wants to multiply the maps with). This function needs one extra term (degree 8), but it has the added advantage that the polynomial is not so unstable beyond the last sample point. Table 2 gives the coefficients for both polynomials, Figure 2 shows the straight primary beam fit with the sample points, and Figure 3 the inverse of the fit to the inverse primary beam, again with the sample points.

Table 2

POLYNOMIAL COEFFICIENTS

	Primary Beam	Inverse Primary Beam
a_0	1.007139	0.9920378
a_2	-0.1338562E-2	0.9956885E-3
a_4	0.6969709E-6	0.3814573E-5
a_6	-0.1444383E-9	-0.5311695E-8
a_8		0.3980963E-11

The r.m.s. deviation of the inverse fit from the sample points is 0.6% of the peak (all percentages here refer to the peak, so beware at the outer fringes!). We estimate that this fit is accurate to about 1% with respect to the weighted average of the measurements. It will be clear that there may be larger deviations in individual cases, depending on frequency, parallactic angle, antenna, and pointing quality. The fit to the straight primary beam is good out to 40 arcmin GHz, the fit to the inverse primary beam is good out to a little further, say, the 5% level, or twice the half power point (44.3 arcmin GHz).

The half power point of the inverse fit lies at R = 22.133 arcmin GHz. Hence the Full Width at Half Power is 44.255/frequency (GHz). Table 3 gives, just for reference, the FWHP's at some commonly used frequencies.

Table 3

SOME PRIMARY BEAM WIDTHS

Band	Frequency (MHz)	FWHP (arcmin)
L	1400	31.6
L	1420	31.2
L	1465	30.2
L	1665	26.6
C	4885	9.06
U	15035	2.94
K	22485	1.97

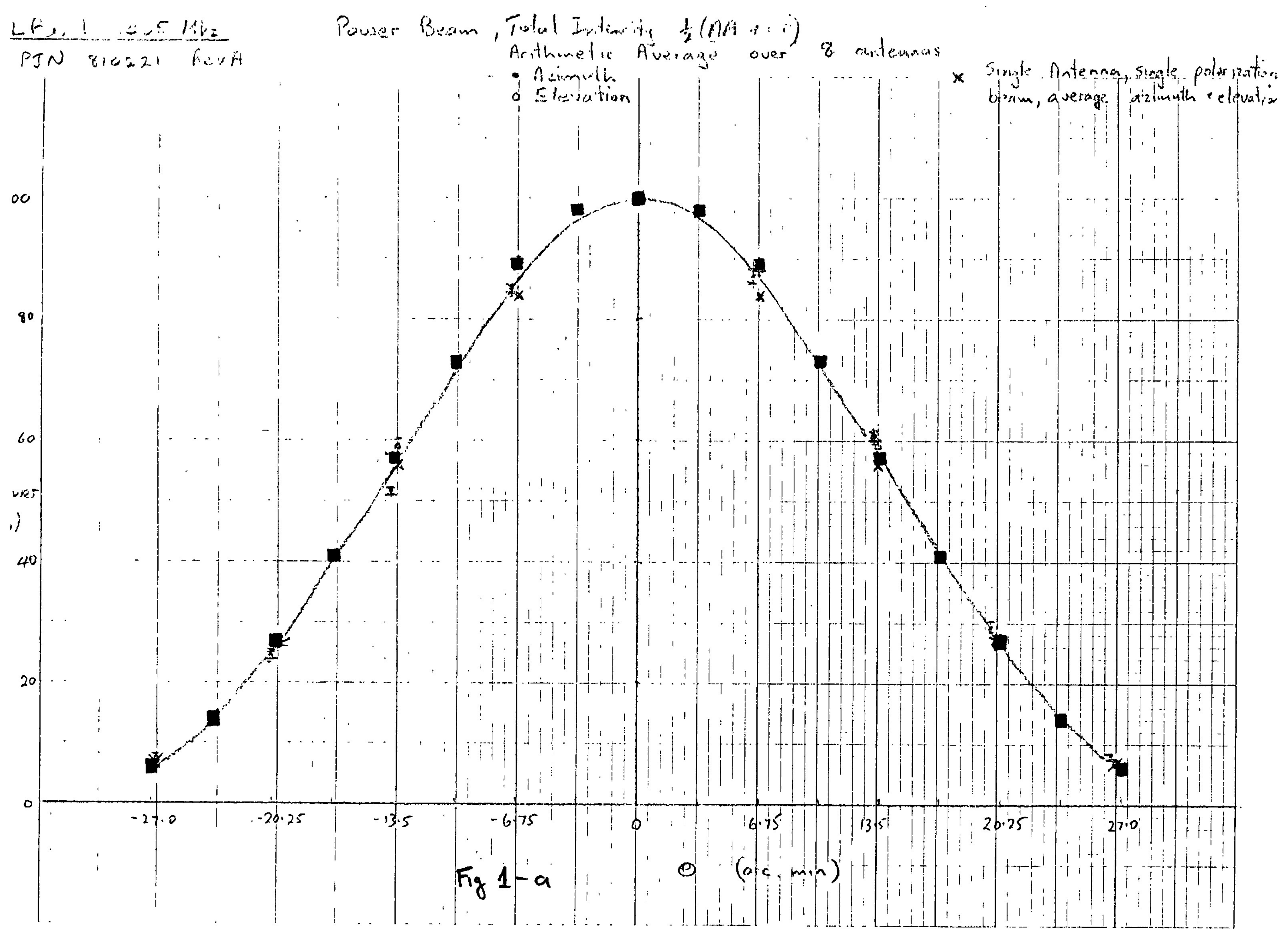

LFs, 1 ..05 Mhz
PJN 810221 RevA
Power Beam, Total Intensity ½(AA + ...)
Arithmetic Average over 8 antennas
• Azimuth
o Elevation
× Single Antenna, single polarization beam, average azimuth + elevation
00
80
60
40
20
0
-27.0
-20.25
-13.5
-6.75
0
6.75
13.5
20.75
27.0
Θ (arc. min)

Fig 1-a

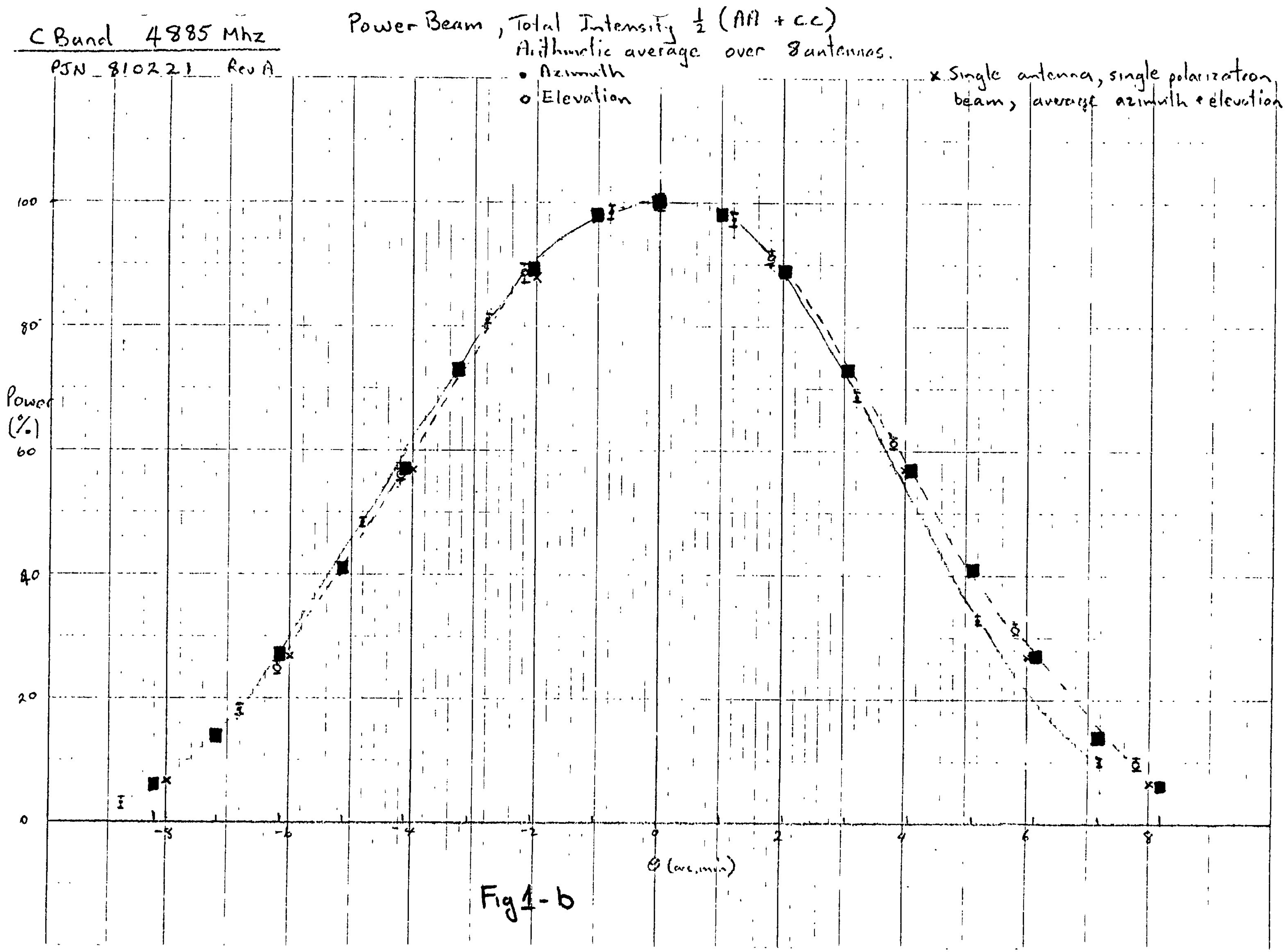

C Band 4885 Mhz
PJN 810221 Rev A
Power Beam, Total Intensity ½ (AA + CC)
Arithmetic average over 8 antennas.
• Azimuth
o Elevation
x Single antenna, single polarization beam, average azimuth + elevation
Power (%)
100
80
60
40
20
0
-8
-6
-4
-2
0
2
4
6
8
Θ (arc min)

Fig 1 - b

Ku Band 15035 Mhz

PJN 810221

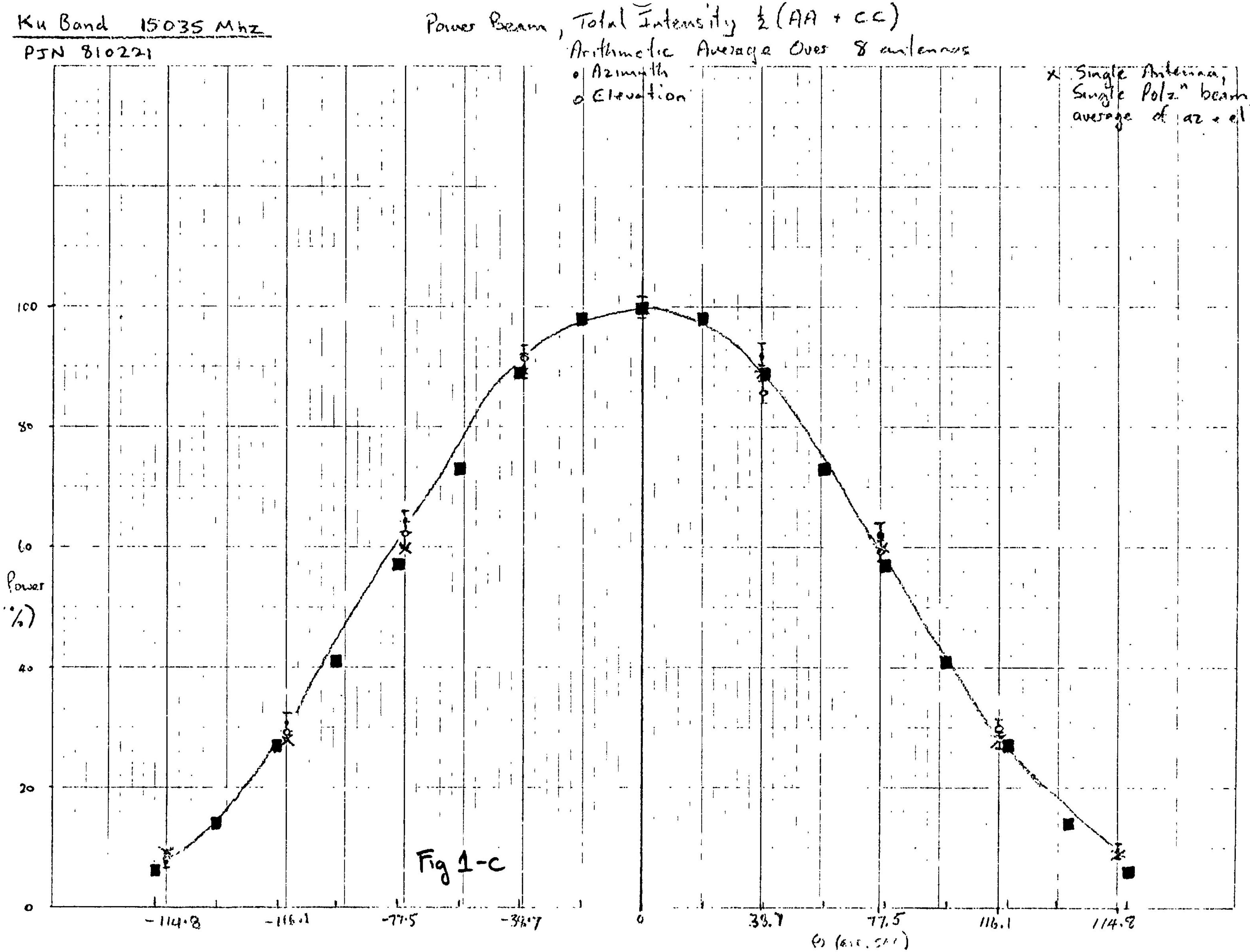


Fig 1-c

K Band 22485 Mhz
PSN 810221 Rev A

Power Beam, Total Intensity ½ (AA + CC)
Arithmetic Average over 8 antennas

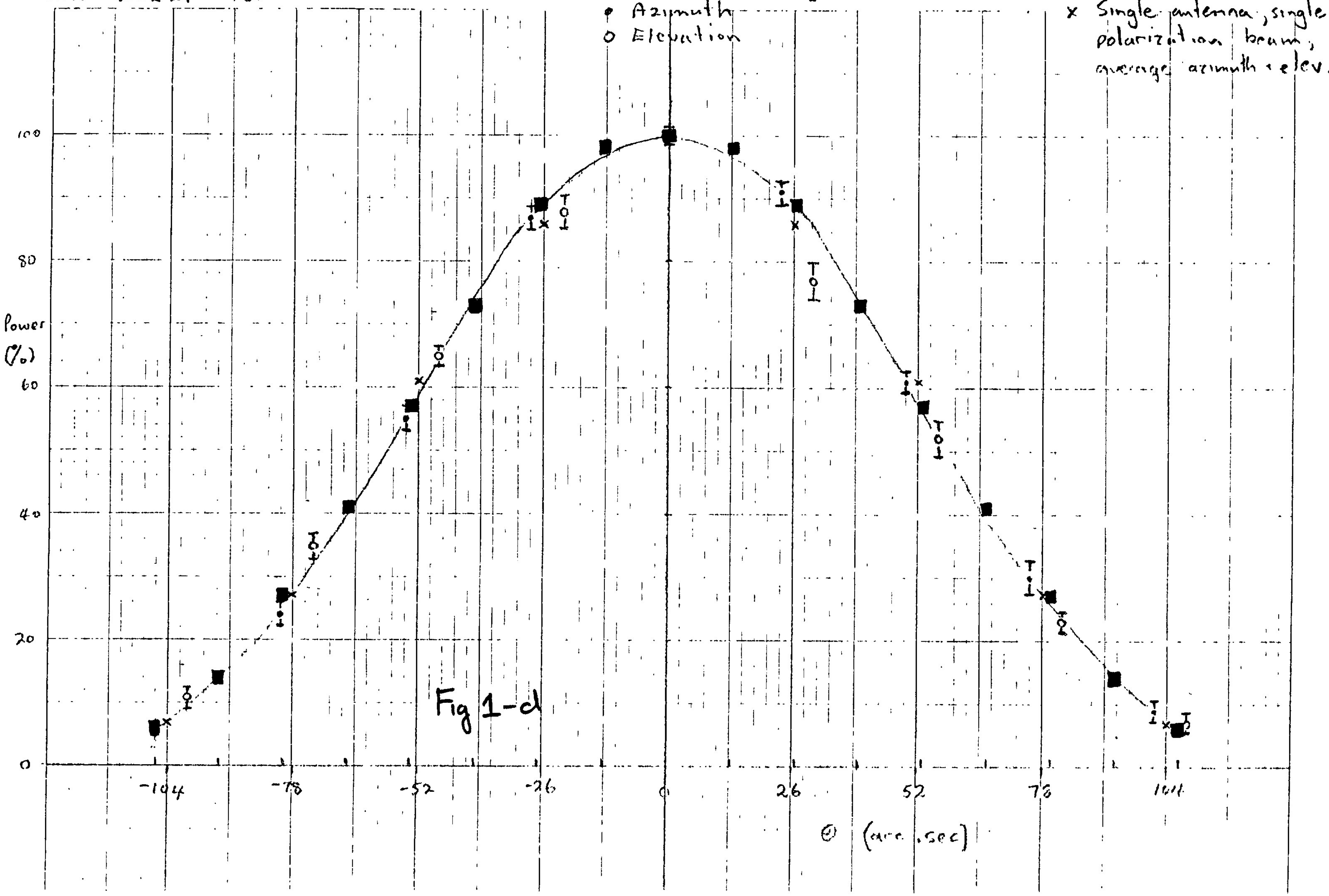
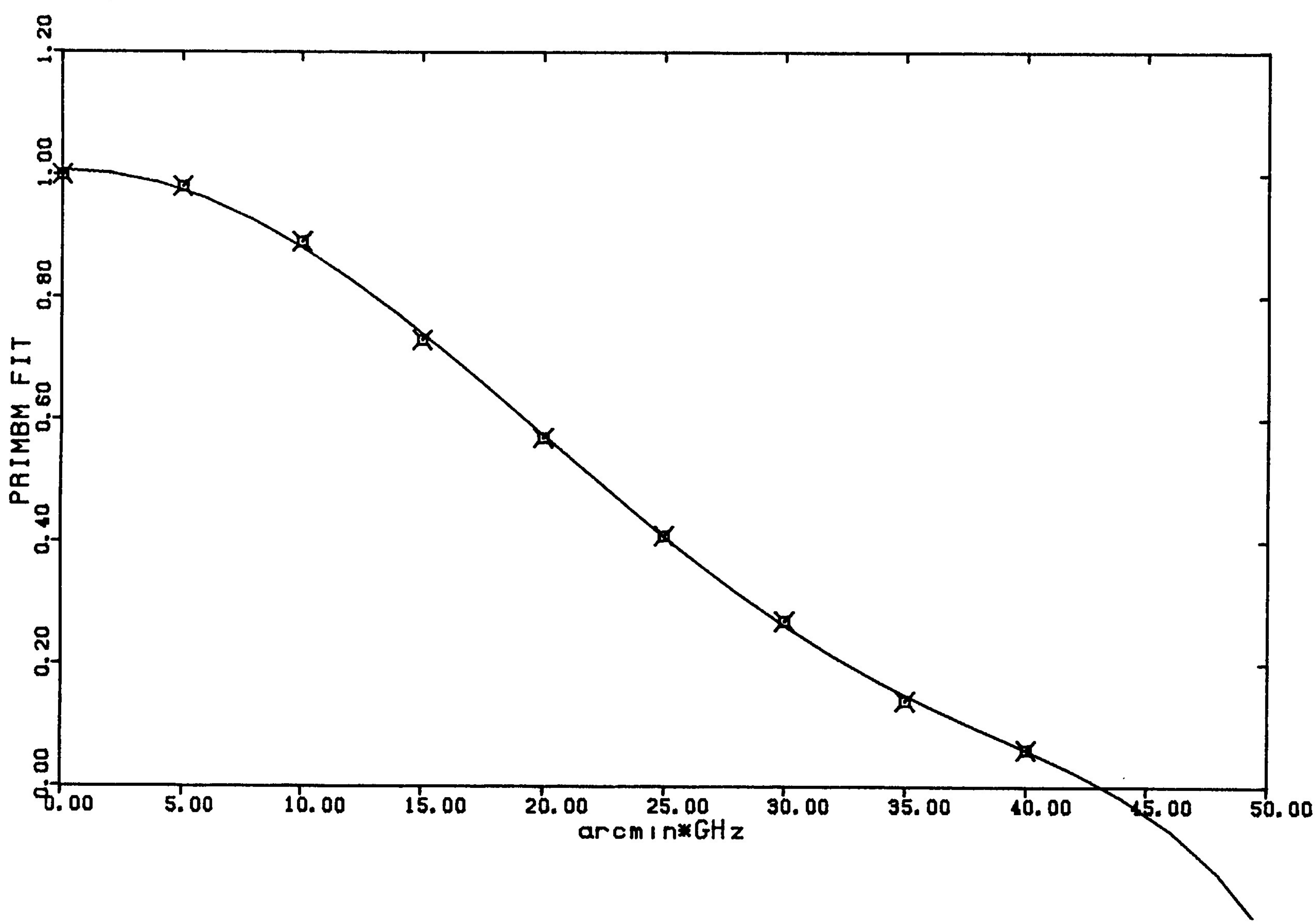


Fig 1-d



1.20
1.00
0.80
0.60
0.40
0.20
0.00
PRIMBM FIT
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
arcmin*GHz

Figure 2

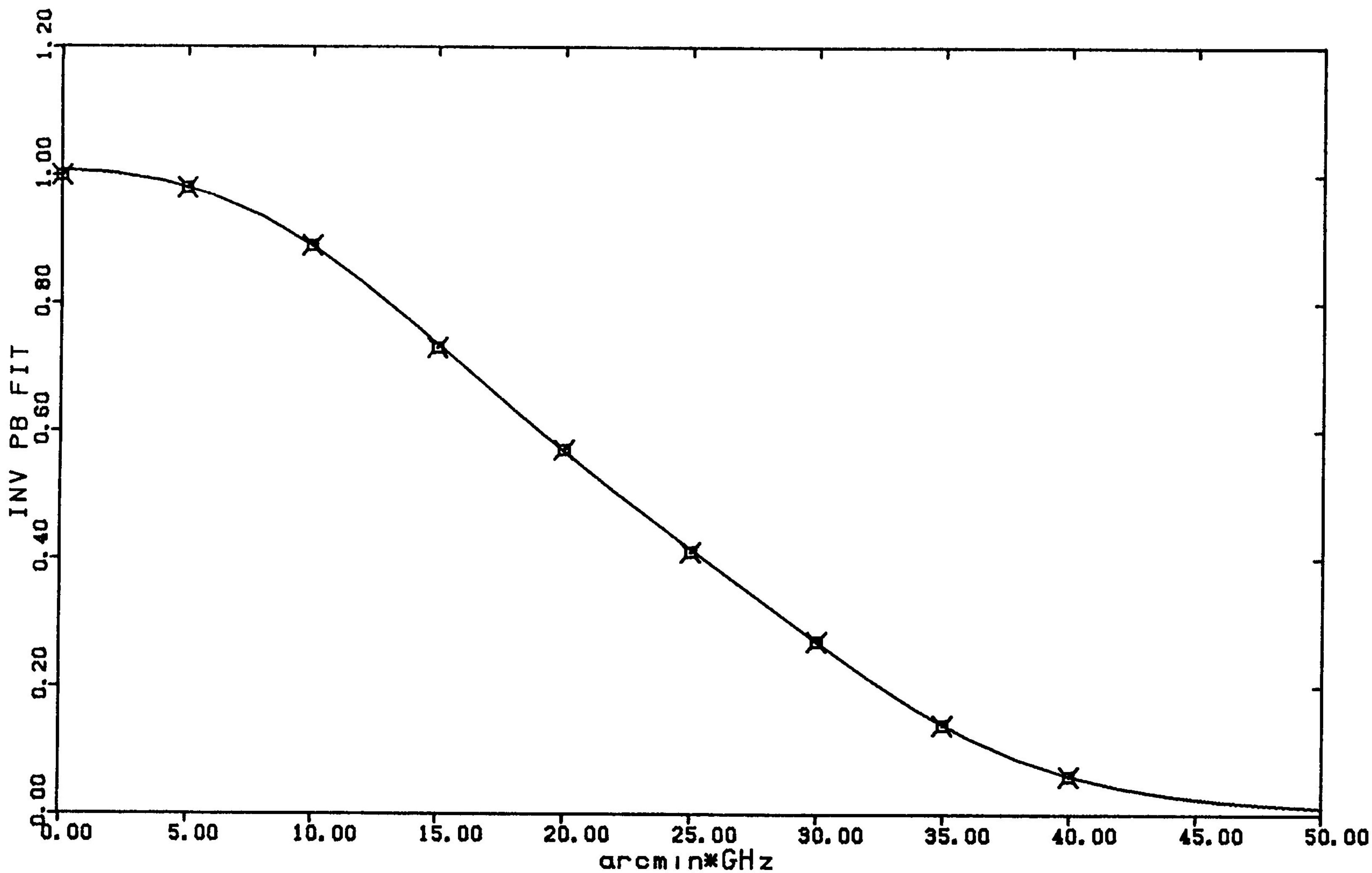

1.20
1.00
0.80
0.60
0.40
0.20
0.00
INV PB FIT
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
arcmin*GHz

Figure 3