4.61 cm and 2.22 cm polarization rotators and feed horns for 150-foot paraboloid at the Algonquin Radio Observatory

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RADIO AND ELECTRICAL ENGINEERING DIVISION

4.61 CM AND 2.22 CM POLARIZATION ROTATORS AND FEED HORNS FOR 150 - FOOT PARABOLOID AT THE ALGONQUIN RADIO OBSERVATORY

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OTTAWA

SEPTEMBER 1967

ABSTRACT

In addition to the X-band polarization rotator (NRC ERB-735), two more polarizers were required for the J- and Ku-band receivers for the 150-foot paraboloid antenna at the Algonquin Radio Observatory. The specified restriction on variation in loss or VSWR with polarization rotation was rather stringent in order that source polarization measurements could be made. The design bandwidth 0.300 GHz centered at 6.500 GHz for J-band, and 0.350 GHz centered at 13.50 GHz for Ku-band. Feed horns were also required for operation at the prime focus although the polarizers are suitable for Gregorian operation also. Calculated secondary patterns are presented for the prime-focus feed horns provided, as well as gain and aperture efficiency calculations.

CONTENTS

FIGURES

TABLES

PLATES

4.61 CM AND 2.22 CM POLARIZATION ROTATORS AND FEED HORNS FOR 150-FOOT PARABOLOID AT THE ALGONQUIN RADIO OBSERVATORY

- R.W. Breithaupt, R. Villeneuve, L.W. Woods -

INTRODUCTION

This report is divided into two major sections which deal with a J-band and a Ku-band polarization rotator (or polarizer), respectively, designed for use with the 150-foot paraboloid antenna at the Algonquin Radio Observatory.

The polarizers are both continuously servo-driven, so that any desired polarization may be maintained with respect to a source as it is swept or tracked. Digital encoders are still to be added so that digital polarization position information will be available for data reduction.

The length of the polarizers was determined by the minimum space available in either the prime focus or Gregorian configuration.

The prime-focus feed horn chosen for J-band (6.500 GHz) gives an edge illumination of -15.8 db, and the two feed horns chosen for Ku-band (13.500 GHz) give illuminations of -15.7 db and -18.5 db.

Secondary patterns for the paraboloid were calculated from each of the prime-focus feed horn patterns, for both an aperture unperturbed by feed legs, and an aperture distribution containing 60% opaque feed-leg shadowing.

Gain and aperture efficiency calculations were made for the paraboloid using these prime-focus feed horns.

A complete description of the X-band (10.690 GHz) polarizer used with this antenna may be found in NRC Report ERB-735.

J-BAND (4.61 cm) POLARIZATION ROTATOR

In principle, this device is similar to that constructed for X-band (10.690 GHz) and described in NRC report ERB-735. Considerable economy in length has been achieved over the X-band model.

A summary of the desired and actual performance is given in Table I, and the complete polarization rotator with feed-horn is shown in Plate I.

The circular waveguide diameter was reduced to 1.253 inches so that no propagating higher-order modes could be excited by discontinuities inside the waveguide. This was accomplished by two quarter-wave transformers, as shown in Fig. 1.

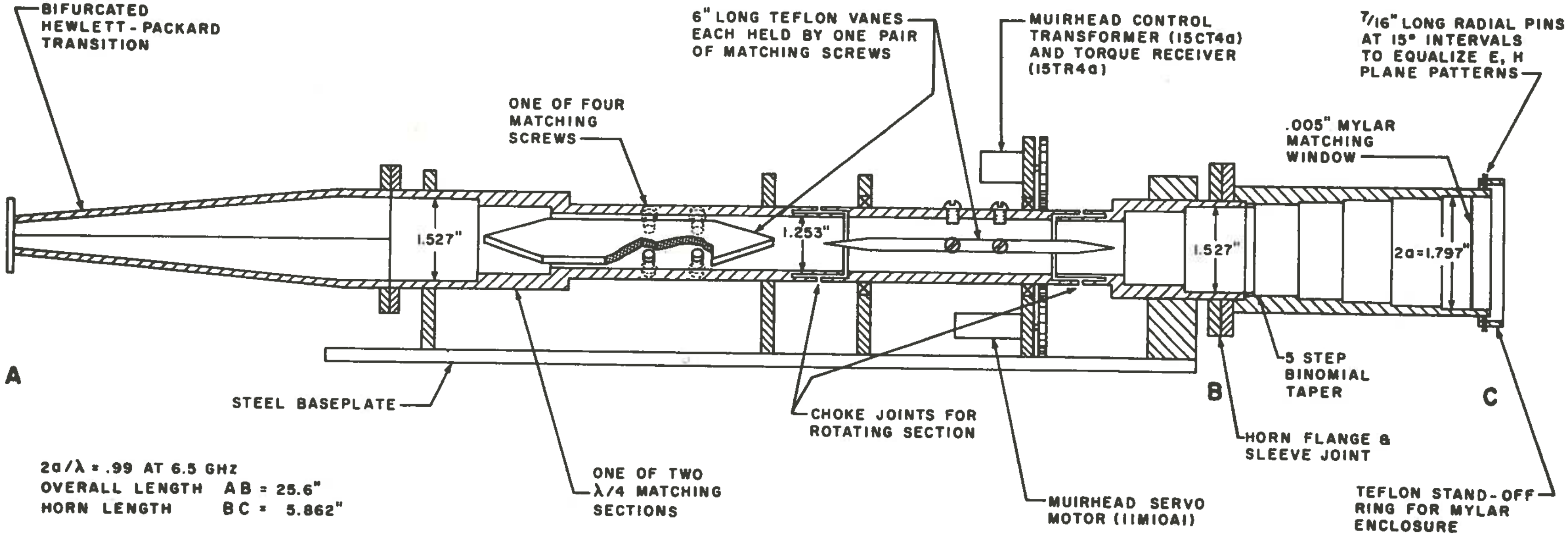

Fig. 1 J-band polarizer schematic

TABLE I

Polarizer characteristics (J-band)

Specification	Desired	Obtained
Center frequency	6.500 GHz	6.500 GHz
Bandwidth	0.300 GHz	0.300 GHz
Average cross polarization across bandwidth for worst rotational setting	-30 db	-38.5 db
Worst cross polarization with rotation at center frequency	-30 db	< -40 db
Change in average VSWR across bandwidth with polarization rotation	<0.03	<0.01
Change in transmitted power with polarization rotation (including loss and mismatch) = .1°K	0.0015 db	0.0035 ± 0.0005 db
Total loss through polarizer (at 6.5 GHz)		0.07 db
Accuracy of polarization setting (limited by synchros)	± 1°	± 1°
Maximum speed of rotation of polarization	2 rpm	~1.7 rpm

Each teflon vane used for differential phase shift in this device is 5.3 inches long and 0.200 inch thick, with a taper 1.5 inches long on either end. Final differential phase shift adjustment was made with two pairs of screws, one pair in the plane of the vane, and the other perpendicular to this. The screws were used to adjust phase shift, to match the vane discontinuity in each plane, and to hold the vane mechanically.

The servo operation of this polarizer is shown in Fig. 2, and it should be noted that there is no provision at present for remote monitoring of discrete increments of polarization change. It is expected that a digital encoder will eventually be added for this purpose.

Transmission loss measurements were made, and the change of loss with rotation was found to be 0.0035 ± 0.0005 db at 6.5 GHz. The total loss in the polarizer is 0.07 db.

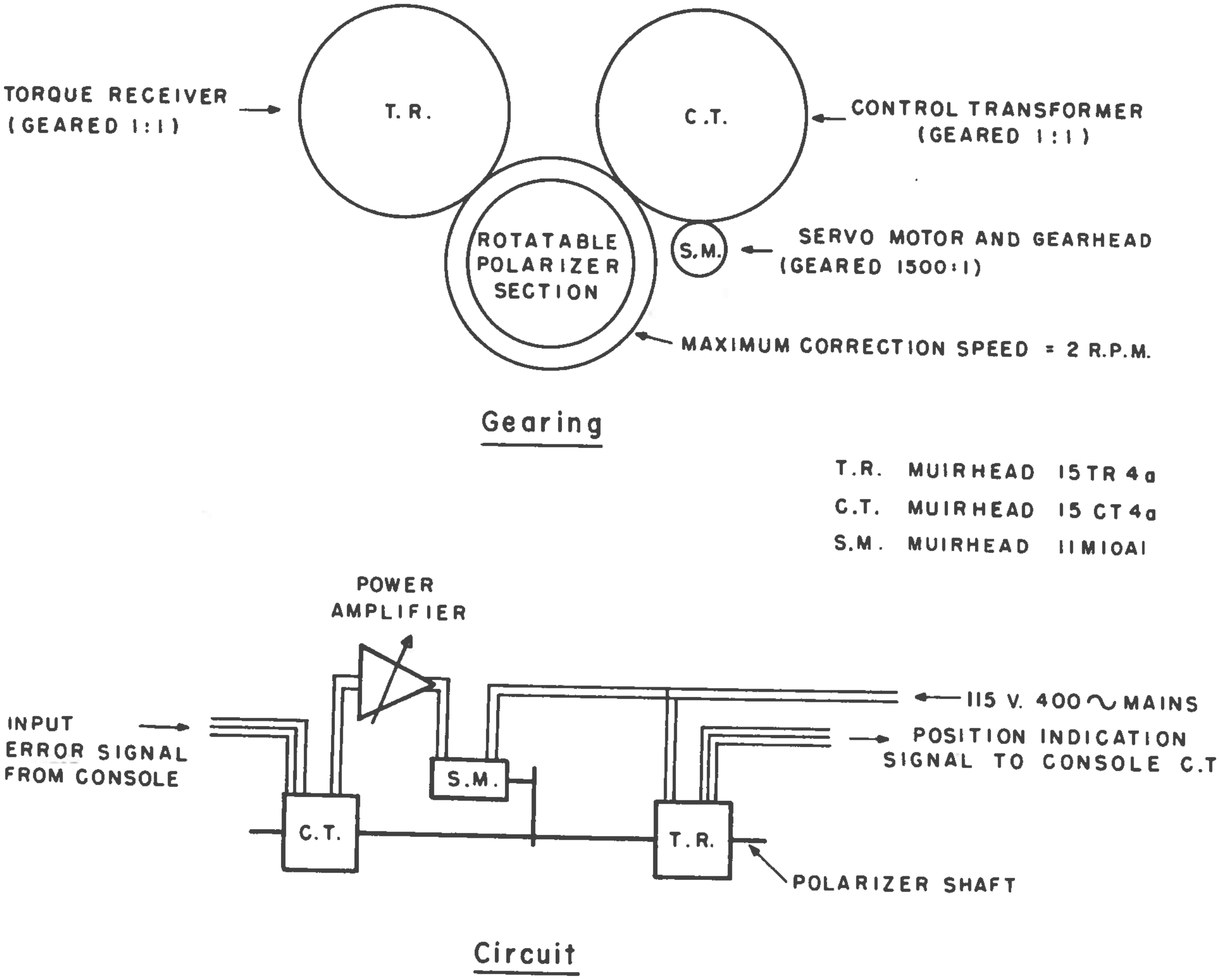

Fig. 2 Polarizer servo schematic

The VSWR of the complete polarizer and horn is shown in Fig. 3 for various angles of rotation. It can be seen that the average VSWR across the frequency band is about 1.035, with the peak being <1.06.*

*Since this device is now being used at ~6.6 GHz, it should be noted that over-all mismatch is < 1.06 up to f = 6.85 GHz, and satisfactory operation should be expected for f_0 = 6.6 GHz.

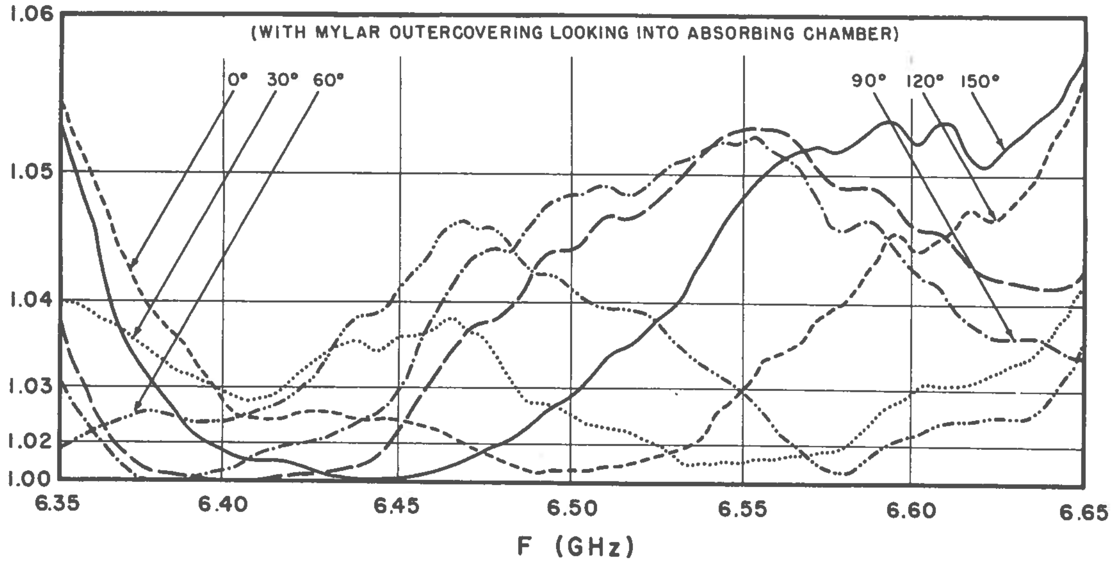

Fig. 3 VSWR of J-band polarizer plus horn with polarization rotation

Cross polarization was measured both as a function of polarization rotation and of frequency. The cross polarization remained <-40 db for all rotations at 6.5 GHz. The frequency variation of cross polarization (at worst rotation) is shown in Fig. 4.

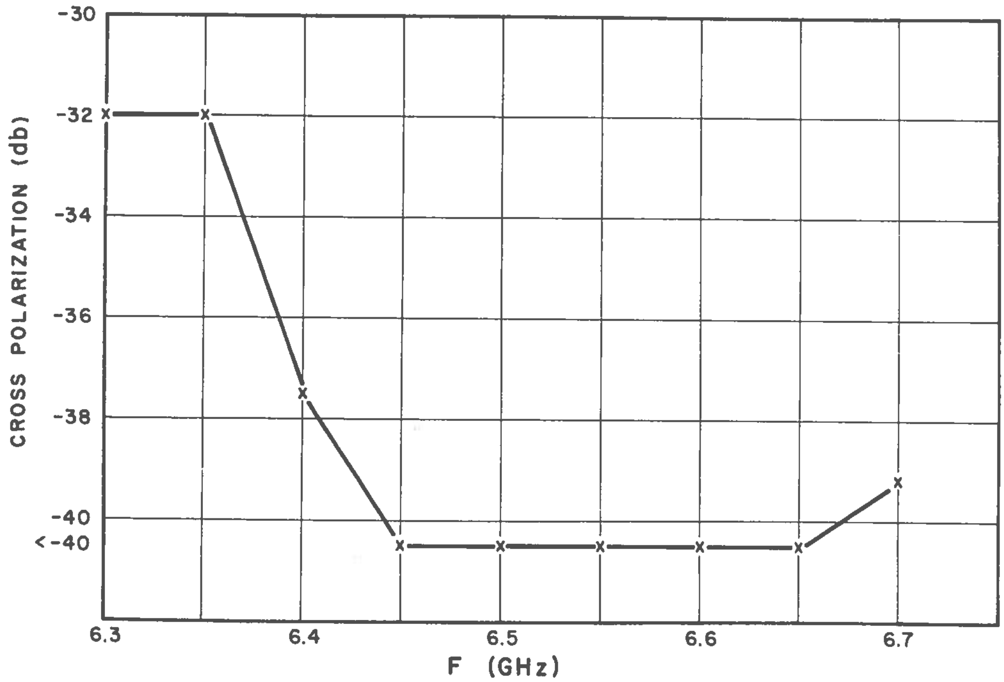

Fig. 4 J-band cross polarization over frequency band

For prime-focus operation, the polarizer is located in the same 10-inch diameter tube as for X-band, with the same weather-proof cover. For Gregorian operation, the front horn flange on the polarizer is compatible with the J-band horn flange of conical section located in the hub room.

Feed Horn

The feed horn for prime-focus operation is shown in Fig. 1, and has a five-step binomial transformer to effect the required diameter change. The characteristics of this horn lie between those of horns No. 1 and No. 3 for X-band and are given in Table II.

The $\frac{7}{16}$-inch radial pins spaced at 15° intervals around the horn mouth equalize the E, H plane patterns to within 0.25 db to 62° off axis where the spread begins to increase. The primary patterns are shown in Fig. 5. Secondary patterns (Fig. 6) were calculated both with and without feed-leg considerations as for the X-band horns in ERB 735. A feed-leg opaqueness of 60% (energy loss) was assumed.

TABLE II

Feed horn characteristics (J-band)

Aperture diameter 2a (inches)		1.797	
$2a/\lambda$		0.99	
		E (db)	H (db)
Primary patterns (equalized)	r = 0.8	- 8.9	- 8.8
	r = 1.0	-13.2	-12.6
Paraboloid aperture distribution	r = 0.8	-10.8	-10.7
	r = 1.0	-16.1	-15.5
Average VSWR of polarizer plus horn over frequency band		1.035	
Radial pin length from horn mouth (inches)		$\frac{7}{16}$	
Spillover past (% power)	r = 0.8	12.4	
	r = 1.0	5.6	

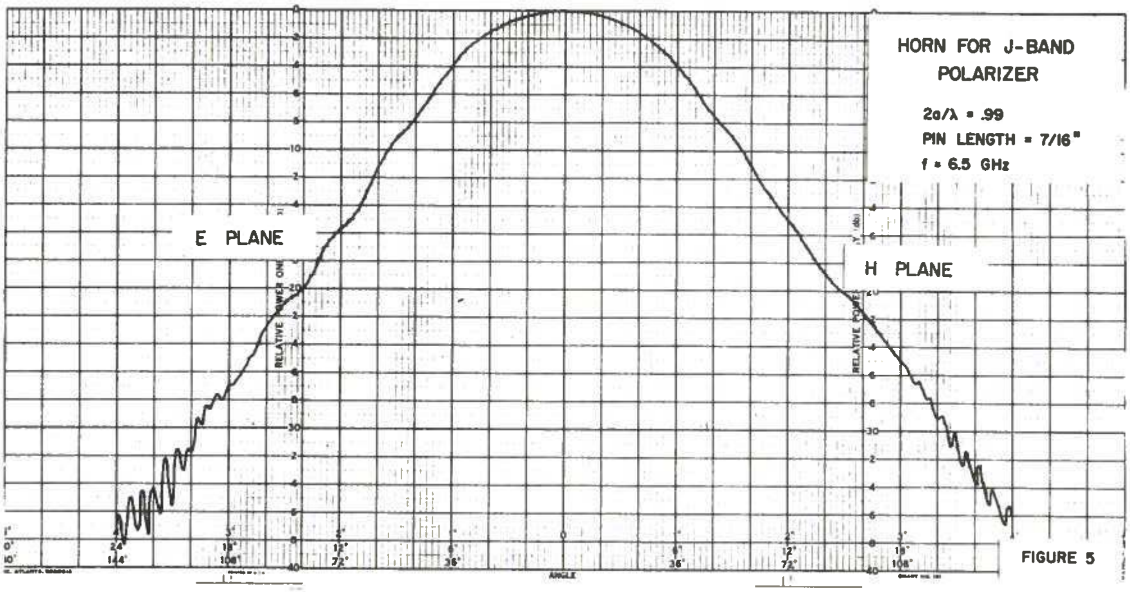

Fig. 5 Primary J-band feed horn patterns

Gain and Aperture Efficiency

The gain

$$G = G_0 \eta_1 \eta_2 \eta_3 \eta_4 \eta_5$$

where the formulae (Equations 8 - 14) of ERB 735 are used with the parameters

$k = 0.0667$

$r_1 = 0.8$

$\alpha = 0.0815$ radian (for correct shadow area)

$\xi_1 = 0.955$ corresponding to -0.4 db loss due to tolerance on solid portion of dish

$\xi_2 = 0.668$ corresponding to -3.5 db loss due to tolerance on mesh portion of dish

$\xi_3 = 0.980$ corresponding to -14 db transmission loss through mesh

The E- and H-plane electric field aperture distributions were assumed to be identical, and found from primary patterns to be represented by:

$$A(r) = 1.0008 - 1.9611r^2 + 1.6069r^4 - 0.4769r^6$$
$$= 0.1695 + 0.1779(1 - r^2) + 0.1762(1 - r^2)^2 + 0.4769(1 - r^2)^3$$

Results are given in Table III.

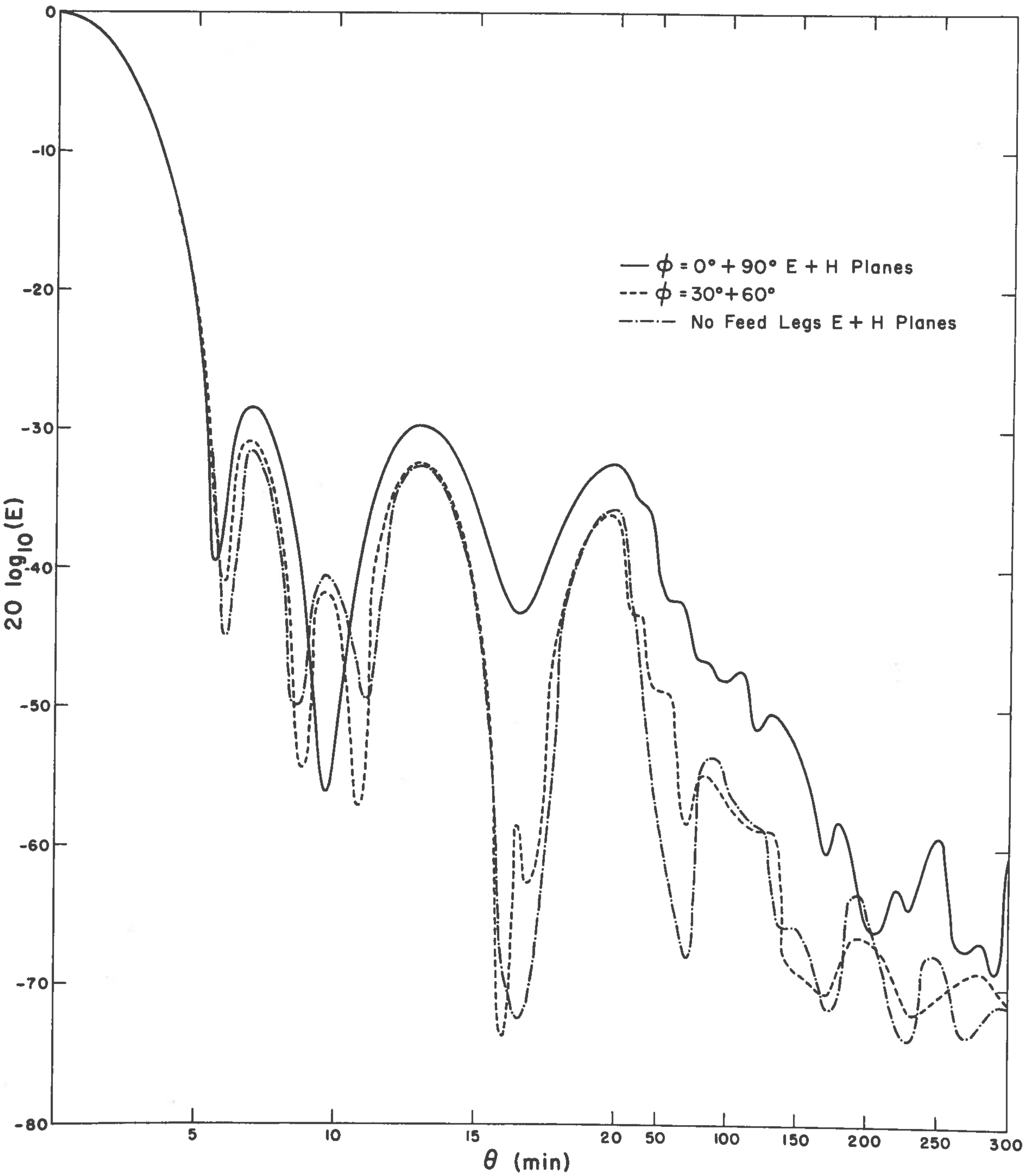

Fig. 6 Secondary patterns for J-band feed horn at prime focus

TABLE III

Gain and aperture efficiency (J-band)

3 db half-beamwidth (minutes)	2.12	
	Gain (db)	Aperture efficiency
Theoretical maximum	69.87	1.000
Illumination factor η_1	-1.12	0.773
Spillover η_2	-0.25	0.944
Mesh transmission η_3	-0.03	0.993
Surface error loss η_4	-0.88	0.816
Focal cabin and feed-leg blocking for 60% opaque quadrapod η_5	-0.25	0.945
Net	67.34	0.558

KU-BAND (2.22 cm) POLARIZATION ROTATOR

This device is similar to that constructed for J band as described previously in this report. The mounting method and possible location of the polarizer is similar to that for both J- and X-band polarizers, but the method for obtaining the required 90° differential phase shift is not. Teflon vanes cut to obtain minimum VSWR and 90° differential phase shift were used in the J- and X-band polarizers. The Ku-band polarizer contains two pieces of circular brass waveguide each squeezed in one plane until 90° differential phase shift was obtained.

Excepting the disadvantage of a narrow inherent bandwidth, there are two advantages in deforming the waveguide: the squeezed section introduces much less mismatch and lower loss variation with rotation than those obtained with either of the X- or J-band polarizers.

A summary of the performance desired and obtained is given in Table IV.

The circular waveguide diameter was reduced from 0.690 inch to 0.650 inch so that no propagating higher-order modes could be excited by discontinuities inside the waveguide. A quarter-wave transformer, following the Hewlett Packard transformer, and again following the rotating section, accomplish this diameter change twice, as shown in Fig. 7.

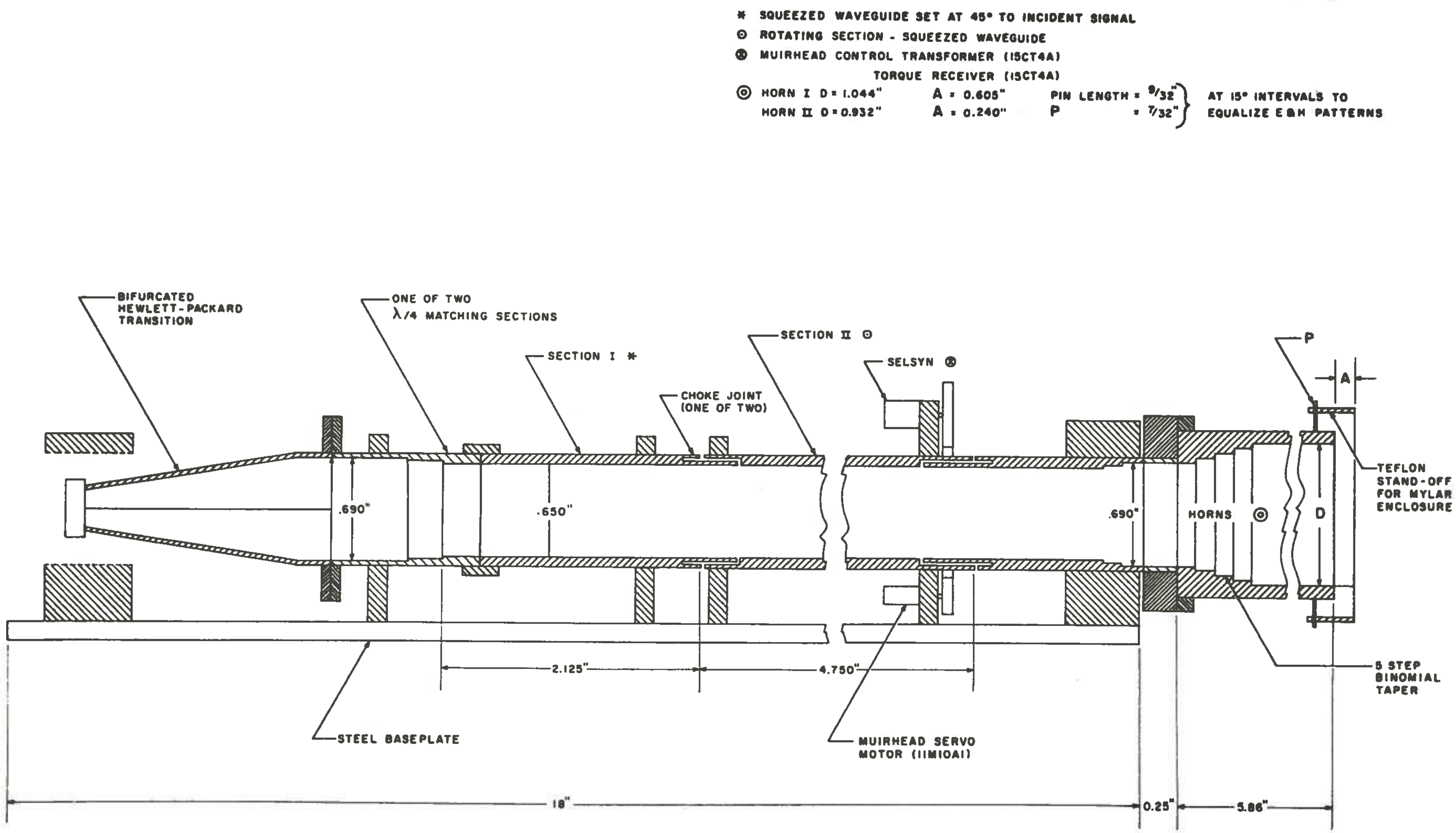

Fig. 7 Ku-band polarizer schematic

TABLE IV

Polarizer characteristics (Ku-band)

Specification	Desired	Obtained
Center frequency	13.500 GHz	13.500 GHz
Bandwidth	0.350 GHz	0.350 GHz
Average cross polarization across bandwidth for worst rotational setting	-30 db	-31.9 db
Worst cross polarization with rotation at center frequency	-30 db	-37.0 db
Change in average VSWR across bandwidth with polarization rotation	<0.03	0.02
Change in transmitted power with polarization rotation (including loss and mismatch) = .1°K	0.0015 db	0.0024 ± .0002 db
Total loss through polarizer (at 13.5 GHz)		0.213 db
Accuracy of polarization setting (limited by synchros)	±1°	±1°
Maximum speed of rotation of polarization	2 rpm	~1.7 rpm

The length of the rotating squeezed section was chosen so that reflections from the joints could not add in phase. The outer diameter was squeezed from 0.750 inch to 0.7965 and 0.7955 inch maximum, respectively, for section I and section II (Fig. 7), the deformation being spread over about three inches of length in each case. A typical phase-shift vs. frequency characteristic is given in Fig. 8.

The VSWR of the completed polarizer and horn is shown in Fig. 9 for various angles of rotation. It can be seen that the average VSWR across the frequency band is about 1.02 with the peak being 1.052 db.

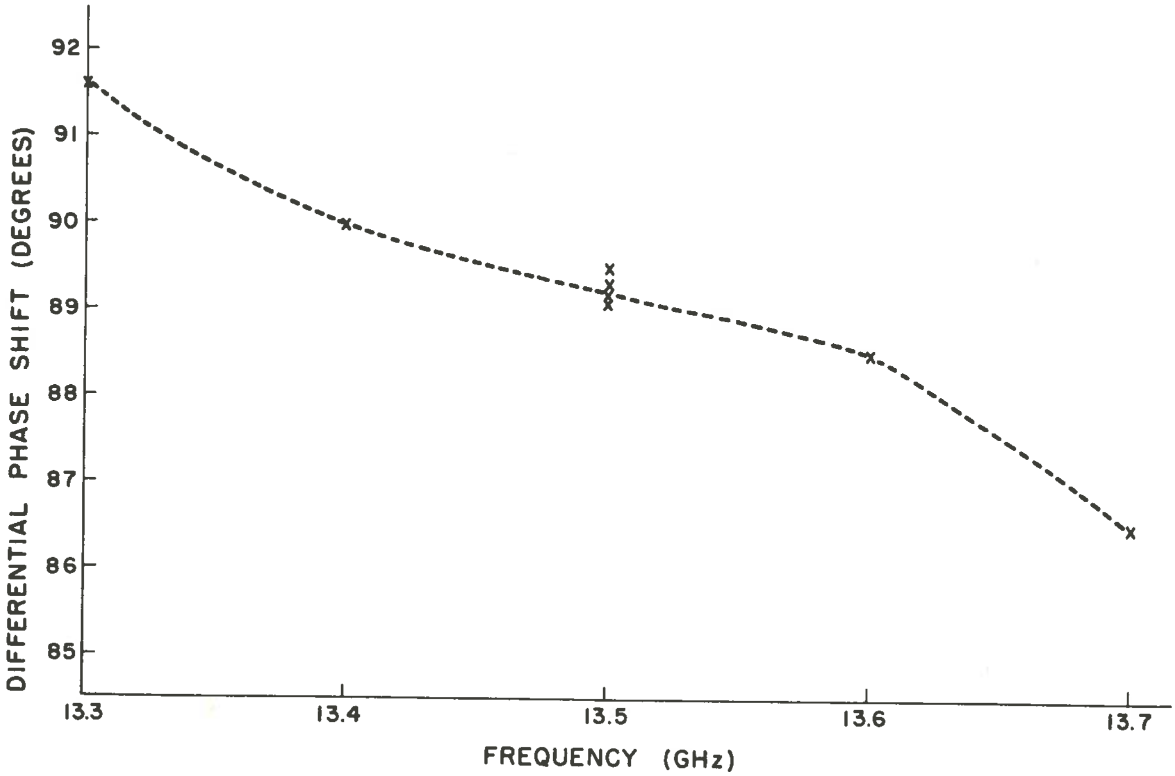

Fig. 8 Typical Ku-band phase shift versus frequency characteristic

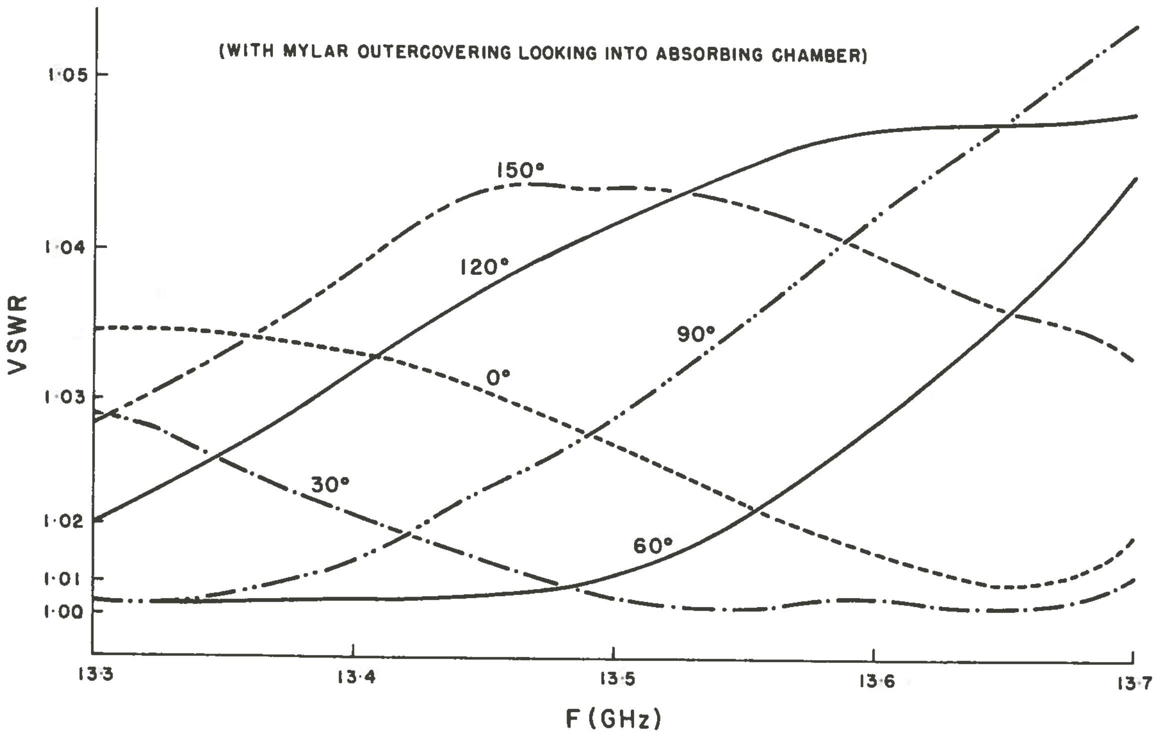

Fig. 9 VSWR of Ku-band polarizer plus horn with rotation

Transmission loss measurements were made, and the change of loss with polarization rotation was found to be 0.0024 db (± .0002 db) at 13.5 GHz. The total polarizer loss is 0.213 db.

Cross polarization was measured both as a function of polarization rotation and of frequency. The frequency variation of cross polarization (at worst rotation) is shown in Fig. 10. The cross polarization remained <-37 db for all rotations at 13.5 GHz (Fig. 11).

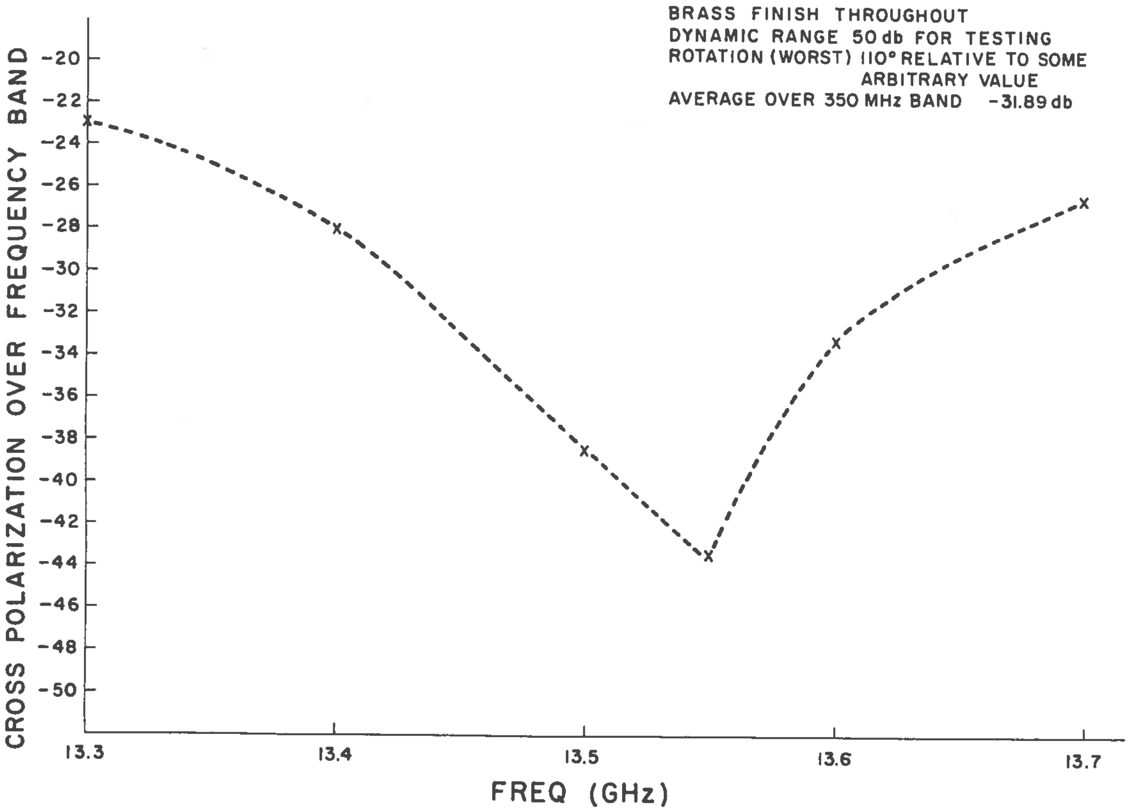

Fig. 10 Cross polarization over frequency band (Ku-band)

The servo operation for this device is similar to that for the J-band polarizer, as is its installation for prime-focus operation. The front horn flange of the polarizer is compatible with the Ku-band conical section horn flange located in the hub room, for Gregorian operation.

TABLE V

Feed-horn characteristics (Ku-band)

		Horn #1		Horn #2	
Aperture diameter 2a (inches)		1.044		0.961	
2a/λ		1.195		1.100	
		E (db)	H (db)	E (db)	H (db)
Primary patterns (equalized)	r = 0.8	-10.9	-10.8	- 9.2	- 9.2
	r = 1.0	-16.3	-15.2	-13.2	-12.7
Paraboloid aperture distribution	r = 0.8	-12.8	-12.7	-11.1	-11.1
	r = 1.0	-19.2	-18.1	-16.1	-15.6
Average VSWR of polarizer plus horn over frequency band and polarization rotation		1.030		1.030	
Radial pin length from horn mouth (inches)		9/32		7/32	
Spillover past (% power)	r = 0.8	7.62		11.42	
	r = 1.0	2.69		5.41	

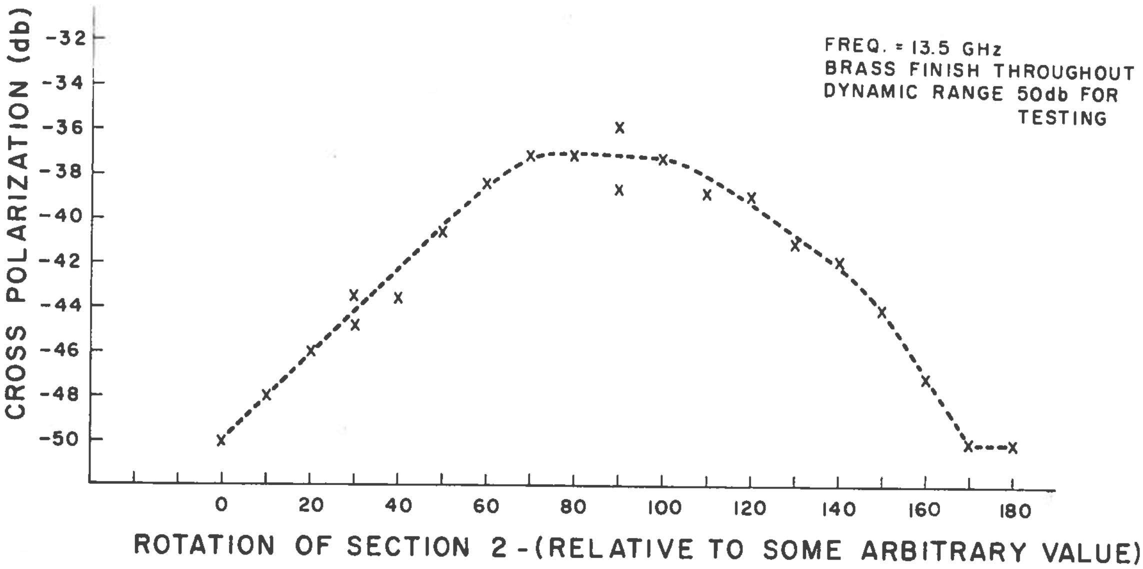

Fig. 11 Cross polarization with polarization rotation (Ku-band)

Feed Horns

The feed horns for prime-focus operation are shown in Fig. 7 and contain five-step binomial transformers. The characteristics of these horns are given in Table V.

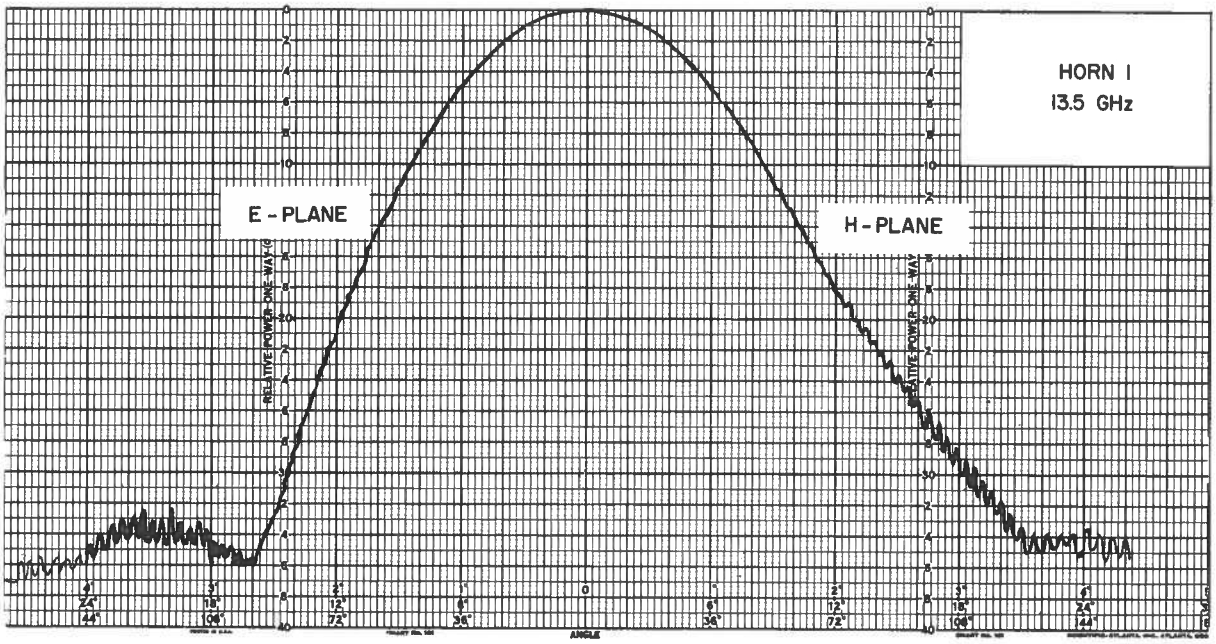

Fig. 12 Primary patterns for Ku-band horn 1

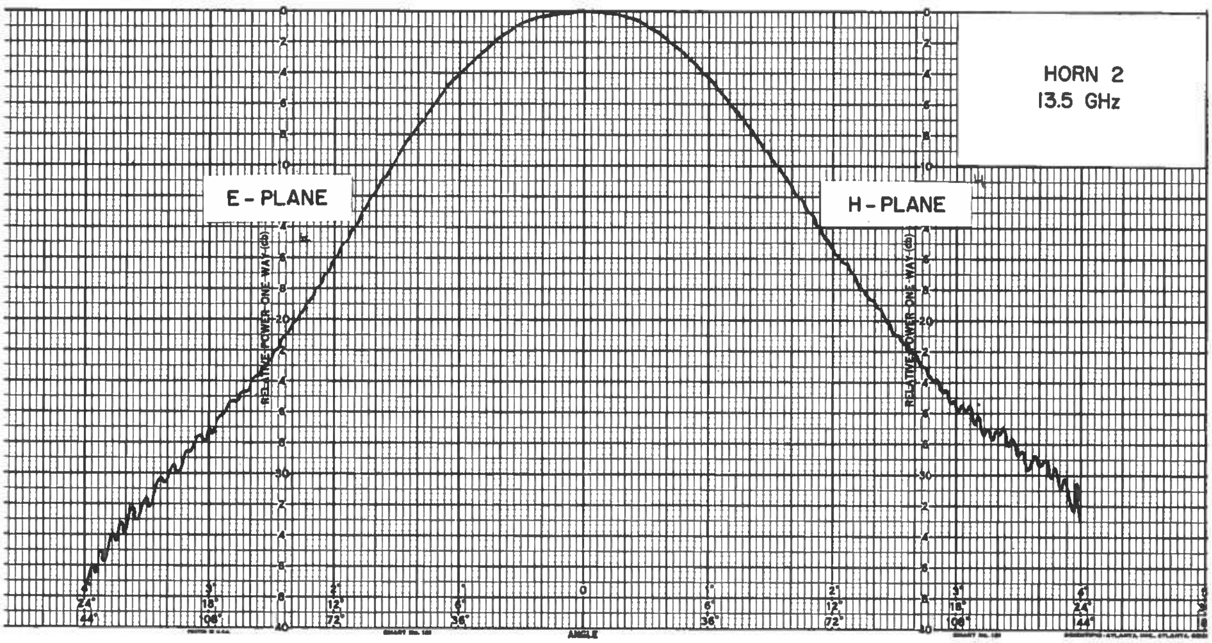

Fig. 13 Primary patterns for Ku-band horn 2

The primary patterns are shown in Figs. 12 and 13. Secondary patterns were calculated as for the X- and J-band horns with 60% feed-leg opaqueness. These secondary patterns are shown in Figs. 14 and 15.

Gain and Aperture Efficiency

As before, the formulae given in ERB 735 are used with the parameters

$k = 0.0667$

$r_1 = 0.8$

$\alpha = 0.0815$ radian (for correct shadow area)

$\xi_1 = 0.834$ corresponding to -1.58 db loss due to roughness on solid portion

$\xi_2 = 0.357$ corresponding to -8.95 db loss due to roughness on mesh portion

$\xi_3 = 0.920$ corresponding to a -8.14 db transmission loss through the mesh

The electric field aperture distributions were found to be

Horn 1

$$A(r) = 0.99084 - 2.2607r^2 + 2.0570r^4 - 0.6600r^6$$
$$= 0.1271 + 0.1268(1 - r^2) + 0.0770(1 - r^2)^2 + 0.6600(1 - r^2)^3$$

Horn 2

$$A(r) = 0.9921 - 1.9257r^2 + 1.5762r^4 - 0.4733r^6$$
$$= 0.1692 + 0.1934(1 - r^2) + 0.1561(1 - r^2)^2 + 0.4734(1 - r^2)^3$$

and results are given in Table VI.

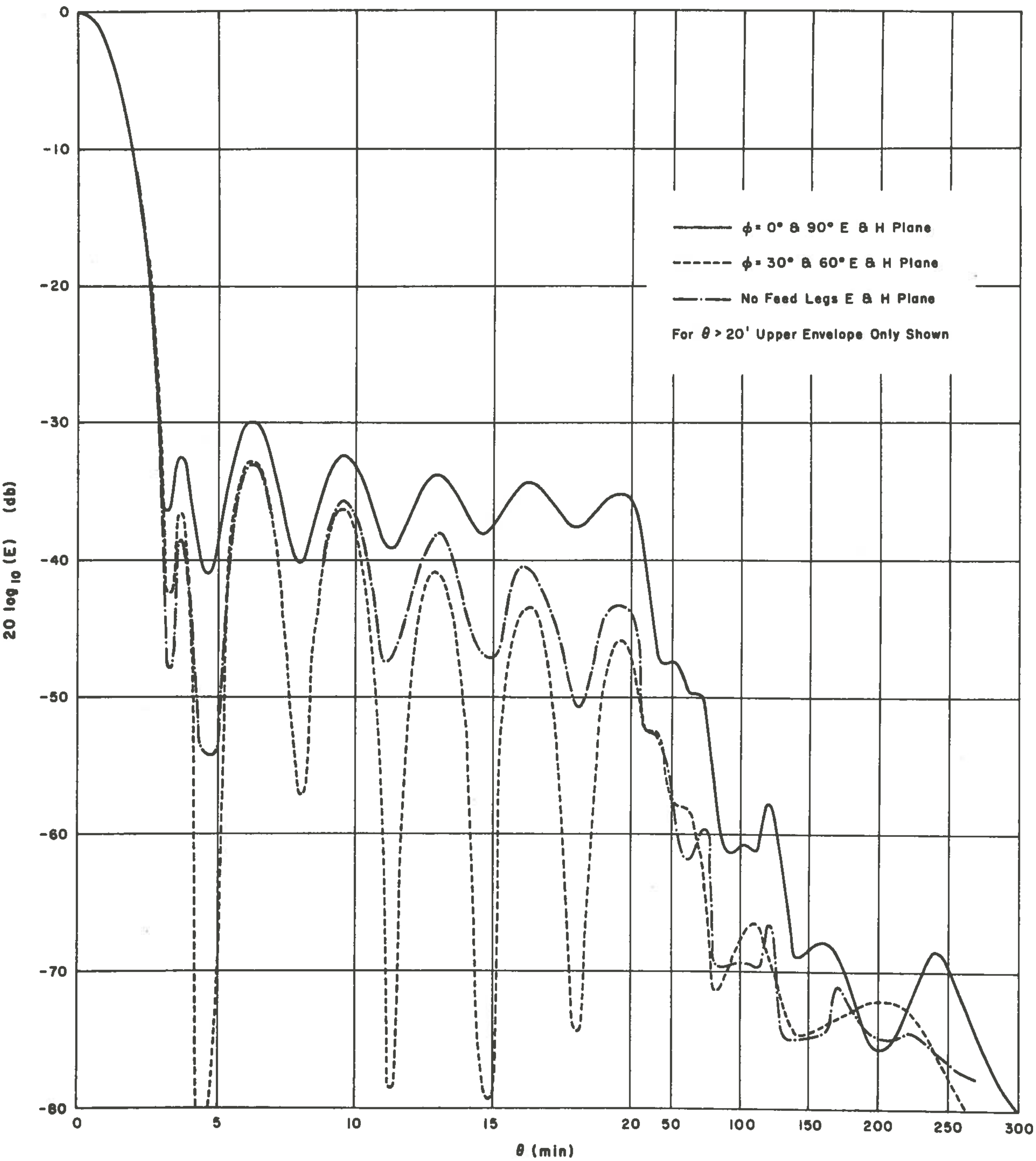

Fig. 14 Secondary patterns for Ku-band horn 1 at prime focus

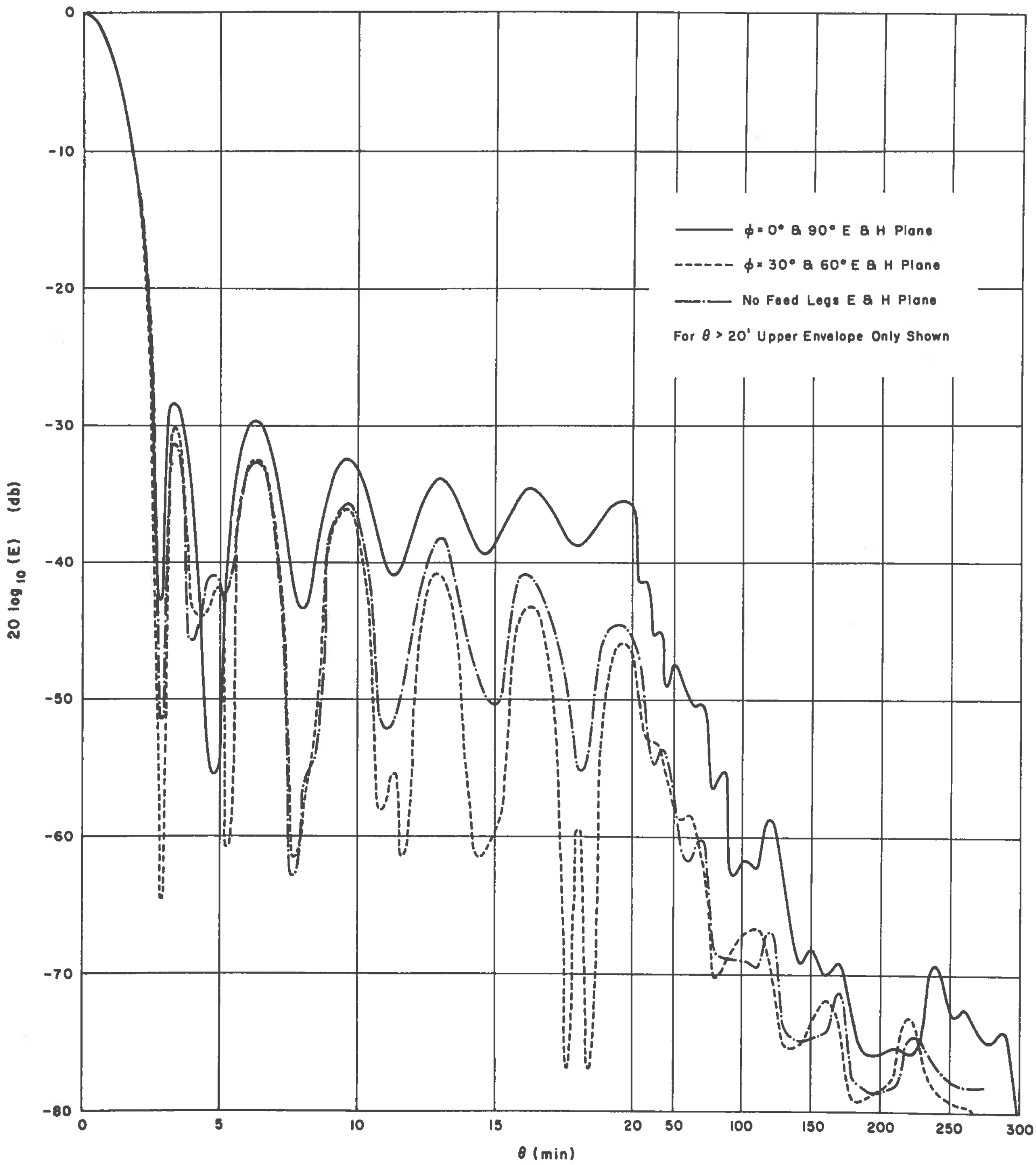

Fig. 15 Secondary patterns for Ku-band horn 2 at prime focus

TABLE VI

Gain and aperture efficiency (Ku-band)

	Horn 1		Horn 2	
3-db half-beamwidth (minutes)	1.08		1.02	
	Gain (db)	Aperture efficiency	Gain (db)	Aperture efficiency
Theoretical maximum	76.22	1.000	76.22	1.000
Illumination factor η_1	-1.50	0.707	-1.10	0.777
Spillover η_2	-0.12	0.973	-0.24	0.946
Mesh transmission η_3	-0.11	0.976	-0.13	0.970
Surface error loss η_4	-2.37	0.580	-2.53	0.559
Focal cabin and feed-leg blocking for 60% opaque quadrapod η_5	-0.26	0.941	-0.25	0.945
Net	71.86	0.366	71.97	0.376

ACKNOWLEDGMENT

The computer program (CREE I) for the calculation of the secondary pattern from a given symmetrical, circular aperture distribution with associated curve fitting was written by F. Farrell. Various calculations in obtaining gain and aperture efficiency were done by Mrs. M. Steen.

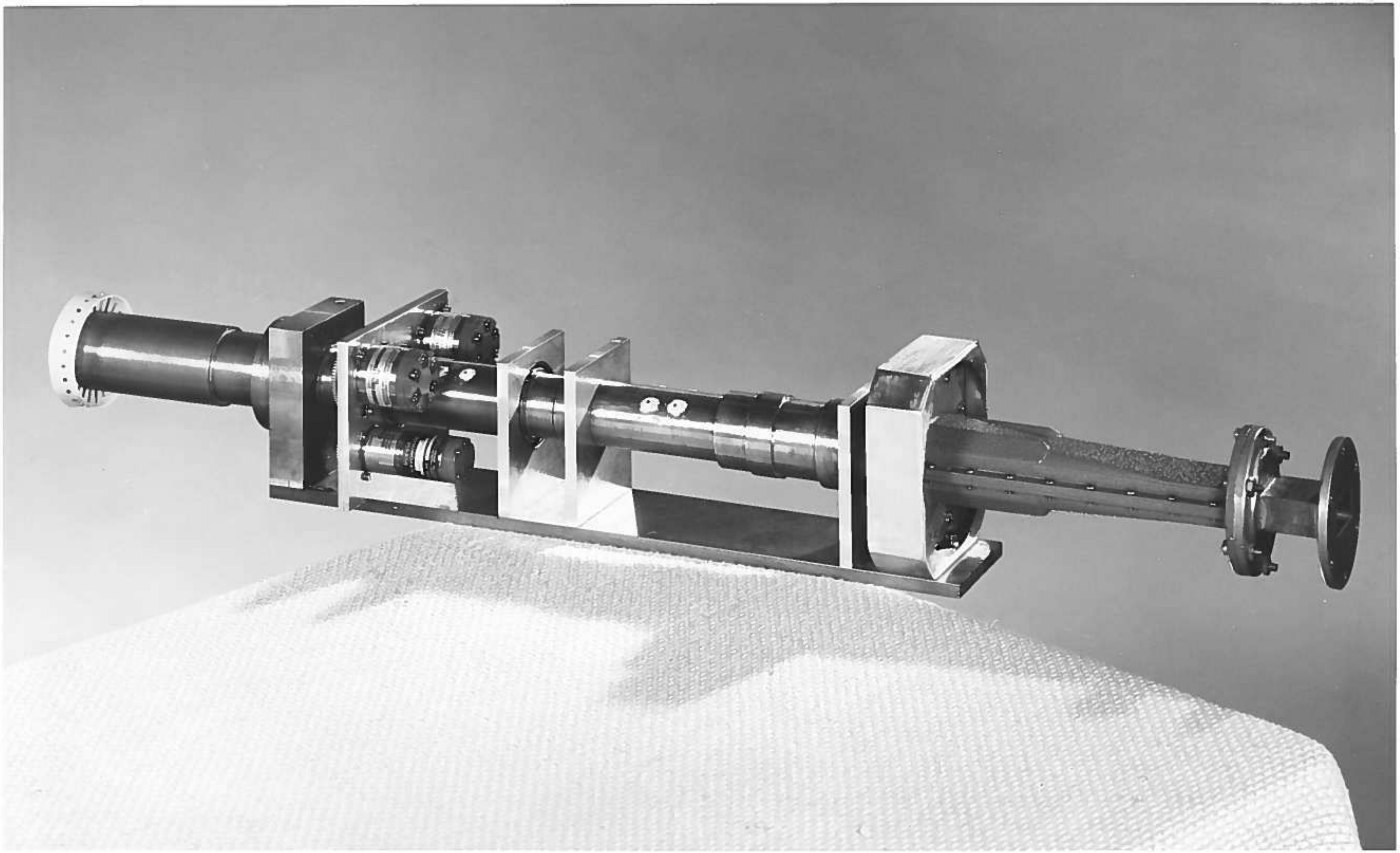

Plate I   Completed J-band polarization rotator with feed horn