National Radio Astronomy Observatory

Charlottesville, Virginia

To: Addressee

November 8, 1972

From: P. Napier

ENGINEERING MEMO #14

Subject: Cassegrain Feed System for NRAO 140-ft. Antenna

A design for a multifeed, nutating subreflector system for the 140' telescope is attached. The system is essentially identical to the proposed VLA feed system. It is hoped to put the system on the telescope in August 1973. I would be glad to hear any comments you may have.

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CASSEGRAIN SYSTEM FOR 140' TELESCOPE

P. J. Napier
November 8, 1972

A. Multifeed Cassegrain System

The "multicone" feed system used by JPL on their 210-ft. antenna[1] appears to be the best way to utilize a multiple cassegrain feed system. It is proposed to use the same system for the NRAO 140 ft. telescope. The advantages of this system are that it has no phase error or boresight shift and should have good spillover performance.

In a "multicone" feed system the feeds are located in a circle around the parabola axis. The subreflector is tilted about the parabola focus to point towards the feed in use. To change feeds the subreflector is simply rotated about the parabola axis.

B. Cassegrain Geometry

Figure 1 shows the proposed cassegrain geometry for the 140 ft.

Paraboloid F/D = 0.4286

Parabola Half Angle = 60.51°

Average Hyperbola Diameter = 10.53 ft. (126.4")

Focus to Feed Distance = 45 ft. (540")

Average Hyperbolic Half Angle = 7.14°

Magnification = 9.348

Eccentricity = 1.240

Focus to Hyperbolic Vertex = 4.35 ft. (52.19")

Angle Between Parabola Axis and Hyperboloid Axis = 4.1°

C. Subreflector

Figure 2 shows the coordinate system for the subreflector. Table 1 details the hyperbolic profile of the subreflector. The hyperboloid axis of symmetry is colinear with the horn phase center. Spillover will be minimized by truncating the symmetrical hyperboloid asymmetrically. This truncation is determined by the boundary formed by the cone, which has its apex at the paraboloid focus and symmetrically circumscribes the edges of the paraboloid. Table 2 details the edge of the subreflector. The hyperboloid will be rotated about the paraboloid axis to focus on the feed being used. The sub-reflector will weigh approximately 150 lbs.

Subreflector tolerances:

(a) Subreflector Surface Deviation - The RMS departure from a best fit hyperboloid must be less than 0.01".

(b) Subreflector Axial Focus - This should be remotely adjustable over a range of $\pm$ 4" with a resetability and stability of 0.1" to keep gain error < 5% at $\lambda = 1.35$ cm.

(c) Subreflector Tilt - The subreflector axis must be parallel to the line between the paraboloid focus and the feed phase center to within $\pm$ 0.1° and must be stable (or known through a readout sensor) to within $\pm$ 40 arc-seconds ($\pm$ .03" at edge).

(d) Subreflector Lateral Focus - Ther vertex of the subreflector must be on the line between the parabola focus and feed phase center to within .2" and must be stable to within $\pm$ .01" to keep pointing errors less than $\pm$ 3 arc. sec.

(e) Rotation About Parabola Axis - To focus on the feed to be used, the subreflector should be able to be remotely rotated about the paraboloid axis to a predetermined position with an accuracy of $\pm 1°$ and must be stable to within $\pm$ 3 arc. min.

D. Nutation

The purpose of nutating the antenna beam is to provide cancellation of atmospheric noise. Other functions such as locating a source or mapping of an extended object can be performed by scanning the antenna.

A square-wave movement of the beam is desirable in order to provide optimum signal-to-noise. The frequency of the square-wave should be > 2 cps and as high as 5 cps, if feasible, in order to cancel atmospheric effects and mechanical instabilities in the receiver. This is evident from our own experience and from the work of Slobin[2]. A maximum of 1/8 of the cycle should be spent in moving from one position to the other; thus the transition time must be < 31 ms and preferably < 12 ms.

The amplitude of the beam deviation must be large enough to make the beams exclusive and thus must be at least a few beamwidths at the longest wavelength of operation. The beam deviation, $\Delta\theta$, for an α rotation of the hyperboloid about its vertex is approximately $2\alpha/M$, where M is the Cassegrain magnification. (If the hyperboloid is pivoted at a point located at a distance, ℓ, behind its vertex, the beam deviation is approximately $2\,\alpha/M - \ell\alpha/F$, where F is the paraboloidal focal length 720"; thus $\ell\alpha/F$ is negligible for ℓ < 14".)

On the basis of the above considerations the following table of transition time, τ, vs. angular movement, α, is recommended:

Beam Deviation $\Delta\theta$	Hyperboloid Rotation α	Preferable Transition Time τ	Wavelength for $\Delta\theta$ = 3 Beamwidths	Hyperboloid Edge Movement
18'	84'	19 ms	6 cm	4"
6'	28'	16 ms	2 cm	1.3"
3.6'	17'	10 ms	1.2 cm	0.8"

Nutation should be in the plane containing the axis of the paraboloid and the axis of the subreflector.

E. Feed Package

Initially four (4) feeds will be positioned on the telescope: L Band, C Band, Ku Band and K Band. There is room on the feed circle for more feeds if required at a later date (e.g. S Band, X Band). The four (4) feeds are being made by Rantec and are described in detail in "Specifications for Cassegrain Feeds" - NRAO October 31, 1972. Approximate dimensions for the feeds are as follows:

Feed	Aperture Diameter (± 10%)	Length (± 10%)	Weight (± 40%)
L Band	62"	85"	1000 lb.
C Band	17"	82"	200
Ku Band	6"	82"	100
K Band	4"	82"	100

Figure 3 shows the feed arrangement and equipment room.

The feeds must be directed to the center of the subreflector area (not the subreflector vertex). This requires that they be tilted at an angle of 4.7° to the paraboloid axis. The centers of all feed apertures lie on a circle with radius 38.4" about the paraboloid vertex. The center of this feed circle is 15.5' (186") above the paraboloid vertex on the paraboloid axis.

The equipment room below the feeds should be circular with a diameter of 10'. The room should be 7.5' high with its floor 34" above the parabola vertex. In this position the ends of the feeds should project approximately 20" into the room.

Mountings for up to five 2 ft. X 2 ft. X 2 ft. floor mounted racks with a total weight of 2000 lbs. should be provided.

Feed Tolerances

(a) Feed Axial Focus - The center of the L Band feed aperture should not be behind the feed circle described above, but may extend up to 6" in front of it. The center of the C, Ku and K Band horns should all lie in the same plane within ± 1" of the feed circle.

(b) Feed Lateral Focus - The center of the K Band feed aperture should be within ± 1" of the line through the paraboloid focus and the subreflector vertex and should be stable to ± .1". The tolerances for the other frequencies are proportionately greater.

(c) Feed Tilt - All feed axis should lie on a line at 4.7° to the paraboloid axis and their tilt in two orthogonal planes should be locally adjustable to ± 3°. The feed tilt should be stable to ± 40 minutes of arc.

F. Dichroic Optics System

To allow the telescope to operate at both C and Ku Band simultaneously a dichroic optics system shown in Figure 4 will be positioned above the C and Ku Band feeds. A supporting system is needed to hold the ellipsoidal reflector over the Ku Band horn and the dichroic reflector over the C Band horn. The support system must provide the necessary positional accuracy and also be capable of swinging the reflectors out of the path of the feed radiation when dual frequency operation is not needed (see photographs of the JPL dichroic-optics system and reference 3). The ellipsoid and dichroic reflectors will be approximately 12" in diameter and will weigh approximately 5 lbs. They will be provided by the feed manufacturer.

Dichroic Optics Feed Support Tolerances

(a) Axial and Lateral Focus - The ellipsoidal and dichroic reflectors must be positioned on a specified point on the axis of the Ku and C Band horns with an accuracy of .1" and should be stable to ± .01".

(b) Reflector Tilt - The reflectors should be positioned at the correct specified angle with respect to the feed axis - this angle should be locally adjustable over ± 3° and should be stable to ± 20 minutes of arc.

References:

1. The following parts of JPL Space Programs Summary give details of the design and construction of the JPL 210-ft. tricone system.

   37-45, Vol. III, pp. 48-51
   37-56, Vol. II , pp. 121-124
   37-57, Vol. II,, pp. 160-165
   37-61, Vol. II , pp. 108-113

2. Slobin, S. D., "A Study of Asymmetrical Cassegrainian - Antenna Feed Applications to Millimeter-Wavelength-Radio-Astronomical Observations," Univ. of So. California, Elec. Science Lab., USC EE Report 321, December 1968.

3. The following JPL publications give details of the design and construction of the JPL dichroic optics system.

   JPL DSN Progress Report, TR-32-1526, Vol. VI, pp. 139-1 1.
   " " " " , TR-32-1526, Vol. VIII, pp. 53 60.
   " " " " , TR-32-1526, Vol. IX, pp. 141-146.
   " " " " , TR-32-1526, Vol. X, pp. 135-142.
   " " " " , TR-32-1526, Vol. X, pp. 186-190.

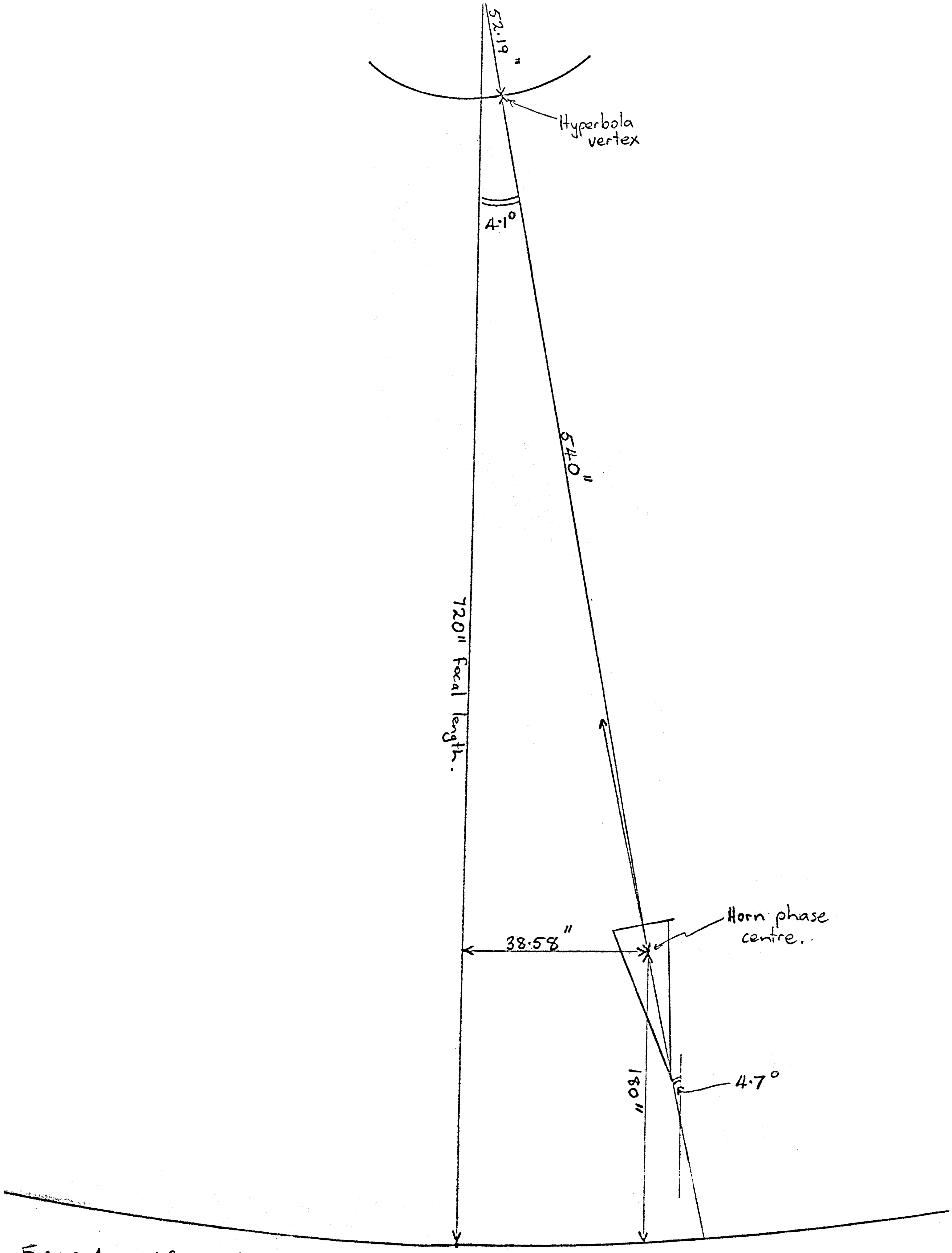


Figure 1. 140ft Cassegrain Geometry

O - Parabola vertex
F - Prime focus
V - Hyperbola verte[x]
P - Secondary focu[s]
(R,φ,z) — azimuthal coordinates hyperbola surface.

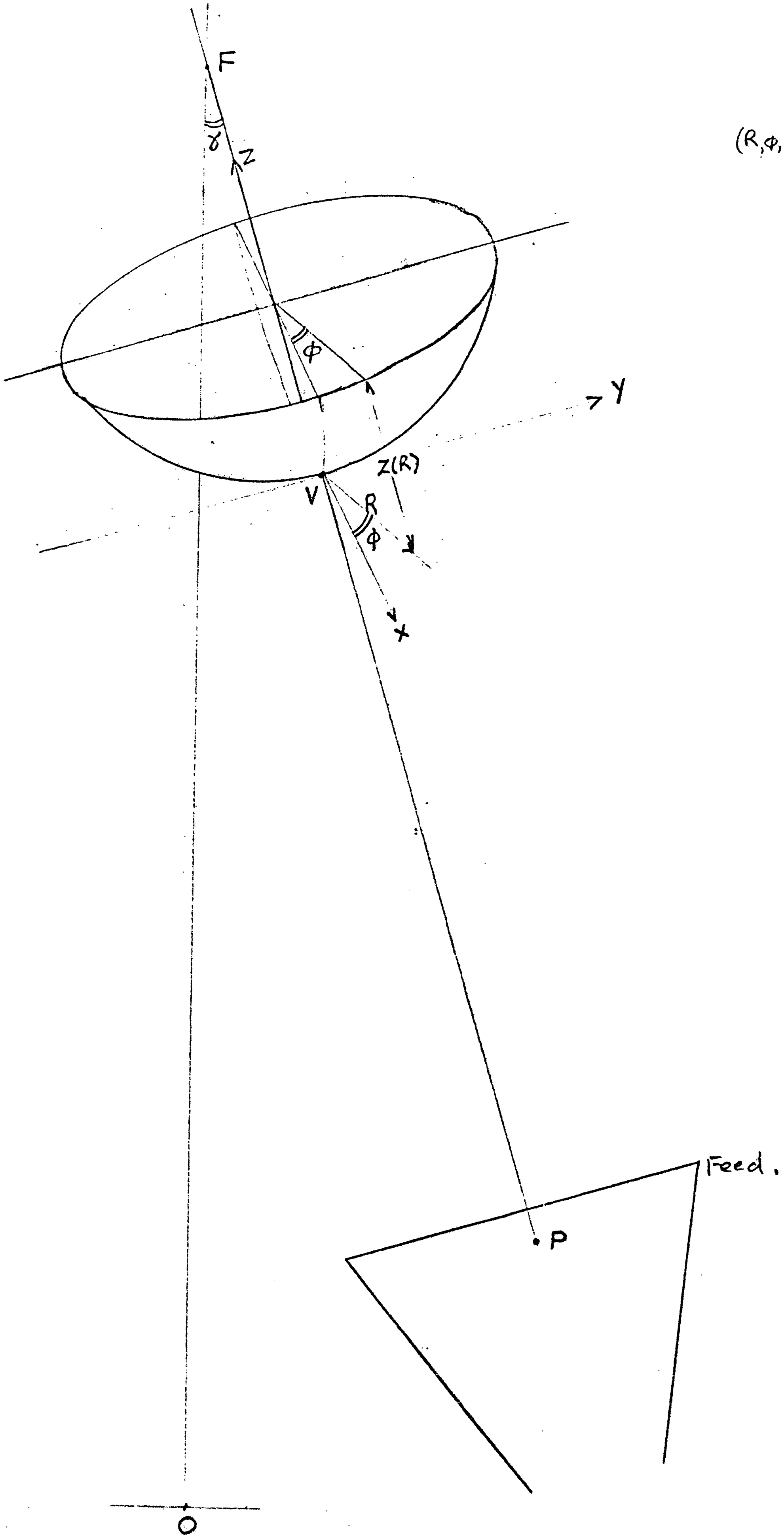
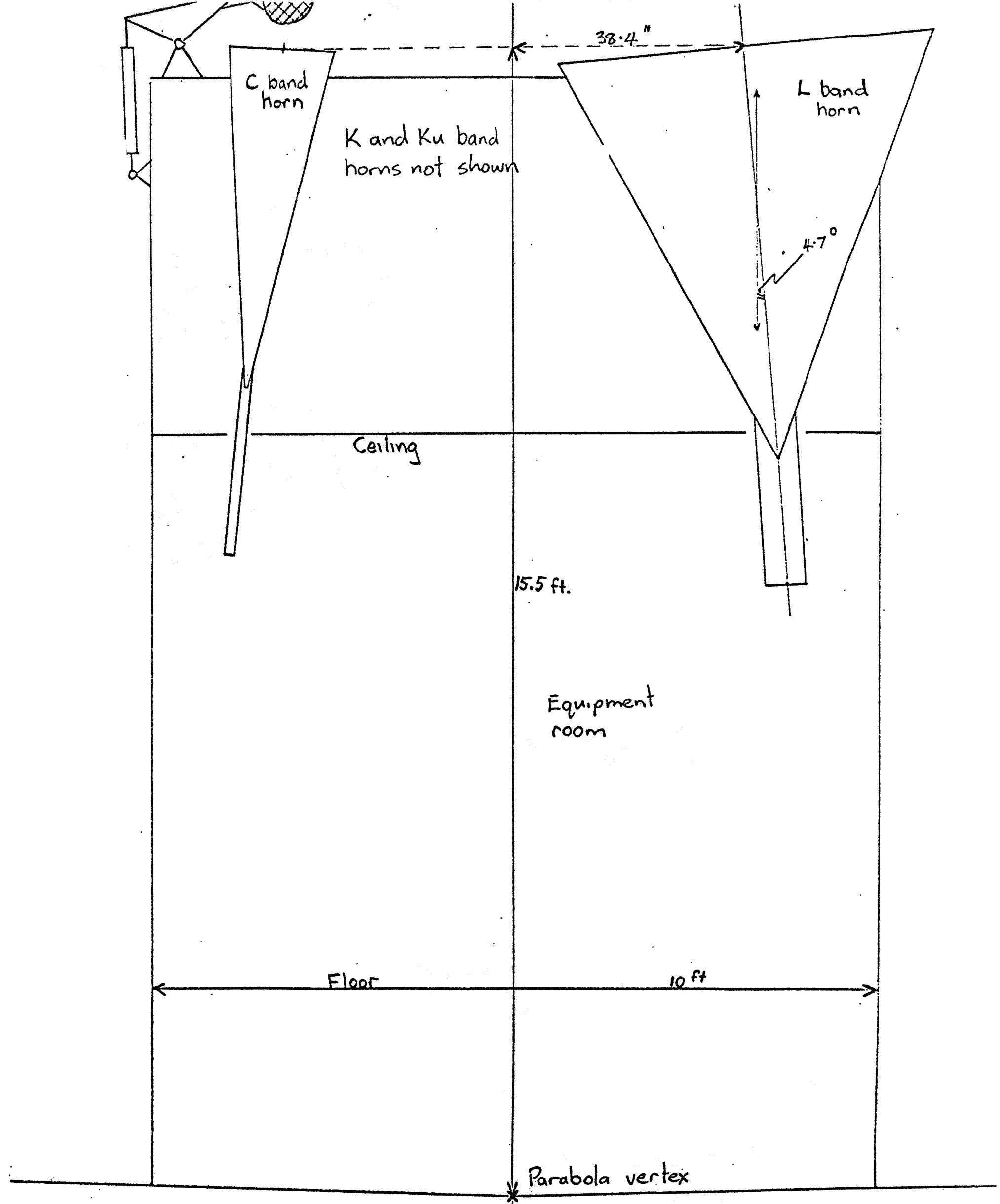
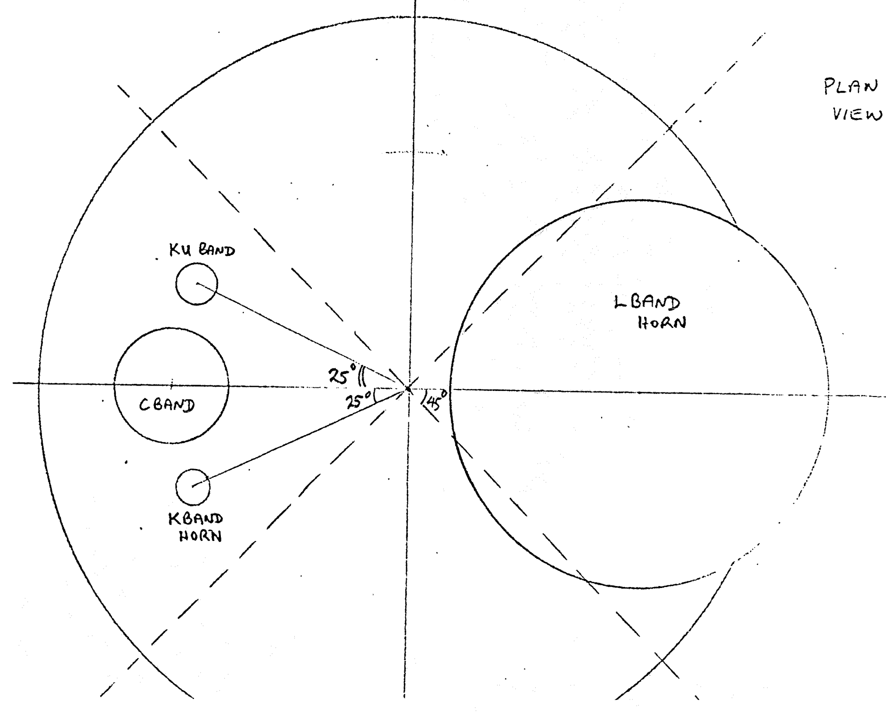


Fig 2 Cassegrain coordinates


38.4"
C band horn
K and Ku band horns not shown
L band horn
4.7°
Ceiling
15.5 ft.
Equipment room
Floor
10 ft
Parabola vertex


PLAN VIEW
KU BAND
C BAND
K BAND HORN
L BAND HORN
25°
25°
45°

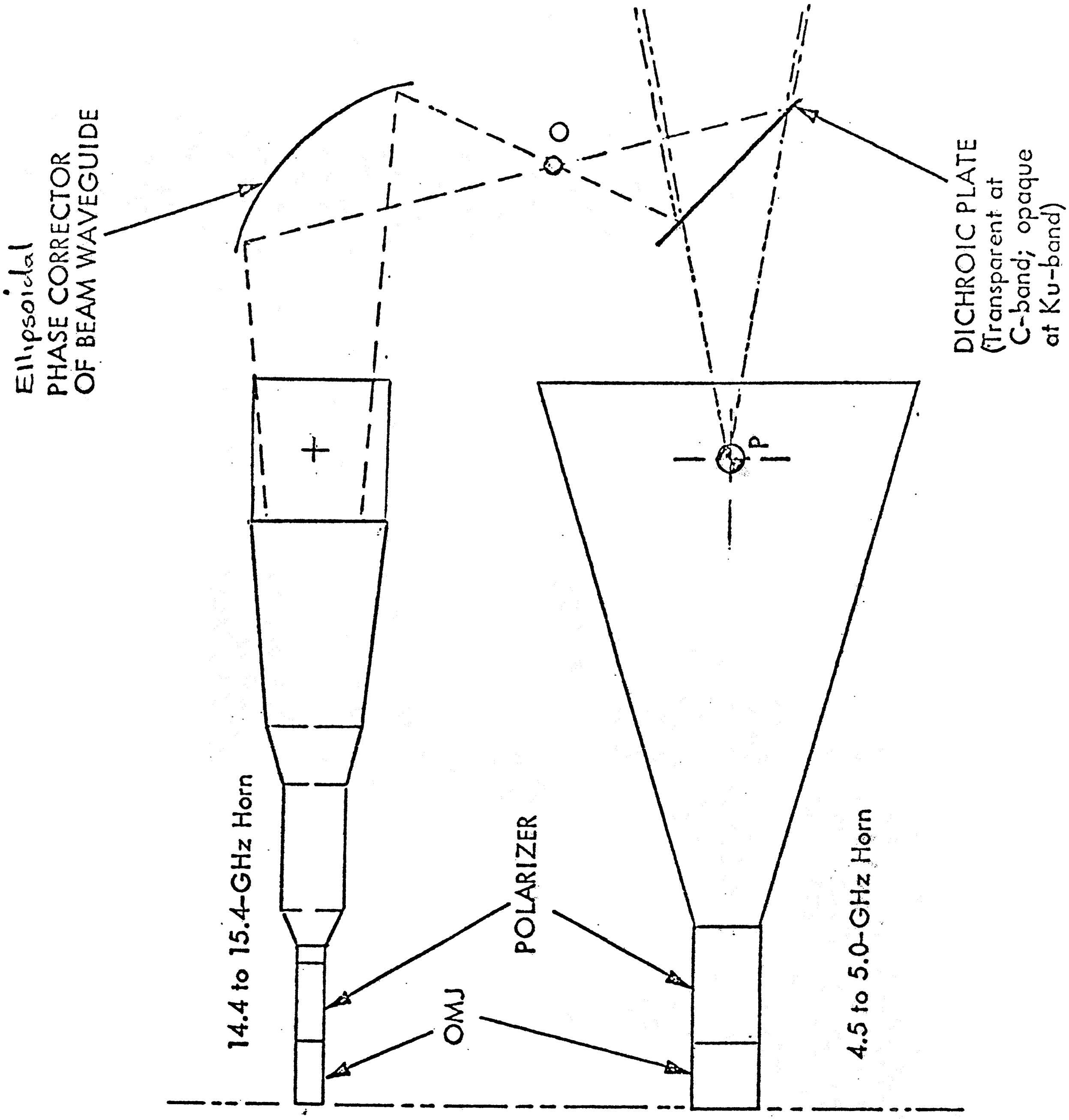


Fig 4. Dichroic Optics System For C and Ku Band.

R	Z(R)	R	Z(R)	R	Z(R)
0.0	0.0	1.00	0.0045	2.00	0.0175
3.00	0.0384	4.00	0.0685	5.00	0.1060
6.00	0.1533	7.00	0.2090	8.00	0.2730
9.00	0.3463	10.00	0.4275	11.00	0.5170
12.00	0.6151	13.00	0.7218	14.00	0.8359
15.00	0.9603	16.00	1.0924	17.00	1.2326
18.00	1.3816	19.00	1.5366	20.00	1.7044
21.00	1.8784	22.00	2.0500	23.00	2.2513
24.00	2.4503	25.00	2.6574	26.00	2.8750
27.00	3.0967	28.00	3.3260	29.00	3.5685
30.00	3.8167	31.00	4.0750	32.00	4.3375
33.00	4.6100	34.00	4.8904	35.00	5.1769
36.00	5.4754	37.00	5.7799	38.00	6.0921
39.00	6.4124	40.00	6.7404	41.00	7.0763
42.00	7.4201	43.00	7.7715	44.00	8.1305
45.00	8.4973	46.00	8.8716	47.00	9.2534
48.00	9.6429	49.00	10.0401	50.00	10.4445
51.00	10.8564	52.00	11.2753	53.00	11.7025
54.00	12.1366	55.00	12.5776	56.00	13.0265
57.00	13.4821	58.00	13.9449	59.00	14.4147
60.00	14.8917	61.00	15.3757	62.00	15.8667
63.00	16.3646	64.00	16.8654	65.00	17.3810
66.00	17.8995	67.00	18.4248	68.00	18.9566

Table 1. Hyperbola profile.

φ PHI	R	Z(R)
0.0	63.067	16.398
2.000	62.872	16.301
4.000	62.678	16.204
6.000	62.486	16.108
8.000	62.295	16.013
10.000	62.105	15.919
12.000	61.917	15.826
14.000	61.731	15.734
16.000	61.548	15.644
18.000	61.366	15.555
20.000	61.188	15.467
22.000	61.012	15.382
24.000	60.840	15.298
26.000	60.670	15.215
28.000	60.504	15.135
30.000	60.342	15.056
32.000	60.183	14.980
34.000	60.028	14.905
36.000	59.878	14.833
38.000	59.731	14.763
40.000	59.589	14.695
42.000	59.451	14.629
44.000	59.318	14.566
46.000	59.190	14.505
48.000	59.066	14.446
50.000	58.948	14.390
52.000	58.834	14.336
54.000	58.726	14.285
56.000	58.623	14.237
58.000	58.526	14.191
60.000	58.434	14.148
62.000	58.347	14.107
64.000	58.266	14.069
66.000	58.191	14.034
68.000	58.122	14.002
70.000	58.058	13.972
72.000	58.001	13.945
74.000	57.949	13.921
76.000	57.903	13.900
78.000	57.863	13.881
80.000	57.830	13.866
82.000	57.802	13.853
84.000	57.781	13.843
86.000	57.765	13.836
88.000	57.756	13.831
90.000	57.753	13.830

φ PHI		Z(R)
-90.000	68.943	19.464
-88.000	68.939	19.462
-86.000	68.926	19.456
-84.000	68.909	19.446
-82.000	68.883	19.432
-80.000	68.849	19.414
-78.000	68.809	19.392
-76.000	68.760	19.365
-74.000	68.705	19.335
-72.000	68.642	19.301
-70.000	68.572	19.264
-68.000	68.496	19.223
-66.000	68.412	19.178
-64.000	68.322	19.129
-62.000	68.225	19.077
-60.000	68.122	19.022
-58.000	68.013	18.963
-56.000	67.897	18.902
-54.000	67.776	18.837
-52.000	67.649	18.769
-50.000	67.516	18.698
-48.000	67.378	18.625
-46.000	67.235	18.549
-44.000	67.087	18.471
-42.000	66.934	18.390
-40.000	66.777	18.307
-38.000	66.616	18.222
-36.000	66.451	18.135
-34.000	66.281	18.047
-32.000	66.109	17.956
-30.000	65.933	17.864
-28.000	65.754	17.771
-26.000	65.572	17.677
-24.000	65.387	17.581
-22.000	65.200	7.484
-20.000	65.012	7.387
-18.000	64.821	7.289
-16.000	64.629	7.191
-14.000	64.436	17.091
-12.000	64.241	16.992
-10.000	64.046	16.893
-8.000	63.850	16.793
-6.000	63.654	16.694
-4.000	63.458	16.595
-2.000	63.262	16.497

Table 2. Edge coordinates of subreflector.