Parkes Holography and Optical Survey

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November 2, 1995

1 Summary

We have carried out a set of detailed measurements of the Parkes antenna prior to the focus cabin upgrade. This involved a precision 4 GHz holography survey (Oct 4-5), and a theodolite survey (Oct 6). The holography was done at an elevation of 42 degrees, and provides an excellent image of the reflector surface, as well as relating the focus cabin to the reflector optics; the theodolite survey was done at the zenith, and ties the focus cabin to a permament theodolite mount at the reflector vertex, as well as to the mean plane defined by a set of 60 targets on the reflector surface.

2 Holography - The Equipment

A block diagram of the equipment is shown in figure 1.

We used a 4.5m antenna as our reference - this is located adjacent to the maser hut, approximately 200m from the main antenna. At a frequency of 4 GHz the beamwidth is large enough ($\sim$ 75 arcmin) that we do not need to worry about the diurnal satellite motion ($\sim$ 0.2 degrees); but it is also so large that confusion with a neighboring satellite was a problem during the setup. IntelSat 174 was our chosen target. This is a series VII satellite with a strong beacon at 3.95 GHz. The problem satellite was IntelSat 177, also a series VII model. In addition to the setup difficulties, we also encountered this satellite during the holography run itself: we scanned an area 8x8 degrees centred on IntelSat 174, so inevitably ran into IntelSat 177. The problem and cure are discussed below - the problem could be resolved, leaving the survey more-or-less unscathed.

Both the reference and the 64m antennas were operated in the prime focus mode, using Chaparral feeds and block downconverters. The feed characteristics were measured on the RP antenna range; the results are shown in figure 2. The edge taper is 10 dB; the phase is constant to within better than 10 degrees over most of the surface, falling to 40 degrees at the edge. The amplitude taper should be present in the aperture illumination distribution; the phase profile is likely to be masked by the focussing effects.

The conversion chains involved an interesting *ad hoc* mixture of synthesisers - three for the reference antenna and two (along with two phase locked loops) for the 64m. All the synthesisers were locked to the maser - see figure 1.

The refurbished Scientific Atlanta receiver along with the 100 KHz filters (at 195 MHz) continue to do sterling service. This unit provides, at a sampling rate of 8 Hz, the amplitude of each signal, along with the phase difference between them. The amplitudes (voltages) are measured to 12-bit precision, and the phase to 0.1 degree.

A PC collects the data as a time-stamped series, and a similar series of time-stamped antenna positions is available from the antenna control task; the first step in the processing is to merge these two series before the calibration and analysis.

3 Setup

1. Feed position angle and focus setting.

The 64m antenna boresight signal was maximised by setting the feed to PA = -30 degrees, and a focus setting of 50mm; unhappily, the focus cabin machinery did not maintain these settings, and a small drift in position angle was observed over the course of the observations.

There was considerably less scope for fine adjustment on the reference antenna, as the settings are defined by holes drilled in the adaptor plate; the final settings are satisfactory, but not necessarily optimum.

2. Signal to noise.

The satellite beacon is specified to have 4 dBW EIRP which should give 2.510^{-15} W at the terminals of the 4.5m antenna. We find that at 1 KHz resolution on a spectrum analyser the satellite signal is 35 dB above the noise floor - consistent with the estimated 50K system temperataure of the downvonverter.

The signal-to-noise at the output from the Scientific Atlanta is bit worse than our *a priori* expectations. The phase rms was 3 degrees, and the amplitude rms for both antennas (on boresight) was 0.02 volts about a mean of 3 volts.

(Note: it was necessary to provide a separate 240 V supply, isolated from the maser hut, to remove distinct gain and phase excursions at intervals of about 30 second).

We attribute the phase rms to the many synthesisers in the conversion chains - the phase locked loops in particular are known to have an rms of 0.5 degrees at 2 GHz; the amplitude rms is consistent with the construction of the amplifiers in the Scientific Atlanta (the variable attenuators in the circuit would now be deemed unsatisfactory).

The image quality is set by the additive noise - the receiver noise of the target antenna. On boresight the 64 m antenna will have a signal-to-noise ratio of about 70 dB. (The satellite noise floor is irrelevant to this calculation, since the receiver noise will be the main noise contributor away from boresight). We can then estimate the signal-to-noise in the holographic image as :

$$S/N = \frac{\text{Boresight S/N}}{\sqrt{\text{Number of pixels}}}$$

$$S/N \sim 25 : 1$$

We can expect therefore $\sigma \sim 0.2$ mm in the 129x129 images.

3. Gain stability.

Neither downconverter is gain stabilised; the unit on the 64m is at least in a reasonably protected environment. This means that the reference antenna could provide no long term check on the satellite stability, and was only used to provide a measure of the gain stability during each scan.

4. Cross-Talk.

Cross-talk between the two channels was detected at a low level - roughly 70 dB below the boresight signals. This appears as a bright spot at the map centre; the level was estimated by determining the

DC level in the periphery of the (az-el) raster data, and was then subtracted from every sample point. Since the dynamic range of the Scientific Atlanta is specified as 60 dB, this level of cross-talk is not unreasonable.

4 Observations and Calibration

Our observing strategy was to make a series of scans in elevation, each scan offset from its neighbor by our Nyquist azimuth sampling interval (0.085 degree). The scans alternated in direction to minimize the scan overheads; a boresight calibration was done after every pair of scans. The azimuth progressed monotonically from negative to positive azimuth offsets. The antenna motion was continuous along each scan; the data collection was continuous (at 8 hz), quite asynchronously with the antenna drive; the data -vs- antenna position was determined after the event, interpolating from the antenna track to the time of each sample.

The scan parameters are summarised in Table 1. The survey took about 7 hours, ending at 8 am. An examination of the calibration data strongly suggests that a significant ($\sim$ 1 arcminute) pointing drift occurred at dawn.

Table 1
Holography Raster Parameters

Satellite mean elevation	42.74 degrees
scan rate	-3.7304 deg/min, in Elevation
scan extent	8.02 degrees
scan spacing	0.0847 degrees in Azimuth
PC sampling interval	0.126 secs
Start	1:10 (am) AEST
End	8:15

The satellite ephemerides had been provided by Intelsat, and were used to correct the position of each scan centre.

The boresight calibration observations which bracketted each pair of scans were used to correct the phase and amplitude data of each scan, and the data were then analysed with the AIPS task HOLGR.

The phase of the calibration (boresight) follow a roughly parabolic curve with a total excursion of 150 degrees. This is consistent with the diurnal satellite motion seen through a 200m interferometer. In addition there are short excursions of 10-20 degrees; since these excursions have a time-scale of 30 minutes or so, simple interpolation between successive boresight observations will reduce the phase errors to below the three degree noise level.

IntelSat 177 is evident in the raw data, shown in figure 3; its amplitude is about 1% (power) of the boresight signal. It is difficult to predict the phase and amplitude of the interfering satellite: the Scientific Atlanta receiver derives its LO reference from the reference antenna which continues to point at IntelSat 174; the signal that is presented to the processing unit of the receiver is therefore the incoherent mixing, in effect, of the two separate satellite signals; the phase is almost certainly unpredictable, while the amplitude probably reflects the spectral overlap between the satellite beacon nearest to 3.95 GHz and the fine tuning chosen to maximise the signal from IntelSat 174. This problem will be addressed before the next observing run: the filter which in effect provides the isolation from

Intelsat 177 has a Q of 5; boosting the Q to 20 or better is straightforward, and should add an additional 10 dB isolation.

The results discussed in section 5 were produced from a data file in which the intruding satellite had simply been edited out. A potentially better approach would exploit the proposition that we have two beam patterns - one centred on IntelSat 174, and a second, somewhat weaker, centred on IntelSat 177. The results so far are disappointing, probably reflecting the phase uncertainty.

5 Results

The Illumination Function

The illumination map shows few surprises - the illumination falls off smoothly as expected (figure 4); the azimuth-averaged illumination profile is shown in figure 5, for comparison with the feed characteristics of figure 2.

The amplitude is not zero outside the antenna perimeter: this is a measure of the noise in the image. The level is 6 % of the peak illumination, in good agreement with the Signal-to-noise predictions.

Reflector Surface Error

The surface error image is shown in figure 6. A "shadow-relief" display of the surface error map is shown in figure 7 to provide an alternative overall view. (The two hatch covers near the vertex are clearly visible, providing a measure of the horizontal resolution of the image).

The surface error map is quite encouraging. Consistent with the earlier 12 GHz survey, we find the central 45m surface to have an rms of $\sim$ 1mm; close examination of the map shows fine detail aligned with the ribs, suggesting that the panels have only a modest departure from the design paraboloid. It is also clear that the outer mesh is quite corrugated. The map shows elevated regions aligned with the ribs, some 5mm above the mean. The mesh is 1-2 mm below the mean. The mesh has an rms of $\sim$ 2.5mm.

Surface RMS (mm)

inner 45m (solid or perforated panels)	1.0mm
outer section (mesh panels)	2.5mm

Figure 8 shows the corresponding surface error map obtained at a frequency of 12 GHz in november 1988.

Feed Position

The analysis task (HOLGR) explicitly searches for the characteristic signatures of feed offsets - axially (focus), and in the focal plane. We found:

$$
\begin{aligned}
Dx &= 5 \text{ mm} \pm 2\text{mm} \\
Dy &= 18 \text{ mm} \pm 2\text{mm (to the north)} \\
Dz &= -2 \text{ mm} \pm 0.5\text{mm}
\end{aligned}
$$

6 Optical Survey

This survey exercise was undertaken prior to the focus cabin upgrade in order to determine the position of the focus cabin relative to the main reflector.

6.1 Coordinate frame

We established a coordinate frame tied to 60 targets on the main reflector; the nominal focus cabin reference point was then tied to this frame.

The focus cabin reference point chosen was the centre of the 5 GHz holography feed horn, at PA -30 degrees and at a focus setting of 55 mm.

The targets chosen were drawn from the targets used in the original Puttock, Minnett and Yabsley survey. These are located directly above the panel adjustment bolts. We chose targets in two rings: one set at a distance of 9 m from the vertex, the second set at 22 m from the vertex. The actual sighting point was the mid point of the 6mm hole at the centre of the cap over the mounting bolt.

The theodolite was positioned on the same axis as the original survey camera; we were able to adapt one of the original calibration assemblies to this end - this provides a precision mount which ensures that the theodolite is co-axial with the original axis.

The theodolite mount adaptor has been left bolted on the antenna to ensure that the theodolite returns to the same position when we come to resurvey the antenna after the upgrade. This simpliies the positioning checks after the focus cabin upgrade; we will of course ultimately be referencing back to the coordinate frame defined by the 60 targets, but this task is made easier if the theodolite mount is left in place.

We define the "z-axis" of our coordinate frame to be the vertical axis of the theodolite, with the Tribrach mount adjusted to place the focus cabin reference point on axis.

The "x-axis" is parallel to the elevation axis of the antenna; the "y-axis" points to the highest point of a tipped antenna.

To summarise: the theodolite's construction defines an accurate coordinate frame -

x-axis at elevation = 0, azimuth = 90.
y-axis at elevation = 0, azimuth = 0.
z-axis at elevation=90.

We placed the theodolite on the Tribrach and made small adjustments to leave the z-axis pointing at the centre of the feed. The azimuth zero was rotated until it was aligned with rib # 16, the high side of a tipped antenna. Our measurements of the targets on the reflector were made in this coordinate frame.

After the upgrade our first task will be to reposition the theodolite's coordinate frame so that the targets have the same coordinates as were measured on October 6. We can then relate the present feed location to the upgraded focus cabin.

6.2 The Survey

The chord length to each target from the theodolite was measured. We used a special tape adaptor which locks to the Tribrach, ensuring that the tape distances are accurately keyed to the theodolite vertical (azimuth) axis.

Each target was observed twice, in the collimation-correcting mode. The mean of the two measurements is the target elevation; the difference is a measure of the error. The errors are normally distributed with an rms of 1.5 arcsecs.

The survey was done at night and took about one hour.

6.3 Results and Discussion

The processed results from the survey are given in appendix A. They show:

- Within each ring the targets lie at a common radius with an error of around 1mm.
- The two rings of targets are concentric, with the centre offset by 1.5 mm from the theodolite axis.
- The targets have an rms surface error of 1.5mm.
- The two target sets do indeed define an excellent coordinate frame.
- In this coordinate frame the focus cabin reference point is offset by 38mm in the North-South plane (to the high side).

7 Discussion

How do our results relate to the Yabsley surface modelling and results?

The antenna has been adjusted to be optimised at an elevation of 55 degrees: the surface is parabolic, and the feed is at the focus. The characteristics are described in terms of a small number of parameters which vary with elevation

The reflector surface (the "best fit paraboloid") :

- (a) focal length (F_Z);

- (b) displacement of the vertex (V_Z);

- (c) rotation of the axis of the paraboloid (θ_Z);

The focus cabin tripod :

- (d) displacement of the feed in the focal plane;

Factors (b), (c) and (d) combine to move the feed away from the optimum focus position.

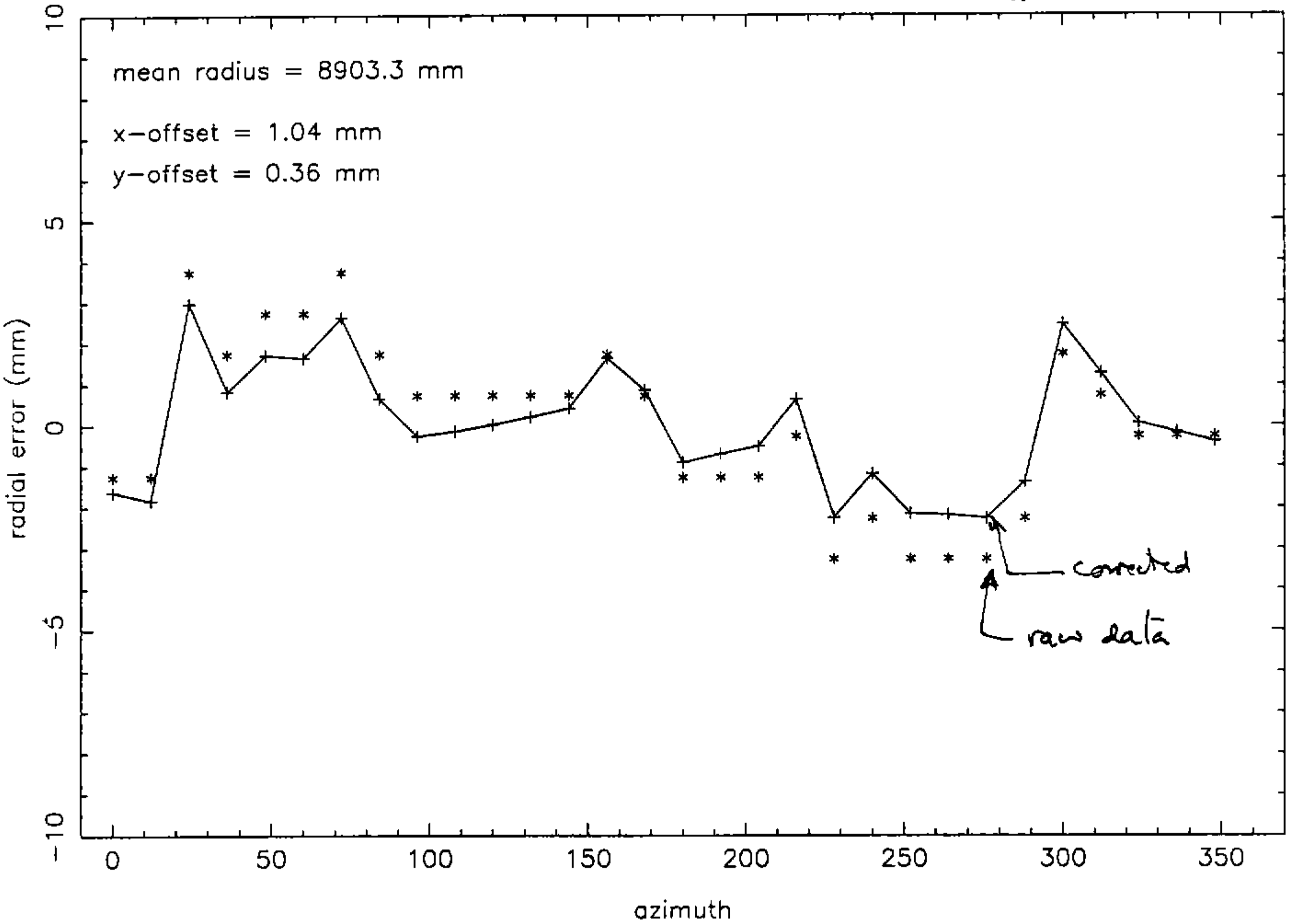
These four functions are shown in figures 9 to 12.

The october 6 holography (at an elevation of 43 degrees) shows an aperture plane with low phase error (ie, the surface closely approximates a paraboloid), and a feed offset in the y-direction of 18mm, in good agreement with figure 10.

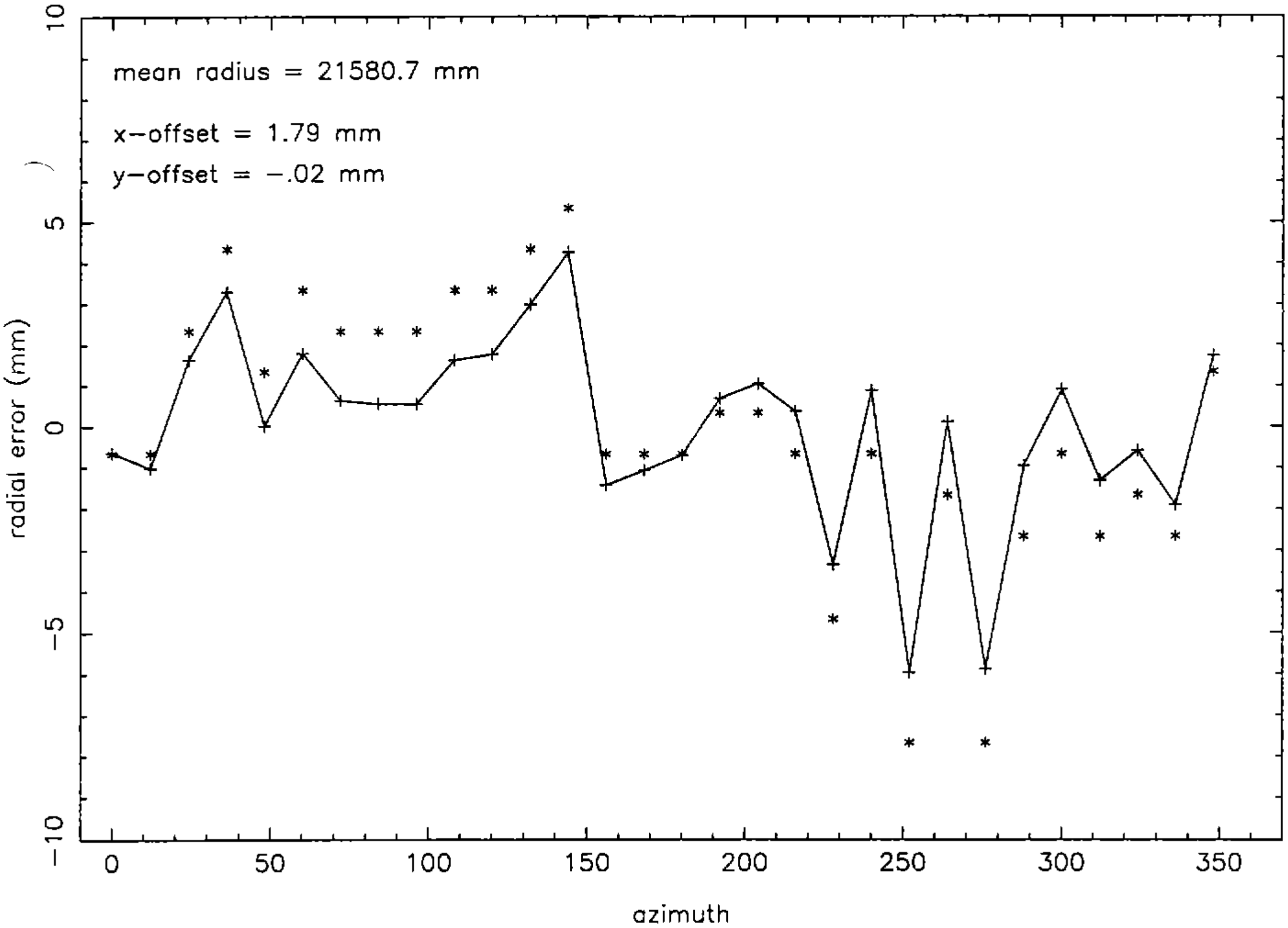
It is somewhat harder to relate the theodolite data directly to the Yabsley figures. The simplest interpretation suggests an offset between feed and the paraboloid axis of about 35mm, compared to a predicted 70 mm. However, the "best fit paraboloid" is not easily related to the two rings of targets surveyed; the trend in the data (280 arcsec tilt for the inner targets, 240 arcsec for the outer) is consistent with a parabola with a vertex shift to the low side, and a positive axis rotation, but this cannot be viewed as a serious test. The main conclusion from the theodolite survey is that we have a very well established coordinate frame in which the focus cabin reference points are defined.

Appendix A1

Inner targets



Outer targets



Appendix A 2

C:\SURVEY\PARKES\oct6\R4INNER.001
C:\SURVEY\PARKES\oct6\R4OUTER.001

ring 4 INNER
Theodolite tilt : 281.1 arc secs
tilt direction 4.92 degrees
Theodolite height error : 0.02 mm

ring 4 OUTER
Theodolite tilt : 246.0 arc secs
tilt direction 7.70 degrees
Theodolite height error : -0.01 mm

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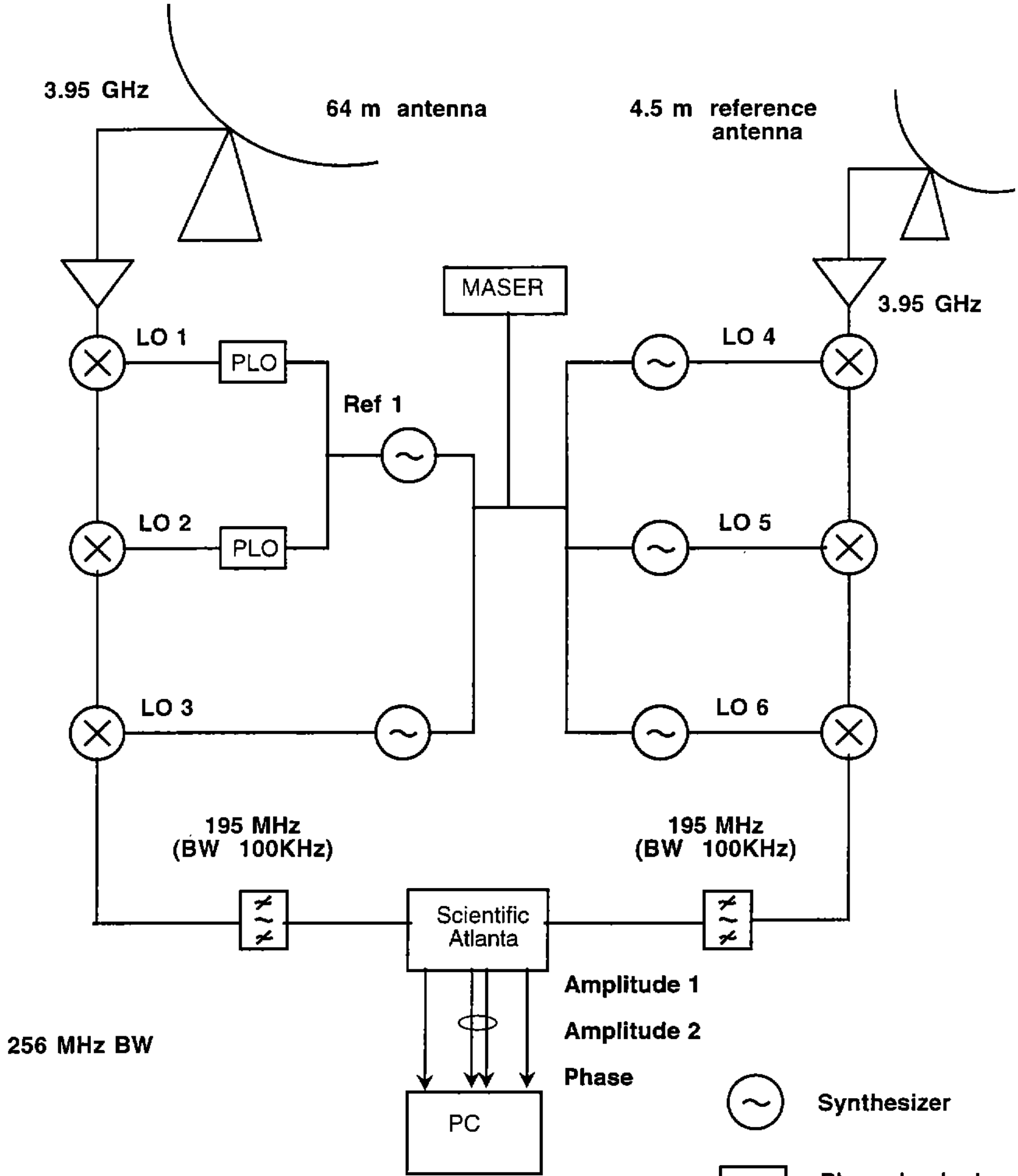
mean tilt : 263.47 arc secs
mean azimuth : 6.22 degrees
mean height error : 0.01 mm; if <0, raise theodolite

Ring 4

(all adjustments in mm)

Panel	Inner left	Inner right	Outer left	Outer right
1	1.51	-1.15	0.86	0.11
2	-1.15	-2.32	0.07	-0.47
3	-2.33	-1.94	-0.49	0.78
4	-1.96	-1.78	0.75	5.17
5	-1.81	1.43	5.18	0.49
6	1.40	0.75	0.44	1.99
7	0.71	-1.21	1.94	-0.96
8	-1.26	1.04	-1.01	-0.85
9	0.87	0.60	-0.86	0.23
10	0.55	1.92	0.17	-1.58
11	1.87	1.54	-1.63	-1.85
12	1.49	2.03	-1.89	-1.39
13	1.98	-0.47	-1.42	-2.03
14	-0.50	0.06	-2.09	-2.10
15	0.07	-0.68	-2.12	-2.47
16	-0.70	0.42	-2.47	-2.50
17	0.42	0.90	-2.49	-2.18
18	0.91	0.26	-2.17	-2.12
19	0.29	0.46	-2.10	-0.60
20	0.49	0.88	-0.60	-1.48
21	0.92	0.12	-1.44	0.92
22	0.17	0.03	0.97	-0.77
23	0.03	-0.19	-0.72	1.09
24	-0.14	-0.11	1.14	2.61
25	-0.06	-0.82	2.66	3.87
26	-0.77	-0.67	4.00	3.71
27	-0.70	-1.26	3.75	1.67
28	-1.23	-0.43	1.71	1.19
29	-0.41	-1.09	1.25	-0.59
30	-1.07	1.47	-0.58	0.78

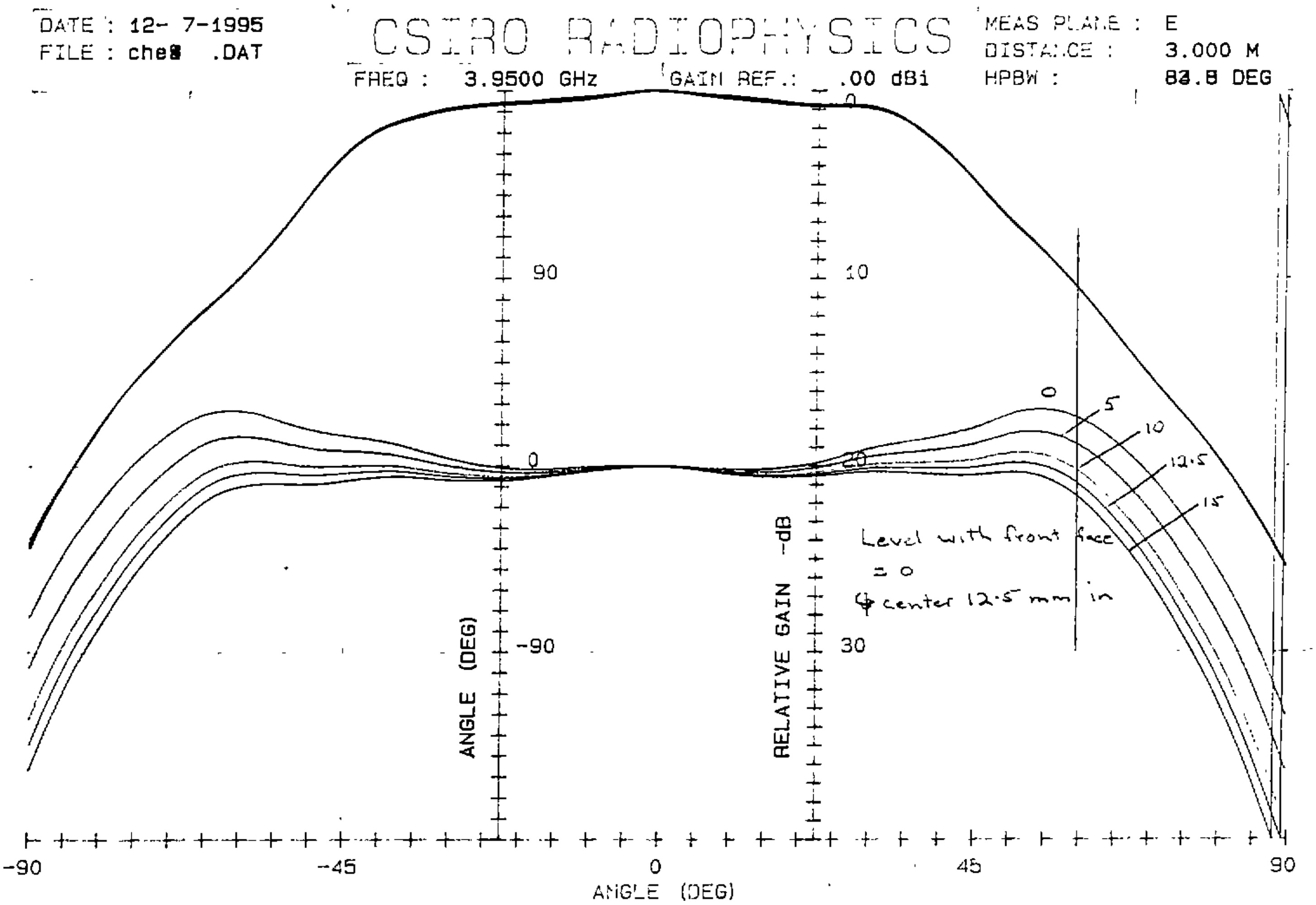
RMS Setting error for this ring : 1.62 mm
RMS half-path error for this ring : 1.53 mm



Ref 1	=	110 416 680 Hz			
LO 1	=	5 300 000 640	LO 4	=	5 300 000 000
LO 2	=	1 987 500 240	LO 5	=	1 949 999 900
LO 3	=	442 499 600	LO 6	=	404 999 900

Parkes Holography Conversion System, '95.

fig 1


DATE : 12- 7-1995
FILE : che8 .DAT
CSIRO RADIOPHYSICS
FREQ : 3.9500 GHz
GAIN REF.: .00 dBi
MEAS PLANE : E
DISTANCE : 3.000 M
HPBW : 83.8 DEG
ANGLE (DEG)
RELATIVE GAIN -dB
ANGLE (DEG)
Level with front face = 0
center 12.5 mm in

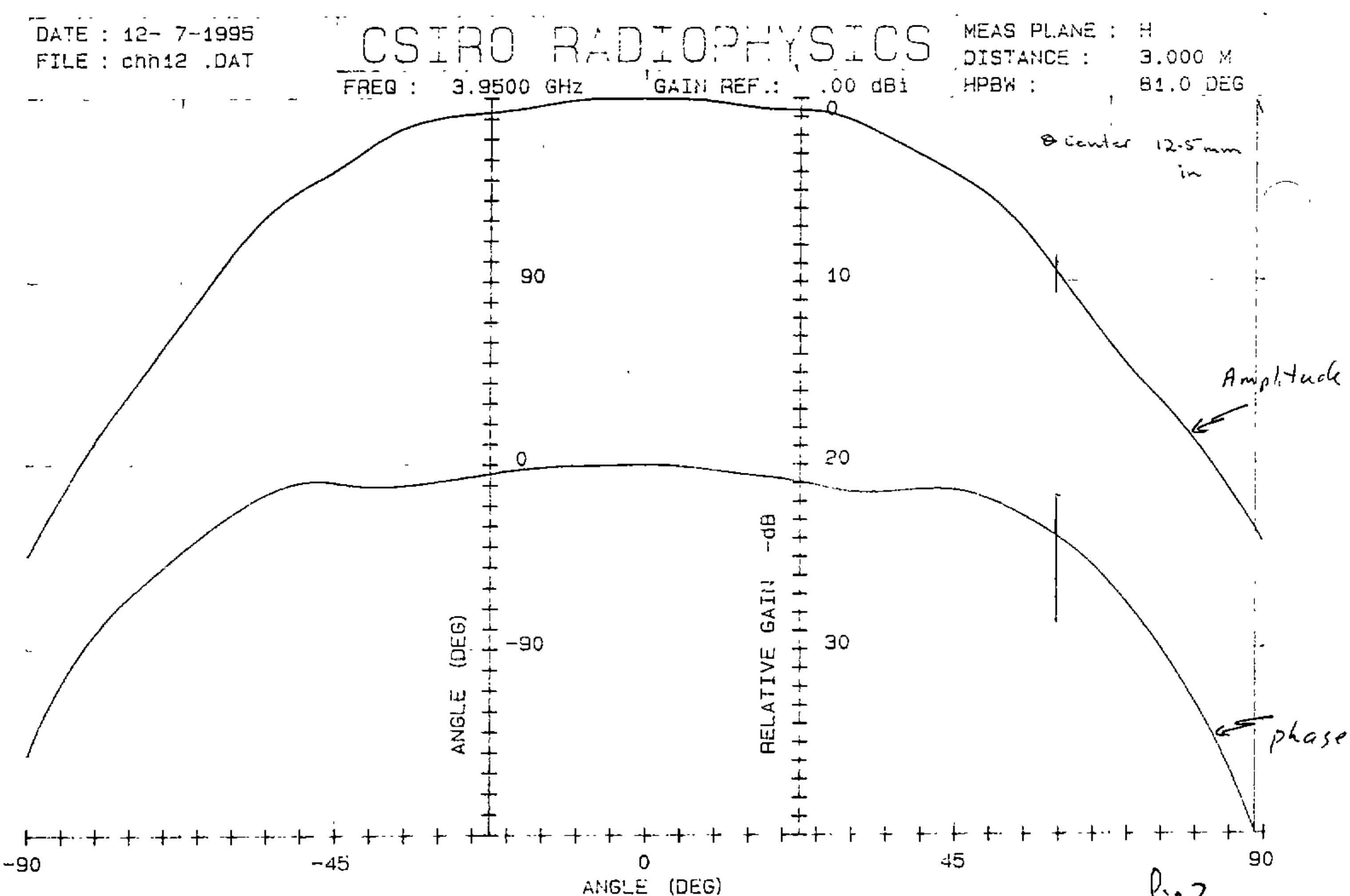
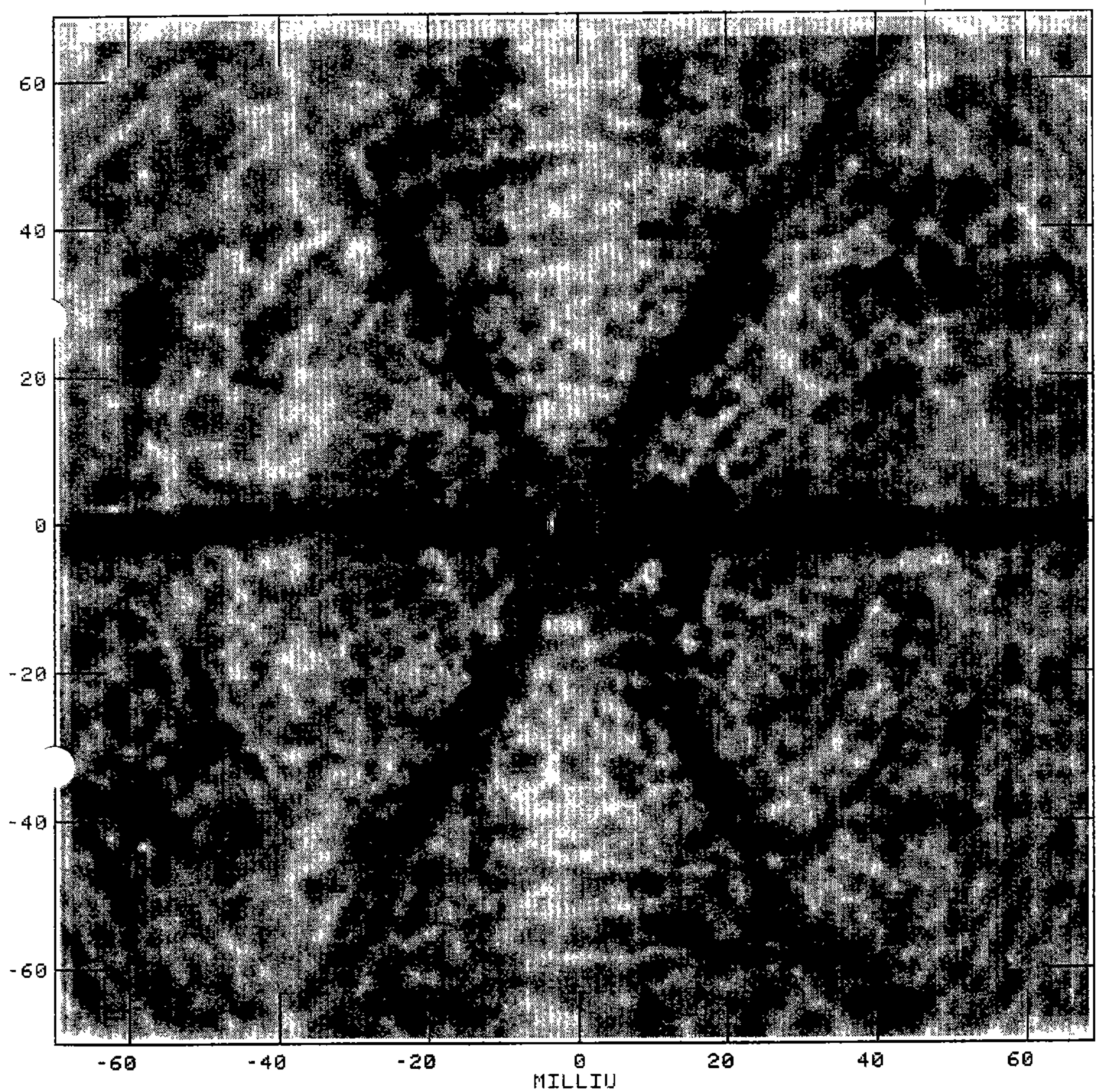

DATE : 12- 7-1995
FILE : chh12 .DAT
CSIRO RADIOPHYSICS
FREQ : 3.9500 GHz
GAIN REF.: .00 dBi
MEAS PLANE : H
DISTANCE : 3.000 M
HPBW : 81.0 DEG
ANGLE (DEG)
RELATIVE GAIN -dB
ANGLE (DEG)
center 12.5mm in
Amplitude
phase

Fig 2

Intelsat 177



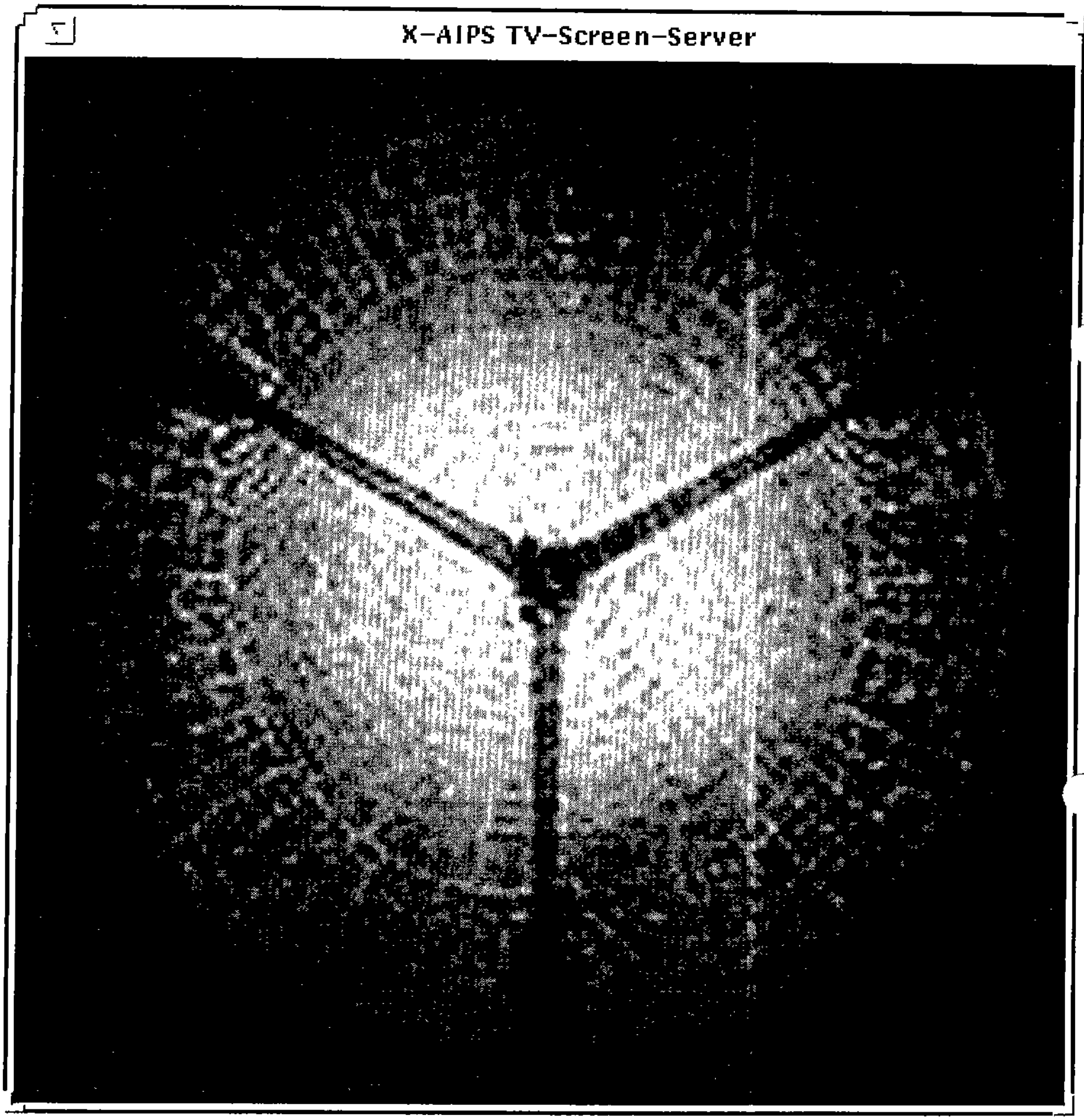
PEAK = 0.2213E+01 VOLT
IMNAME= PK951005_129.BEAM.1

Fig 3

Oct 6

49 G

AM?

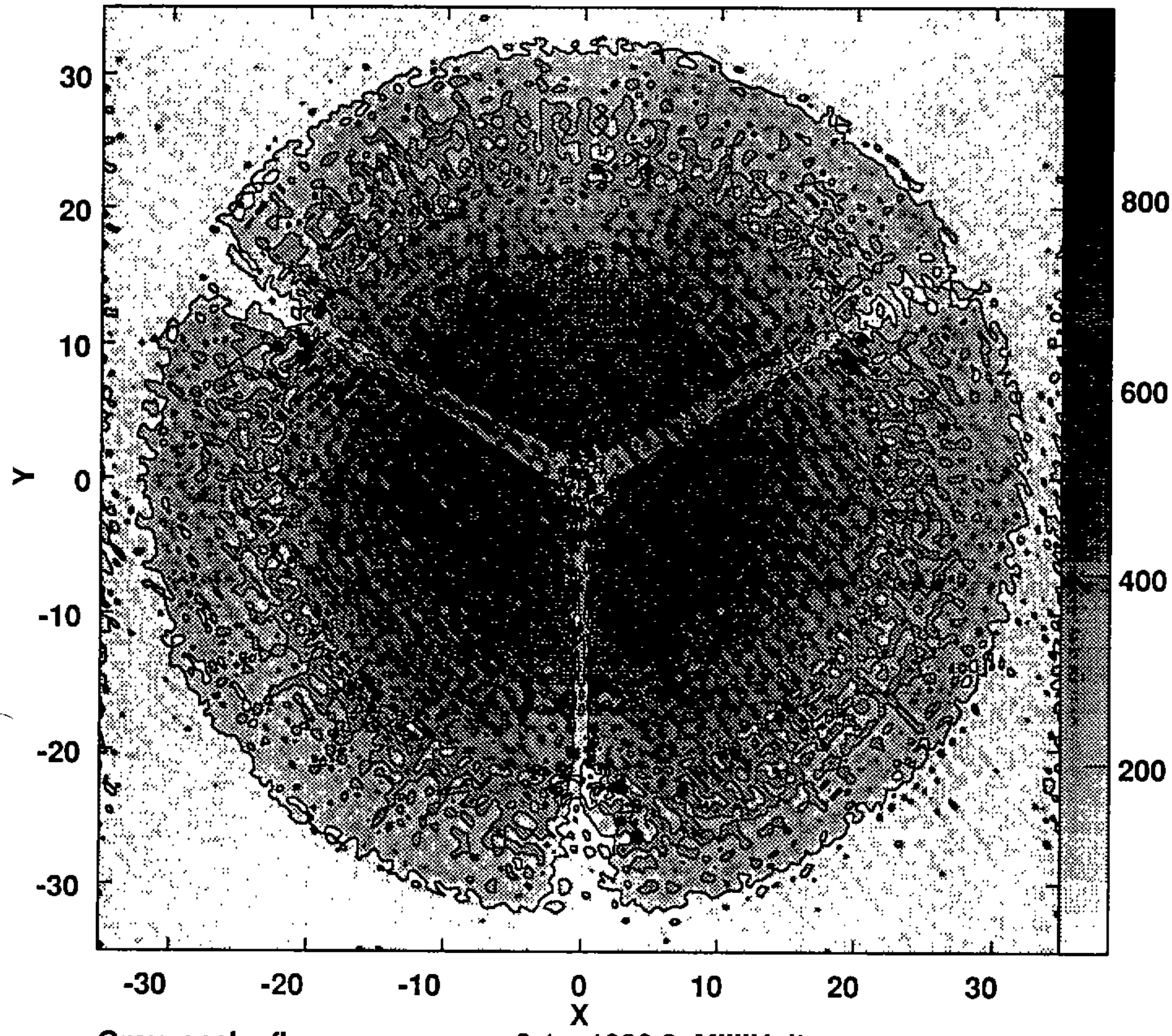


Aperture ILLUMINATION

fig 4 (a)

Plot file version 3 created 19-OCT-1995 12:10:36

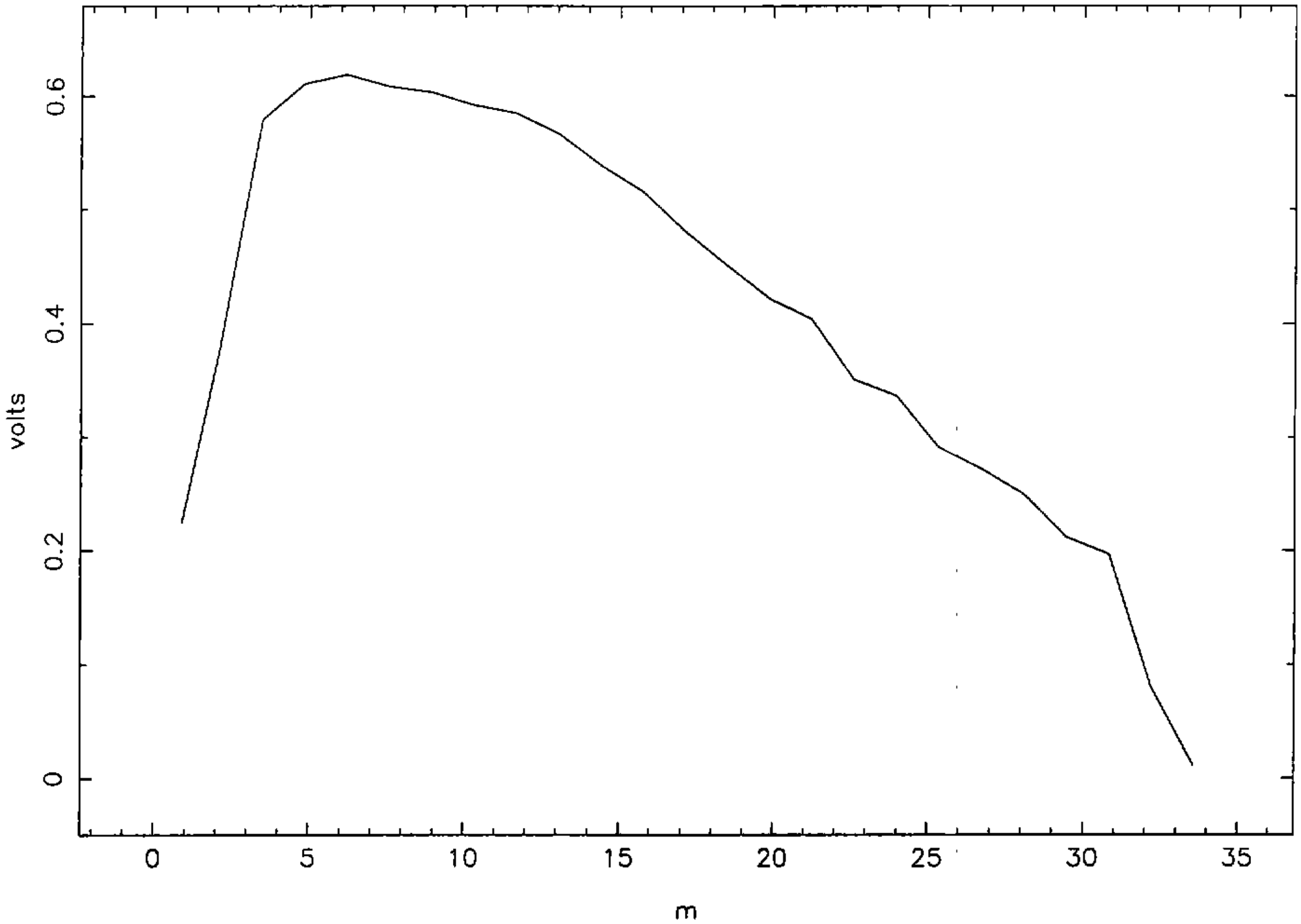
PKS129.V_AMP.1



Grey scale flux range= 0.1 1000.0 MilliVolt
Peak contour flux = 1.0000E+00 Volt
Levs = 1.0000E-01 * (1.000, 3.000, 5.000,
7.000, 9.000)

fig 4 (b)

aperture illumination function



illumination function at the feed

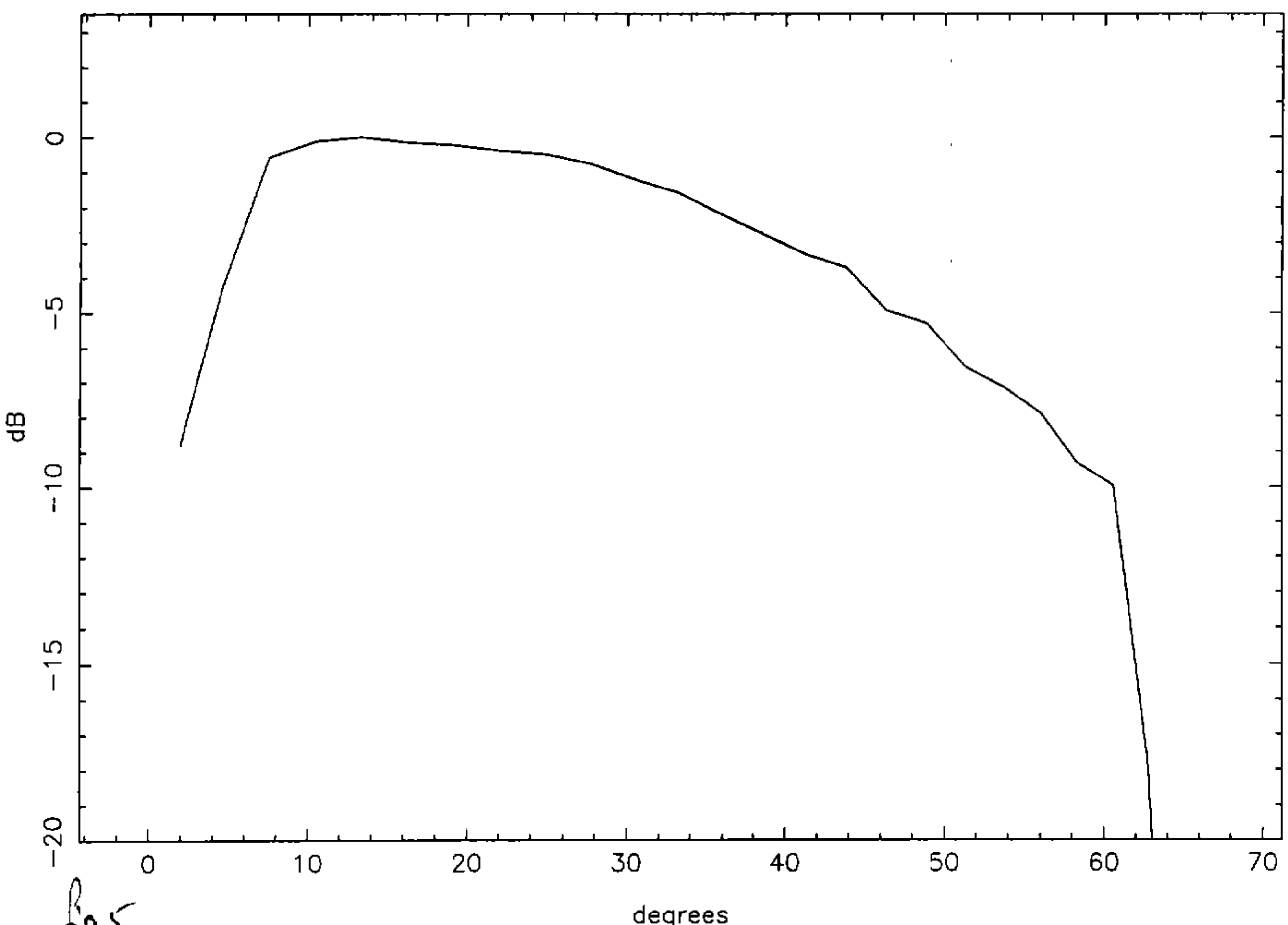
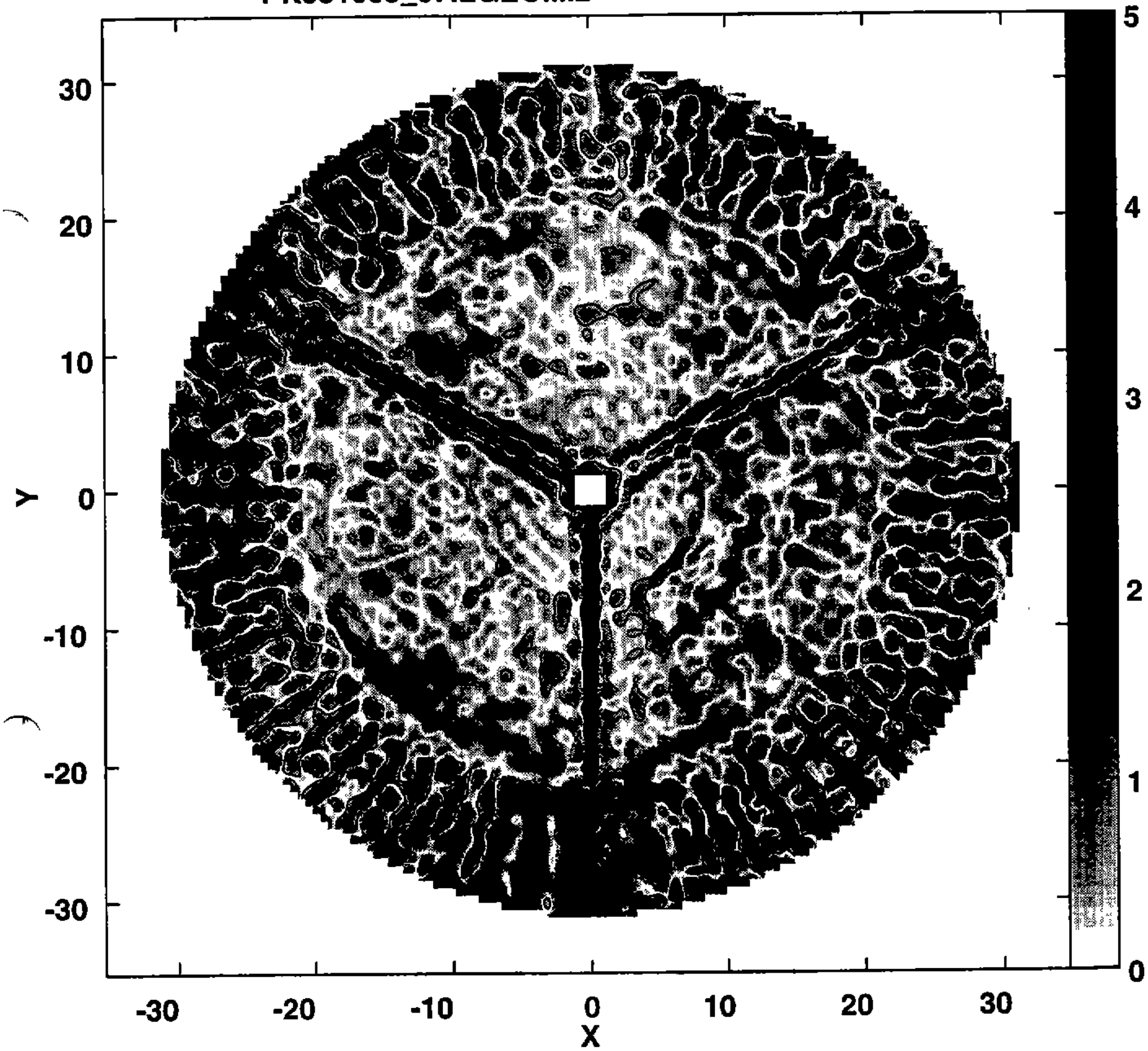


fig 5

4 GHz — Oct 1995

Plot file version 1 created 02-NOV-1995 09:02:38

PK951005_97.LGEOM.2



Grey scale flux range= 0.000 5.000 MilliMeter
Peak contour flux = -3.8024E-02 Meter
Levs = 1.0000E-03 * (-3.00, -1.00, 1.000, 3.000)

fig 6 (a) Surface errors — contours at −3. mm
−1. mm
+1.
+3.

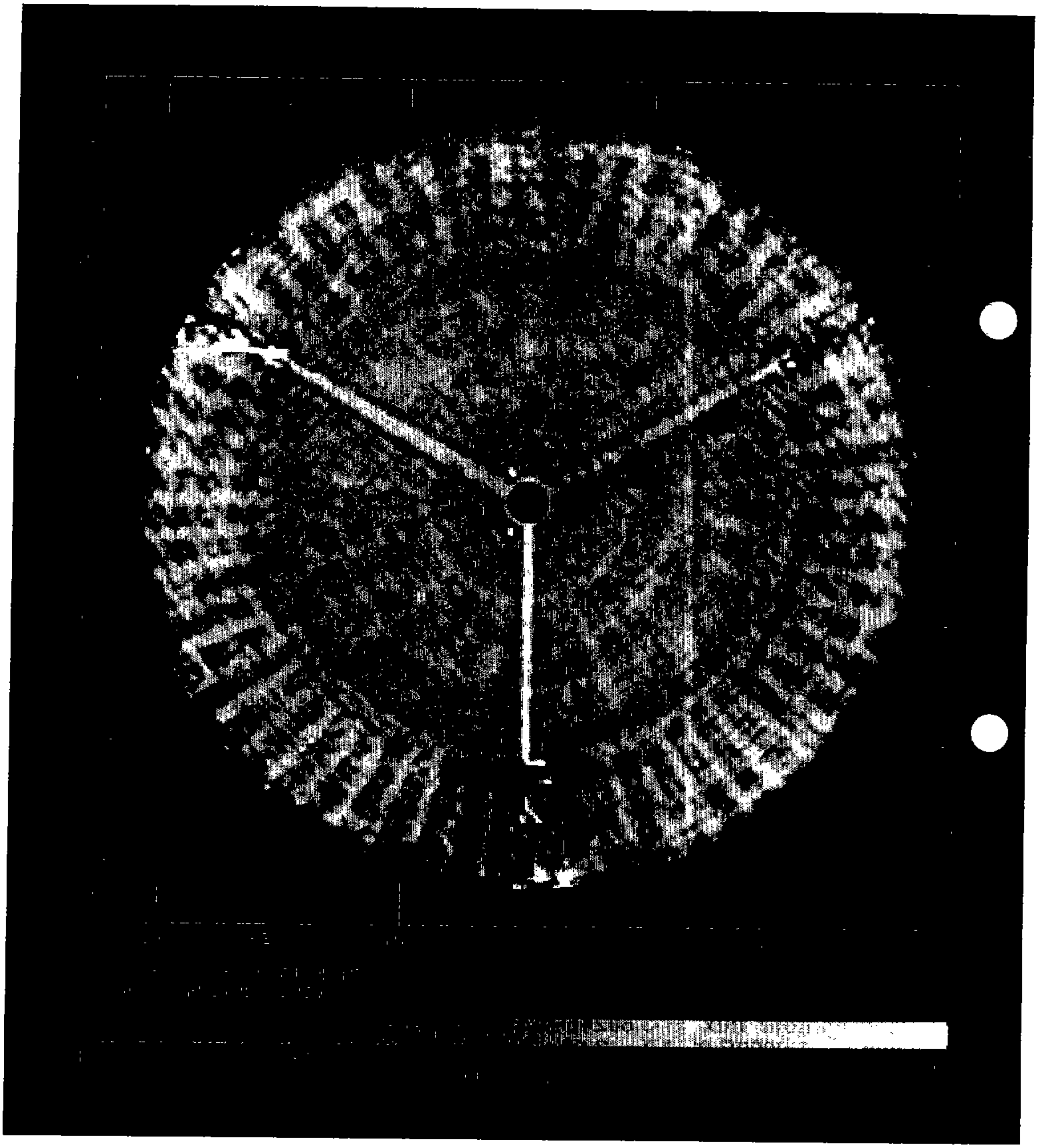


fig 6(2)

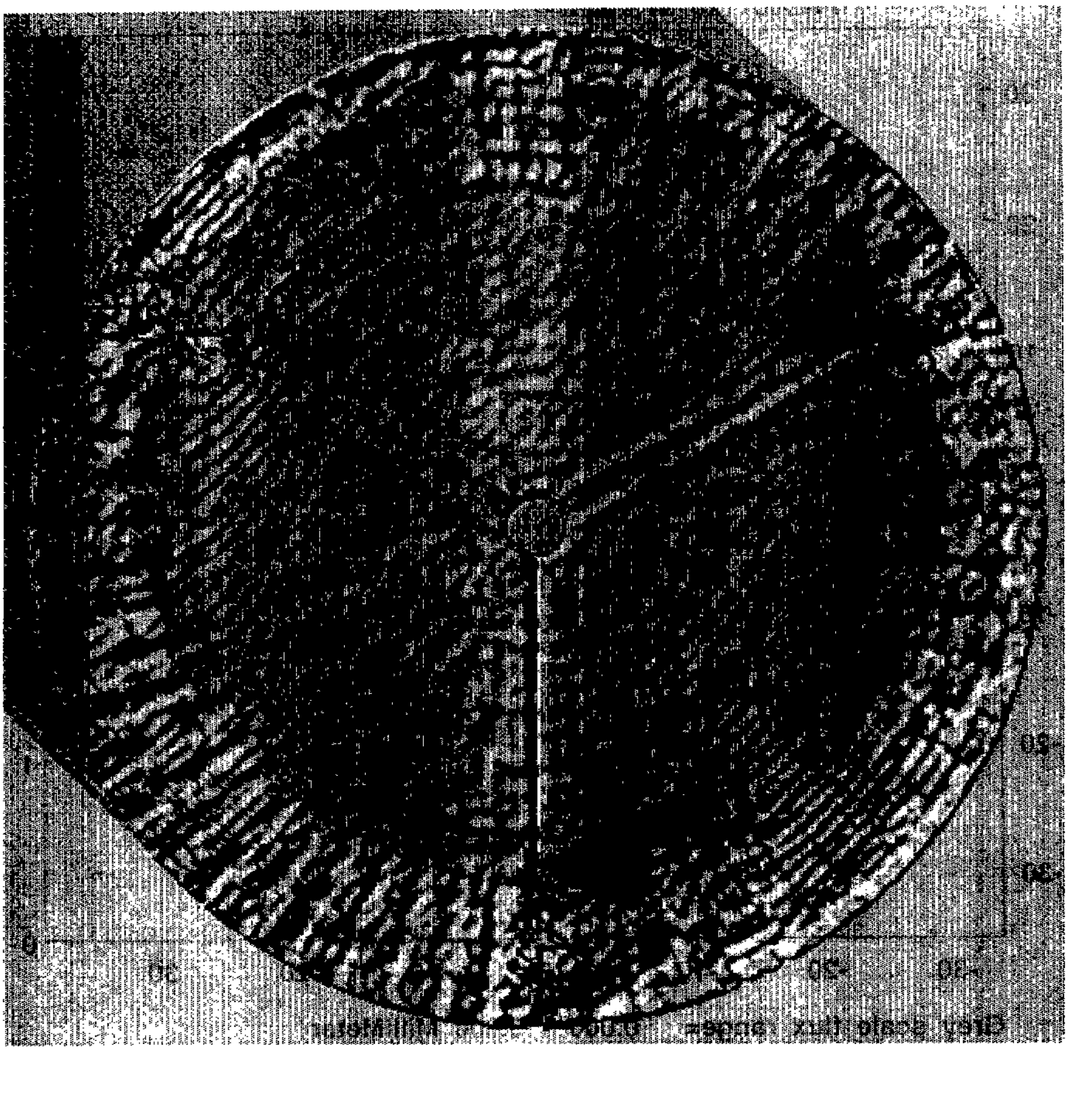


fig 7

12 GHz — Nov. 1988

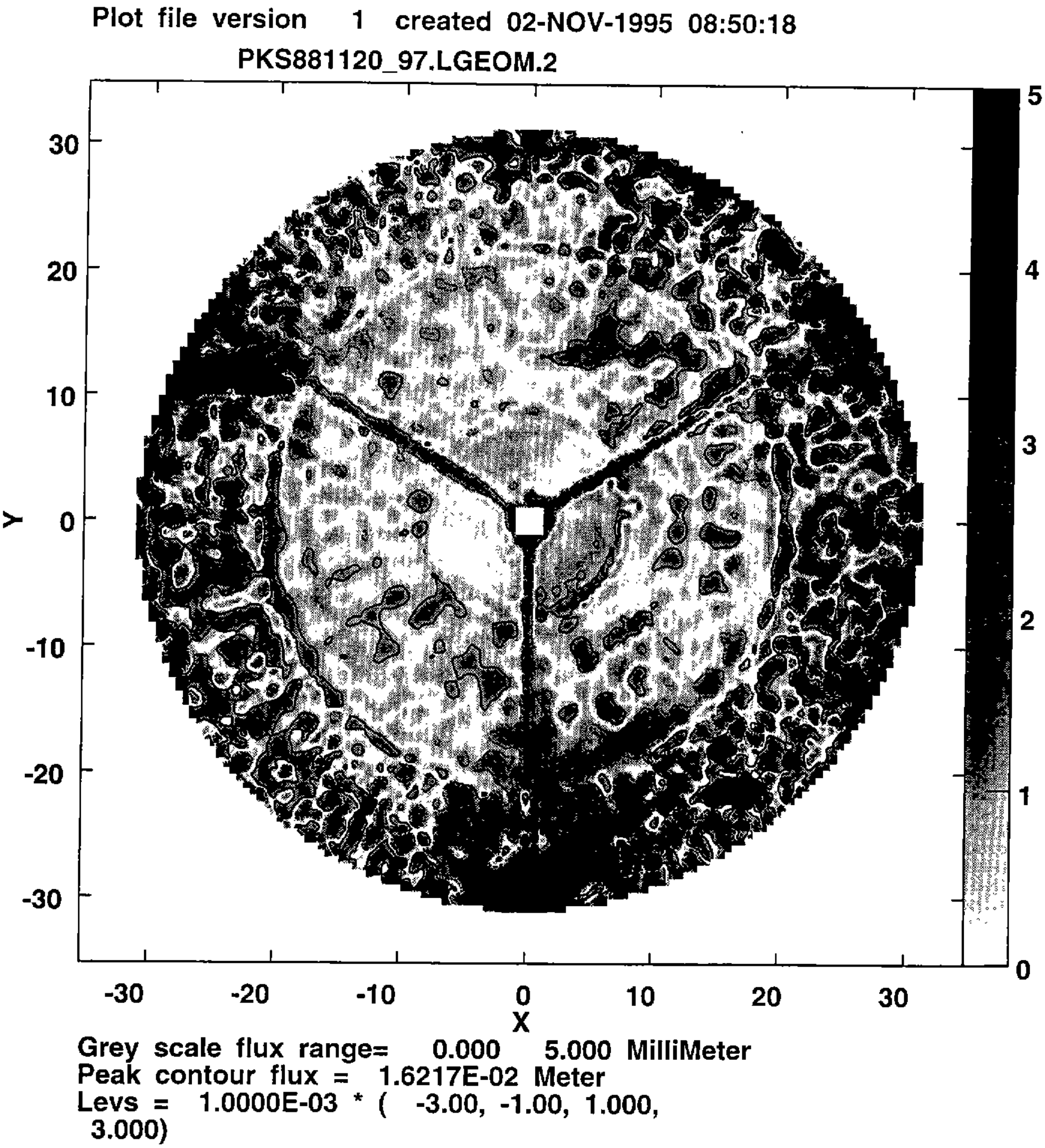
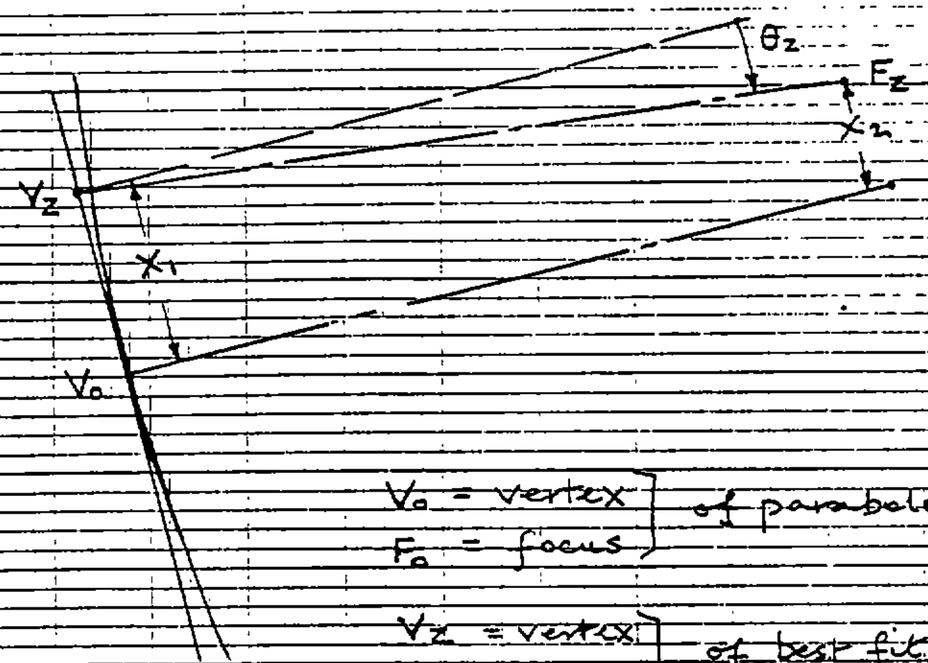


fig 8 12 GHz surface error image (Nov. 1988)



V_o = vertex } of paraboloid at
F_o = focus } Z.A. = 0°

V_Z = vertex } of best fit paraboloid
F_Z = focus } at Z.A. = Z.

θ_Z = B.F.P. Axis Rotation.

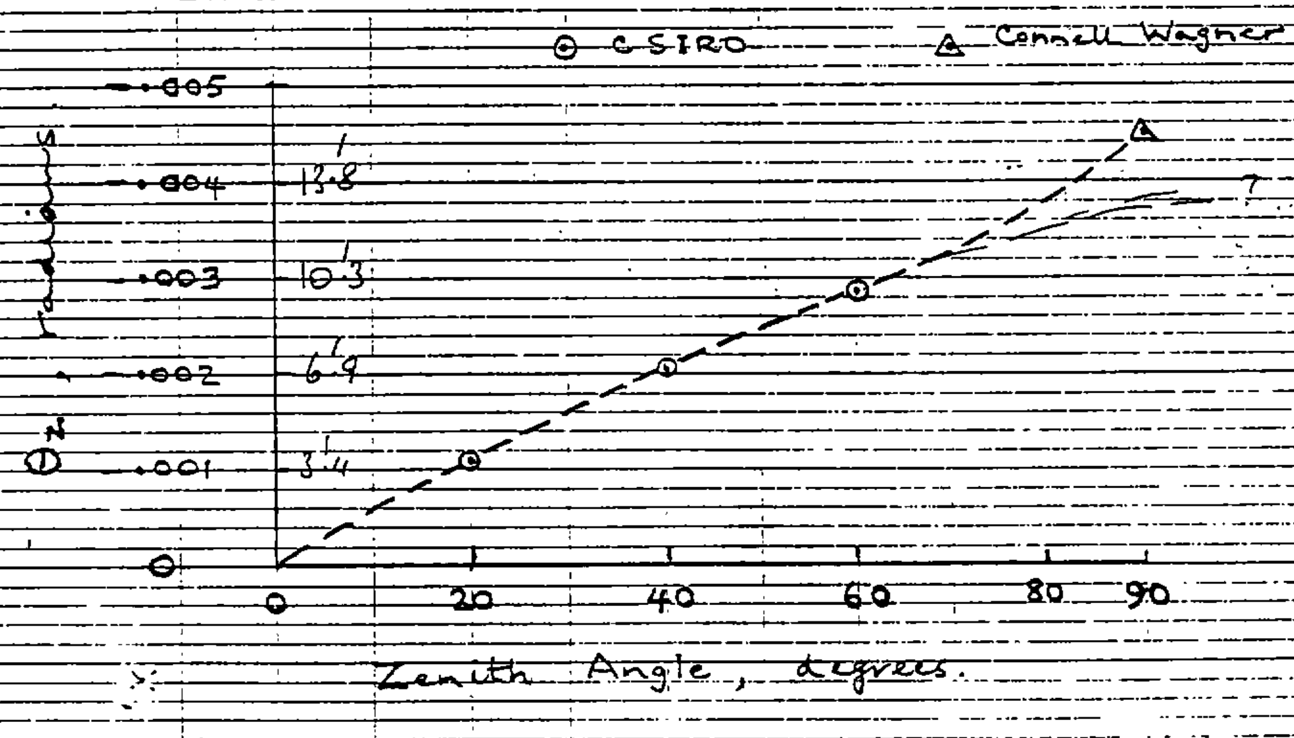
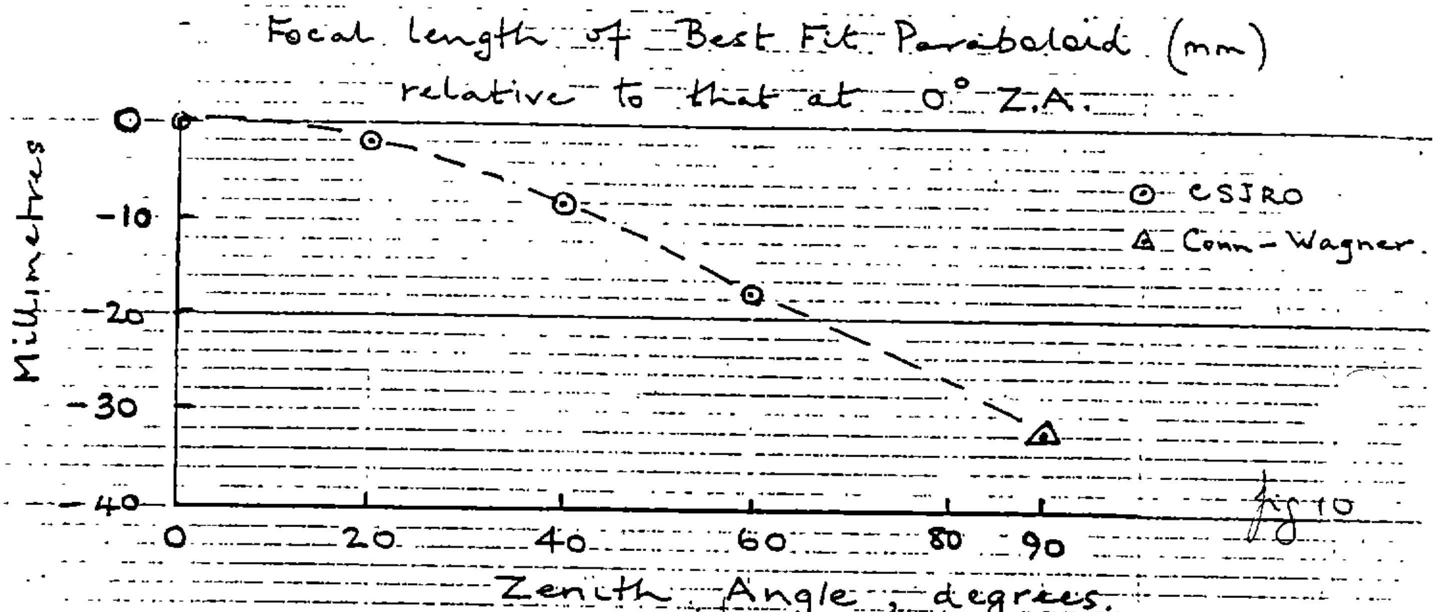
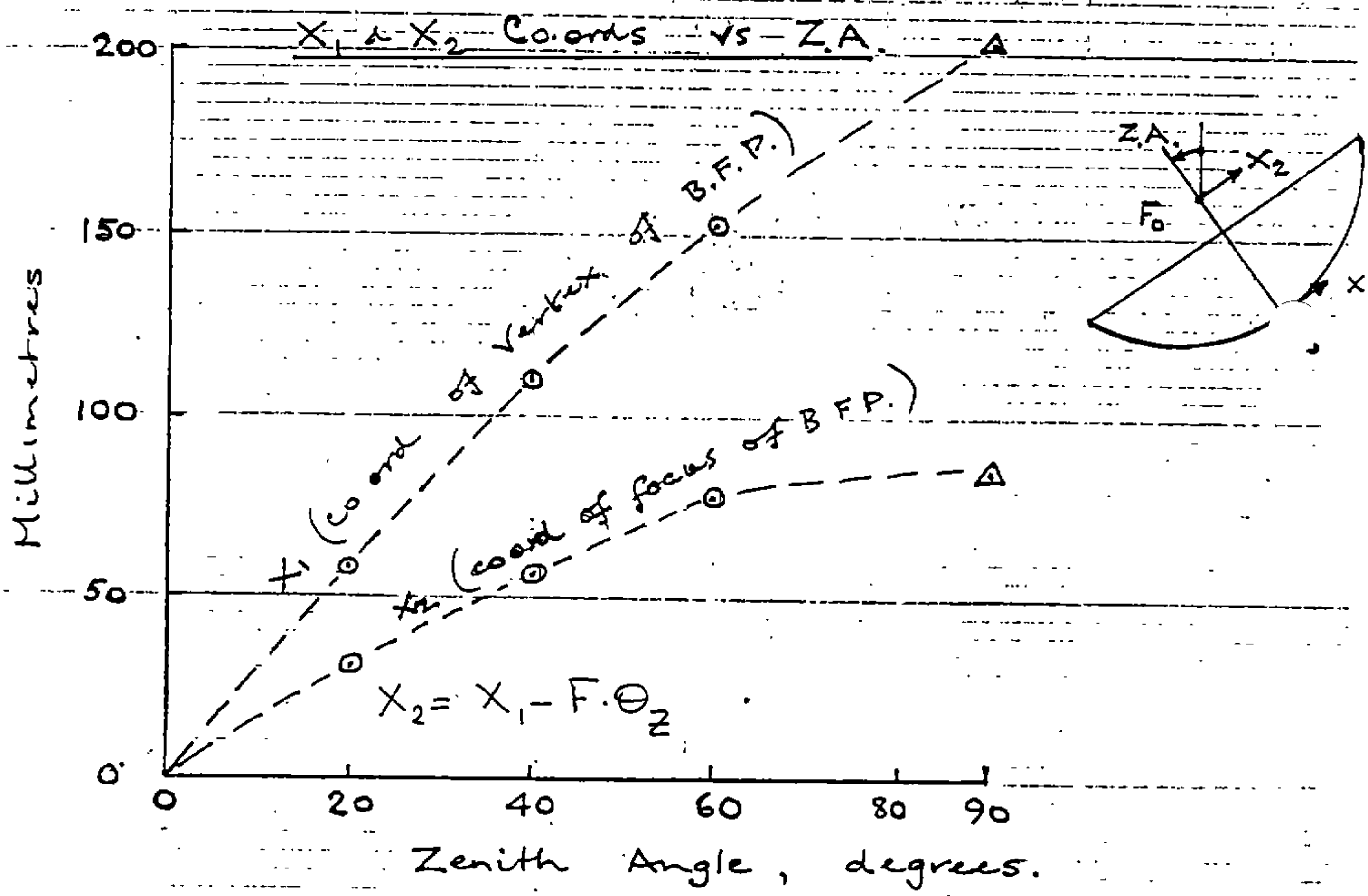


fig 9



Focal length of Best Fit Paraboloid (mm)
relative to that at 0° Z.A.
Millimetres
0
-10
-20
-30
-40
0
20
40
60
80
90
⊙ CSIRO
△ Conn - Wagner.
Zenith Angle, degrees.

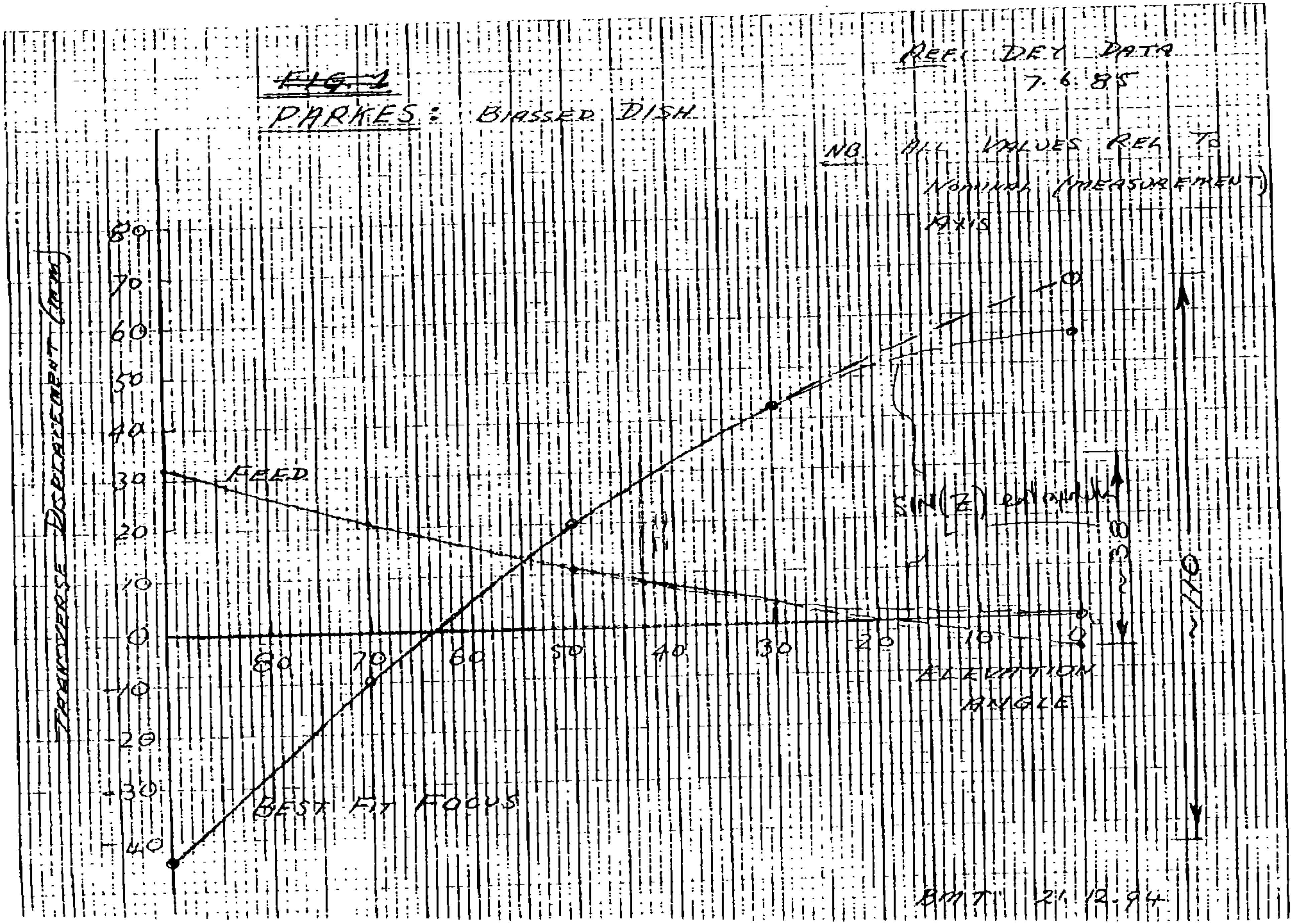
fig 10



X1 & X2 Co.ords vs Z.A.
Millimetres
200
150
100
50
0
0
20
40
60
80
90
x1 (co ord of vertex of B.F.P.)
x2 (coord of focus of B F P.)
X2 = X1 - F.θZ
Z.A.
X2
F0
X
Zenith Angle, degrees.

fig 11

fig 12



~~FIG. 1~~
PARKES: BIASSED DISH
REF: DEY DATA 7.6.85
NB. ALL VALUES REL TO NOMINAL (MEASUREMENT) AXIS
TRANSVERSE DISPLACEMENT (mm)
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
FEED
BEST FIT FOCUS
SIN(Z) behaviour
~38
~110
80
70
60
50
40
30
20
10
ELEVATION ANGLE
BMT 21.12.94