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A TURNSTILE CONICAL-SCAN FEED TO IMPROVE TRACKING-ANTENNA PERFORMANCE ON APOLLO-INSTRUMENTED SHIPS

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GREENBELT, MARYLAND

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Paul A. Lantz
Advanced Development Division

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ABSTRACT

This report describes the design, development, and fabrication of a turnstile for use as a conical scanning feed in a 30-foot paraboloidal reflector. On the Apollo-instrumented ships telemetry tracking antenna, this feed will replace a balanced conical logarithmic spiral now operating over the wide band from 225 to 2300 Mhz. The turnstile operates over the narrow frequency band from 225 to 260 Mhz and provides both senses of circular polarization simultaneously, resulting in superior performance over the narrower frequency band of operation. It was necessary to remove a cavity backing the turnstile, because of excessive drag on the drive unit. Some compromise in primary pattern directivity resulted; however, performance is superior to that of the existing feed. Mechanical design characteristics permit direct replacement provided that the feed assembly is refocused.

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SYMBOLS

A	area of antenna aperture
b	pedestal height of voltage distribution curve for aperture illumination
D	diameter of circular aperture of reflector
E-plane	plane, in field of dipole pattern, containing the dipole
E	voltage at any discrete point in field of antenna
F	focal length of paraboloidal reflector antenna
G	directivity gain of antenna
H-plane	plane, in field of dipole antenna, orthogonal to the dipole
I	current at any discrete point in field of antenna
k	constant multiplier of cosine term in aperture distribution
m	index power number
n	index power number
r	normalized radius in aperture plane
β	angular displacement of feed from reflector axis
ϕ	angle off axis in antenna pattern in elevation plane
θ	angle off axis in antenna pattern in azimuth plane
ξ_A	aperture efficiency
ξ_S	spillover efficiency

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INTRODUCTION

The medium-gain tracking telemetry antenna aboard each of the three Apollo-instrumented ships is a paraboloidal reflector having at its focal point a conical scanning feed consisting of two balanced, bifilar, conical logarithmic spiral elements inclined at a 20-degree angle on each side of the axis of symmetry. The reflector has a 30-foot-diameter aperture and a focal length-to-diameter ratio, $f/D = 0.30$. Twelve panels of 2-inch-thick aluminum honeycomb form a solid reflecting surface 12 feet in diameter at the vertex, and twenty-four outer panels of 5/8-inch "Squarex" aluminum extend the aperture to 30 feet. An electrically driven azimuth-over-elevation pedestal provides 0.2-degree tracking accuracy.

The conical scanning feed, operating over the frequency band 130 to 2300 Mhz, is housed in a conical radome attached to the feed-drive housing. Eight fiberglass spars support the feed assembly. Figure 1 is a photograph of the antenna aboard USNS Vanguard (T-AGM-19). Basic characteristics of the antenna system are:

Aperture diameter	30 feet
Focal length	9 feet
Frequency of operation	130 to 2300 Mhz
Gain (referred to beam crossover)	18 db at 230 Mhz 35 db at 2200 Mhz
Polarization	Simultaneous right circular and left circular
Axial ratio	3 db
VSWR	1.8:1
Sidelobe level	15 db below peak intensity
Crossover level	1 db
Scan rate	10 cps
Tracking accuracy	0.20 degrees
Tracking rate	Elevation, 30 deg/sec Azimuth, 35 deg/sec
Acceleration rates	Elevation, 15 deg/sec/sec Azimuth, 35 deg/sec/sec

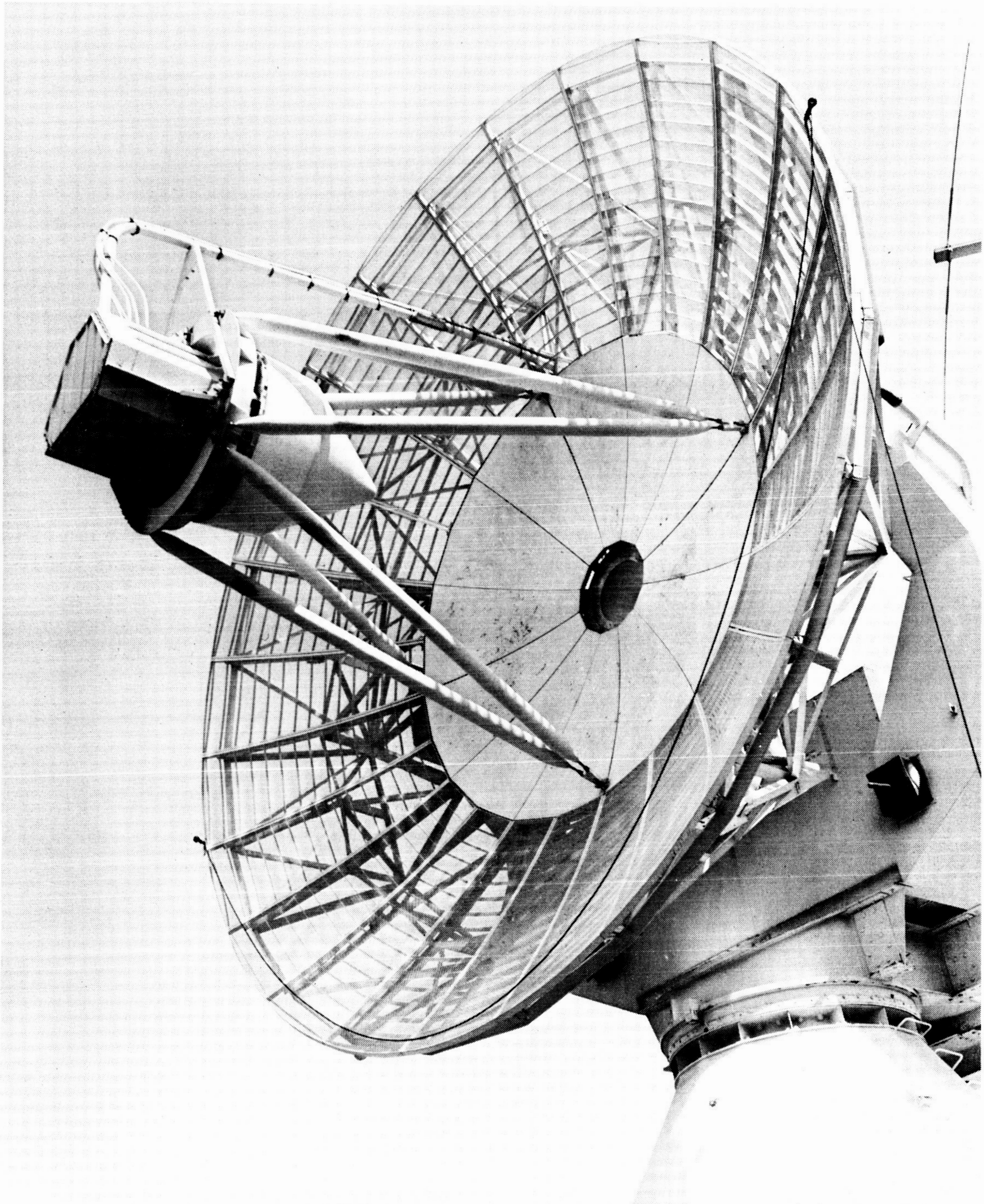


Figure 1. Apollo Instrumentation Ships Tracking Telemetry (4-1) Antenna

BACKGROUND

The reflector now uses a conical scanning feed which consists of a pair of balanced bi-filar conical logarithmic spirals, one wound in the right circular sense and one in the left circular sense. Rotation of these off-axis spirals about the reflector axis of symmetry provides conical scanning capability. This feed is designed to operate over the frequency band 130 to 2300 Mhz, in order to meet Apollo mission requirements in the 225- to 260-Mhz band as well as Department of Defense requirements at L- and S-band frequencies.

Performance of the antenna system can be significantly improved for Apollo mission requirements by retrofitting the reflector with a feed designed for operation over the narrow band from 225 to 260 Mhz and by properly focusing the feed for these frequencies. This report describes the design, development, and performance of a retrofit feed of this type.

ELECTRICAL DESIGN

Choice of Feed Type

The conical log-spiral antenna now in use has performance characteristics[1] which make it a good feed for reflectors when broadband operation is required. Pattern shape and directivity are relatively independent of frequency, and impedance is constant when special care is used in designing the balun and base terminal load. The radiation is unidirectional, without the need of a ground plane, going in the direction of the apex, and is polarized circularly.

Another circularly polarized feed for reflectors is the turnstile in which pairs of crossed dipoles are fed 90 degrees out of phase. The pattern, which is bidirectional, can readily be made unidirectional by placing a reflector behind the dipoles. To meet the narrowband requirements of the Apollo mission, the turnstile is considered to be a superior feed, because of its simplicity. The typical 2:1 variation in E- and H-plane beamwidth can be eliminated by locating the turnstile in a cavity. Ellipticity is thereby minimized for angles off the axis of

[1]Dyson, John D., "The Characteristics and Design of The Conical Log Spiral Antenna, University of Illinois, Antenna Laboratory Report 65-4, May 1965

the turnstile. Such a device, designed specifically for the 215- to 260-Mhz frequency band, was available as a catalogue item.[2] Moreover, the necessary hybrid junction[3] was available for use in combining linear polarizations to provide simultaneous right- and left-circularly polarized outputs. It was necessary only to design a suitable device for attaching the feed to the conical scanning drive, and to establish the necessary physical displacement, to produce the desired conical scan pattern.

Primary Patterns

Feeding the two elements of a turnstile antenna with currents equal in amplitude and 90 degrees out of phase will produce a field pattern which is essentially that obtained by superimposing the patterns of two half-wave dipoles. On the axis of the turnstile, the radiation pattern has circular symmetry. The pattern of a paraboloidal reflector feed must be modified by the attenuation arising from space divergence in order to establish the effective illumination taper. Figure 2 is a plot of this space attenuation expressed in decibels. Figure 3 is a plot of the relationship of "angle-off-axis" to radial displacement outward from the axis of symmetry in the aperture plane. Figures 2 and 3 were used to obtain the effective primary-illumination taper (pattern) shown in Figure 4. Many aperture distributions have been catalogued for paraboloidal reflectors having circular apertures. These functions[4] are of the general form

$$b + k(1 - r^m)^n \qquad (1)$$

and have the important advantage that both the secondary pattern and directivity can be computed in closed form. Inclusion of the fixed pedestal height, b, allows close approximation of actual measured primary patterns, and the variable, r, is normalized radius in the aperture plane. It was found that the measured primary pattern was found to closely resemble the function $0.195 + 0.805(1 - r^{1.51})^2$ and this function, plotted in Figure 4, was used in computing the secondary patterns

[2] Radiation Systems, Inc., 1755 Old Meadow Road, McLean, Va. catalogue number 1623-02

[3] Radiation Systems, Inc., catalogue number 2631-02

[4] Hanson, R. C., "Microwave Scanning Antennas", Academic Press, 1964, p. 64

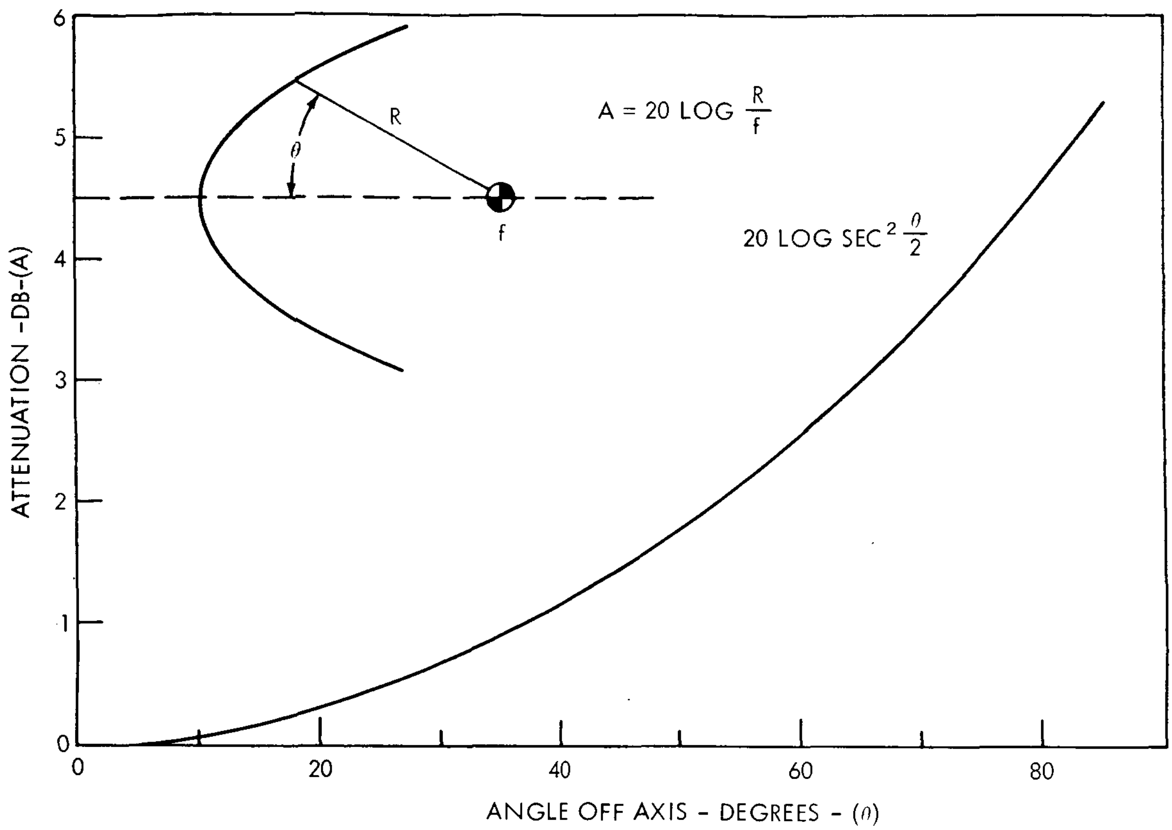


Figure 2. Space Attenuation

and efficiency. Although the function assumes rotational symmetry for the primary pattern, the comparison is valid because of the considerable effort expended to equate the E-plane and H-plane beamwidths of the primary pattern.

Reflector Blockage Effects

When a reflector feed blocks some of the reflected radiation, the antenna pattern is adversely affected in two ways: the gain is somewhat reduced, because some power cannot be reflected in the forward direction, and the sidelobes are increased. As a matter of convenience, these degradations are usually computed as a ratio of the percentage of area blocked; this manner of computation is not rigorous, because it assumes equal amplitude over the total aperture, whereas this distribution is in fact tapered.

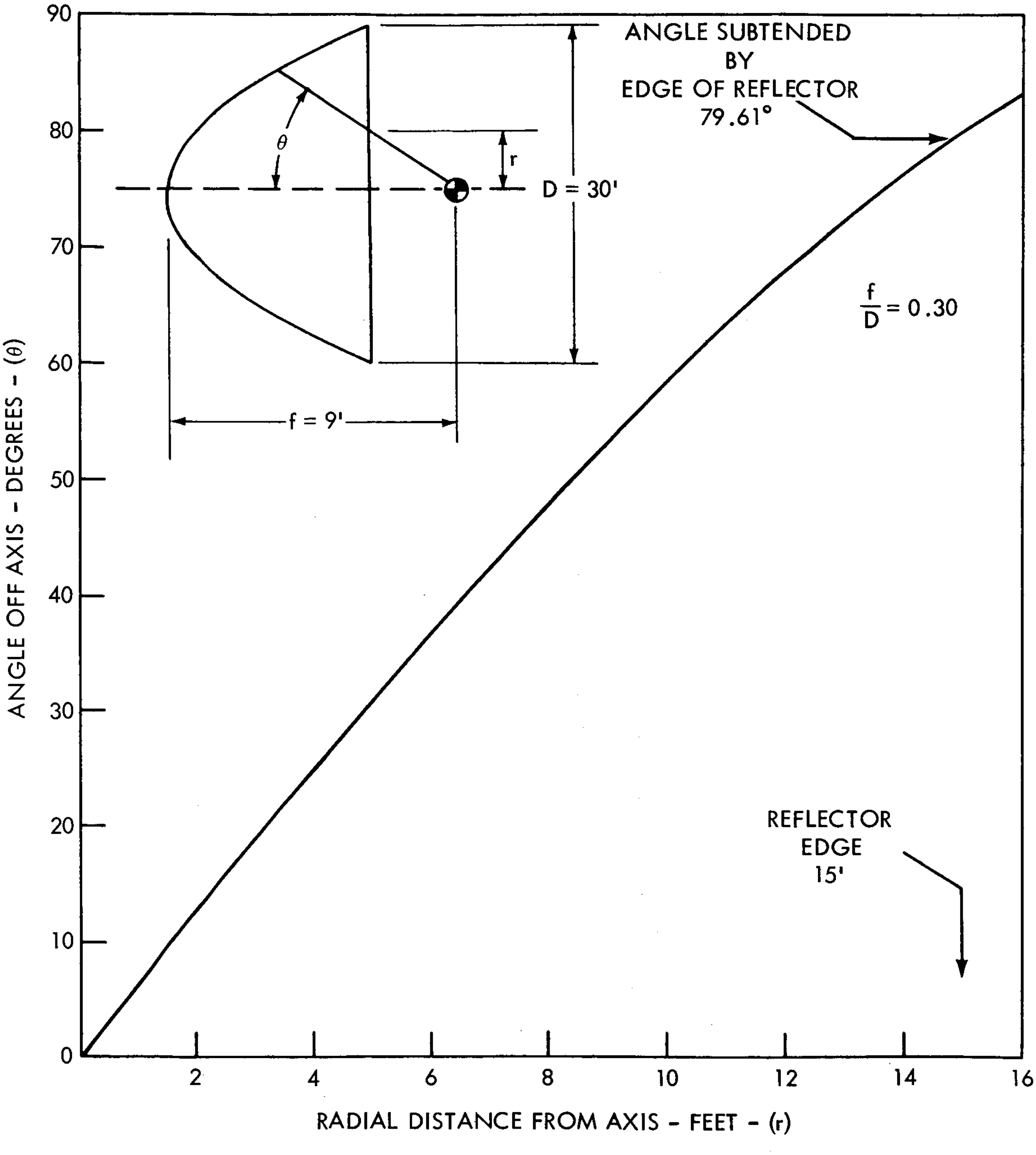


Figure 3. Aperture Plane Radius vs Angle Off-Axis of Reflector

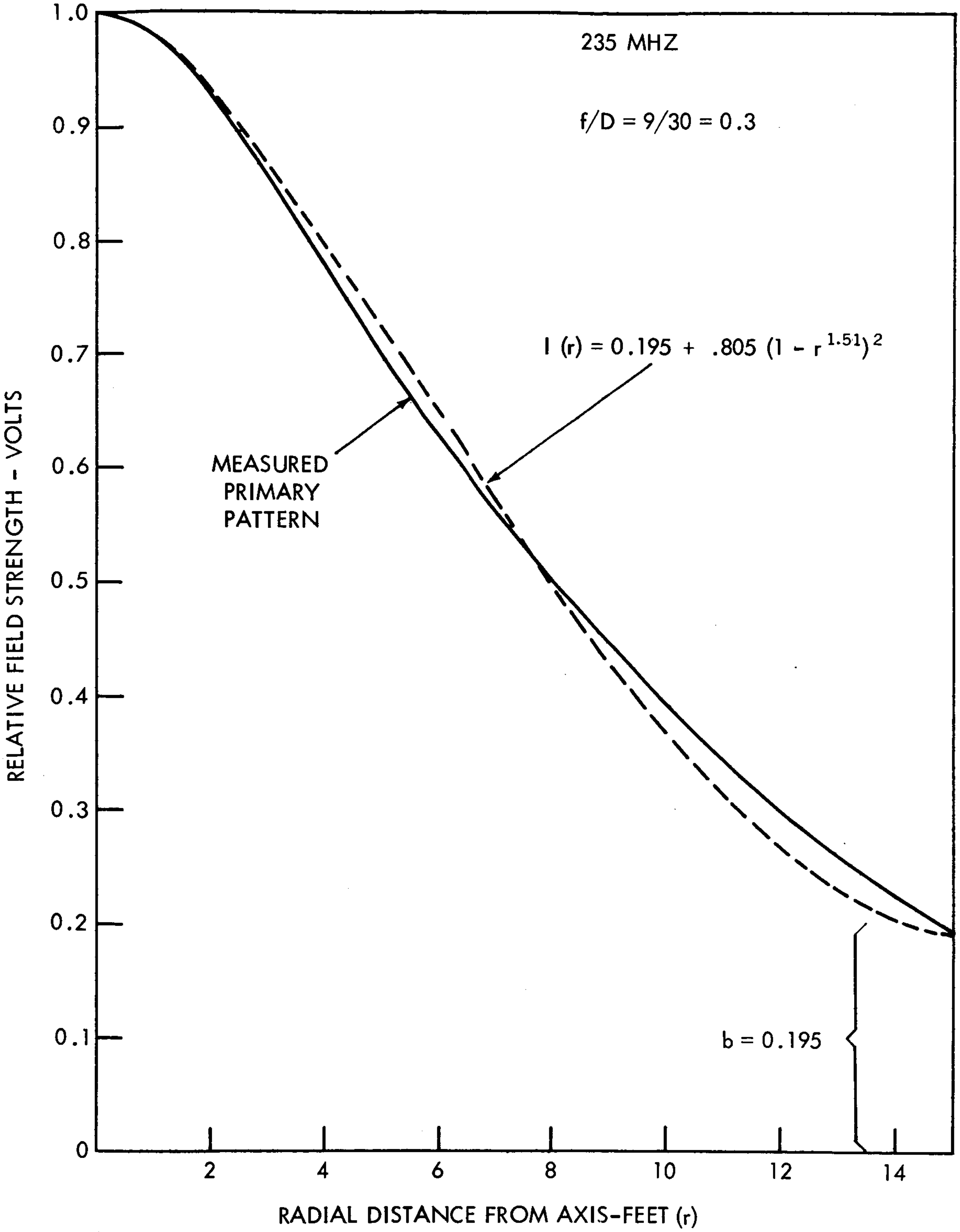


Figure 4. Primary Pattern Adjusted To Include Space Attenuation

A more precise determination of the degradation caused by blockage has been evolved by George G. Chadwick. * In Chadwick's method, the relative amplitude levels of the secondary field from the reflector are sampled at discrete angular increments in both azimuth and elevation. This distribution of radiation is numerically recorded, in grid form, over the area bounded by the circular aperture of the reflector. This radiation distribution is then overlaid with the blockage pattern, and numerical increments of the blockage field are subtracted out. As a result, areas of greater illumination intensity (where the maximum blockage occurs) receive the proper weight in computing the resultant far-field pattern. Effective far-field sidelobe levels are more precisely determined in this manner. The blockage pattern was established for this purpose by photographing the antenna (Figure 5) from a position on the reflector axis of symmetry.

Secondary Pattern Predictions

The secondary far-field pattern was computed on a GE Model T-35 digital computer by feeding in normalized primary pattern amplitude as a function of feed angle. These data are derived from the primary pattern and the blockage correction described above. Figure 6 is the resultant secondary pattern. The half-power beamwidth appears as 2 x 4.6 = 9.2 degrees, and the half beamwidth at the 1-db level (crossover) is 2.8 degrees. The sidelobe level is 24.7 db. Figure 7 is another plot of this same pattern, referred to the axis of symmetry of the reflector; that is to say, the pattern is plotted to show the beam from the reflector for two positions of the conical scan feed 180 degrees apart. Because the pattern is rotationally symmetric, Figure 7 represents the azimuth cut and the elevation cut, as well as any other plane of cut through the pattern. Figure 7 is also representative of either sense of circular polarization.

Feed Displacement Computation

Lateral displacement of a feed in the transverse plane of a reflecting system does not produce a one-to-one correspondence between feed displacement and the secondary pattern. The ratio of the angle to the secondary pattern maximum, and the angle of the displaced feed, is called the beam-deviation factor and depends upon the f/D ratio of the

*Radiation Systems, Inc., 1755 Old Meadow Road, McLean, Va. 22101

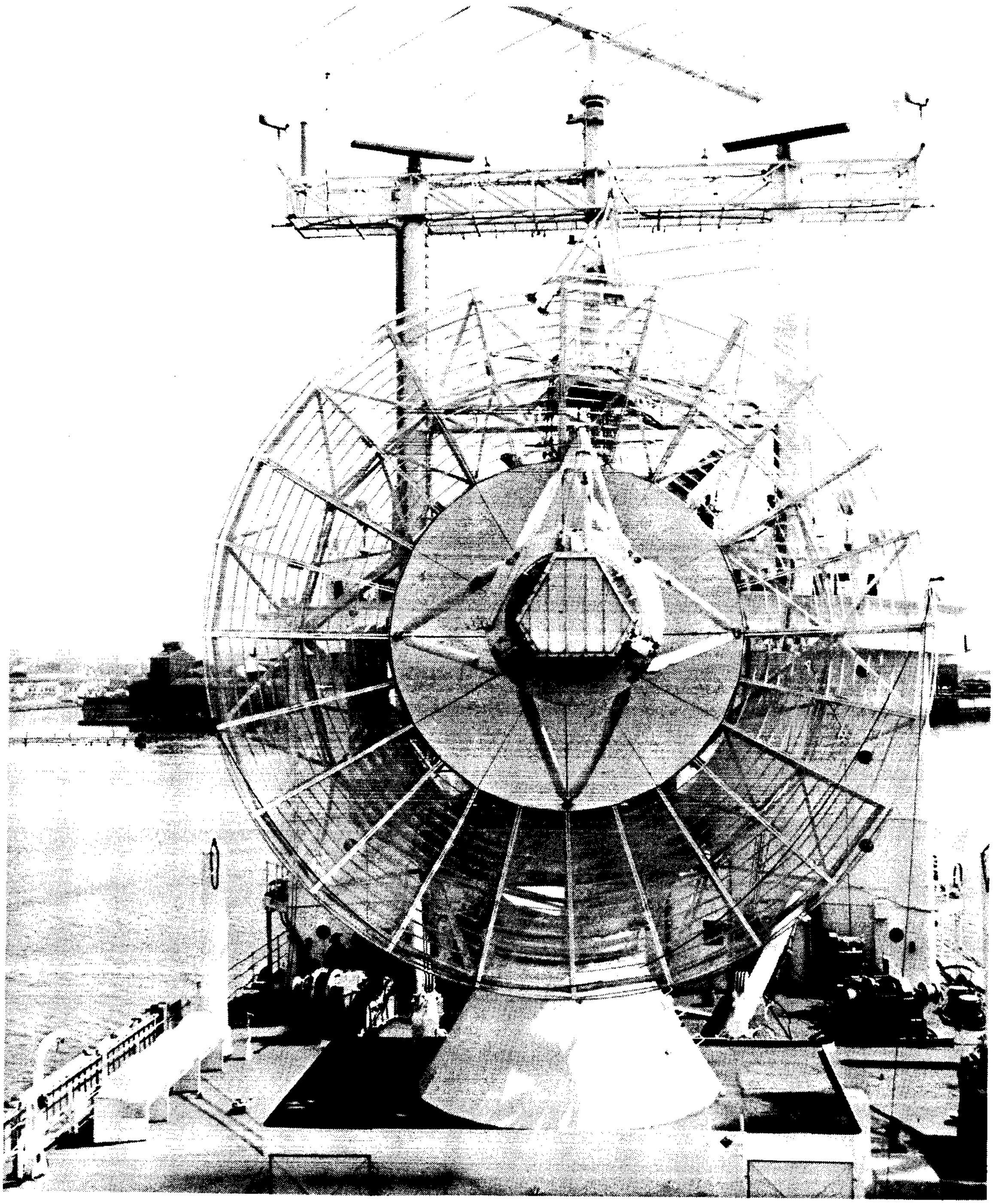


Figure 5. On-Axis View of Antenna Aperture

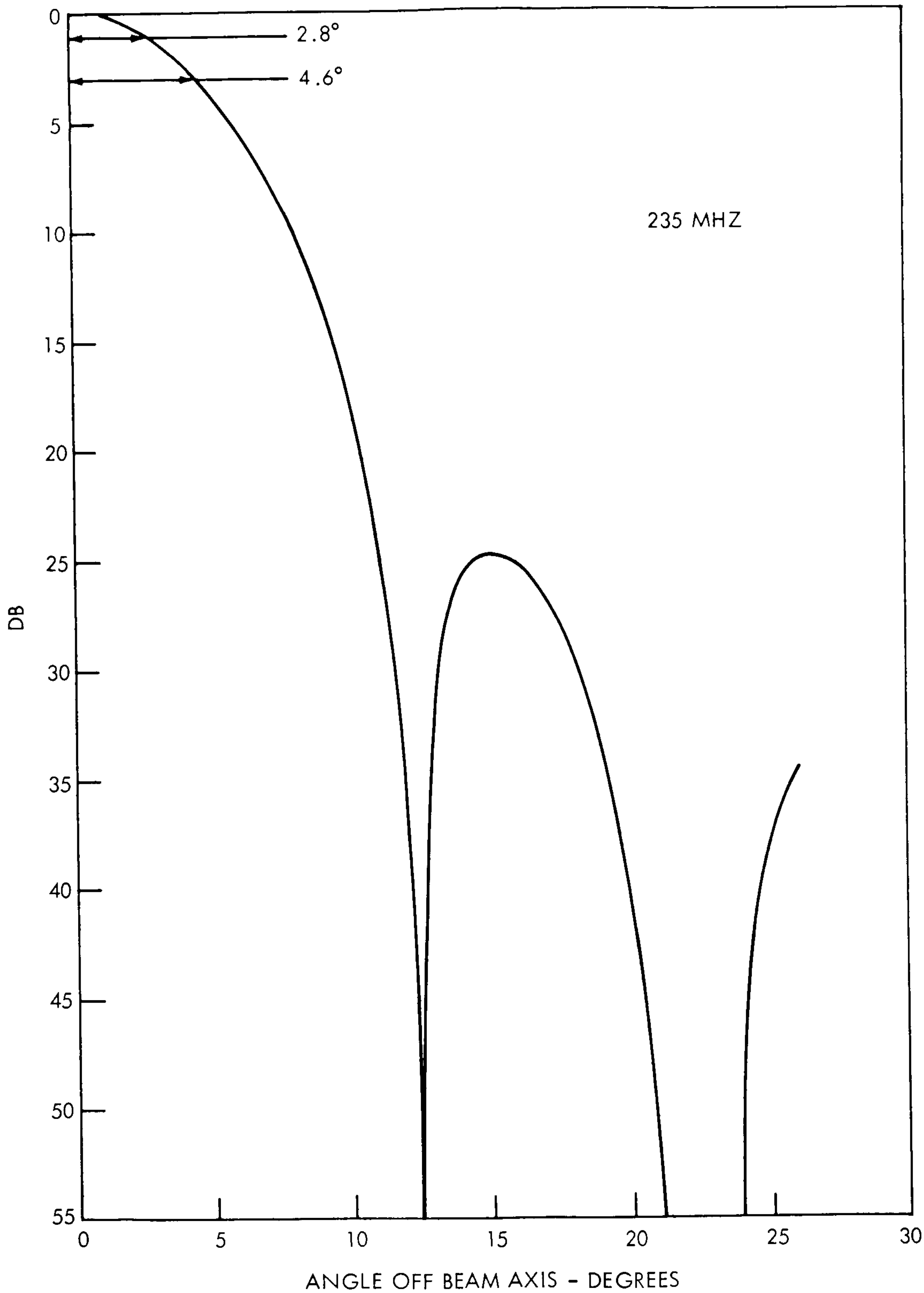


Figure 6. Secondary Pattern Corrected For Aperture Blockage (Cavity-Backed Turnstile)

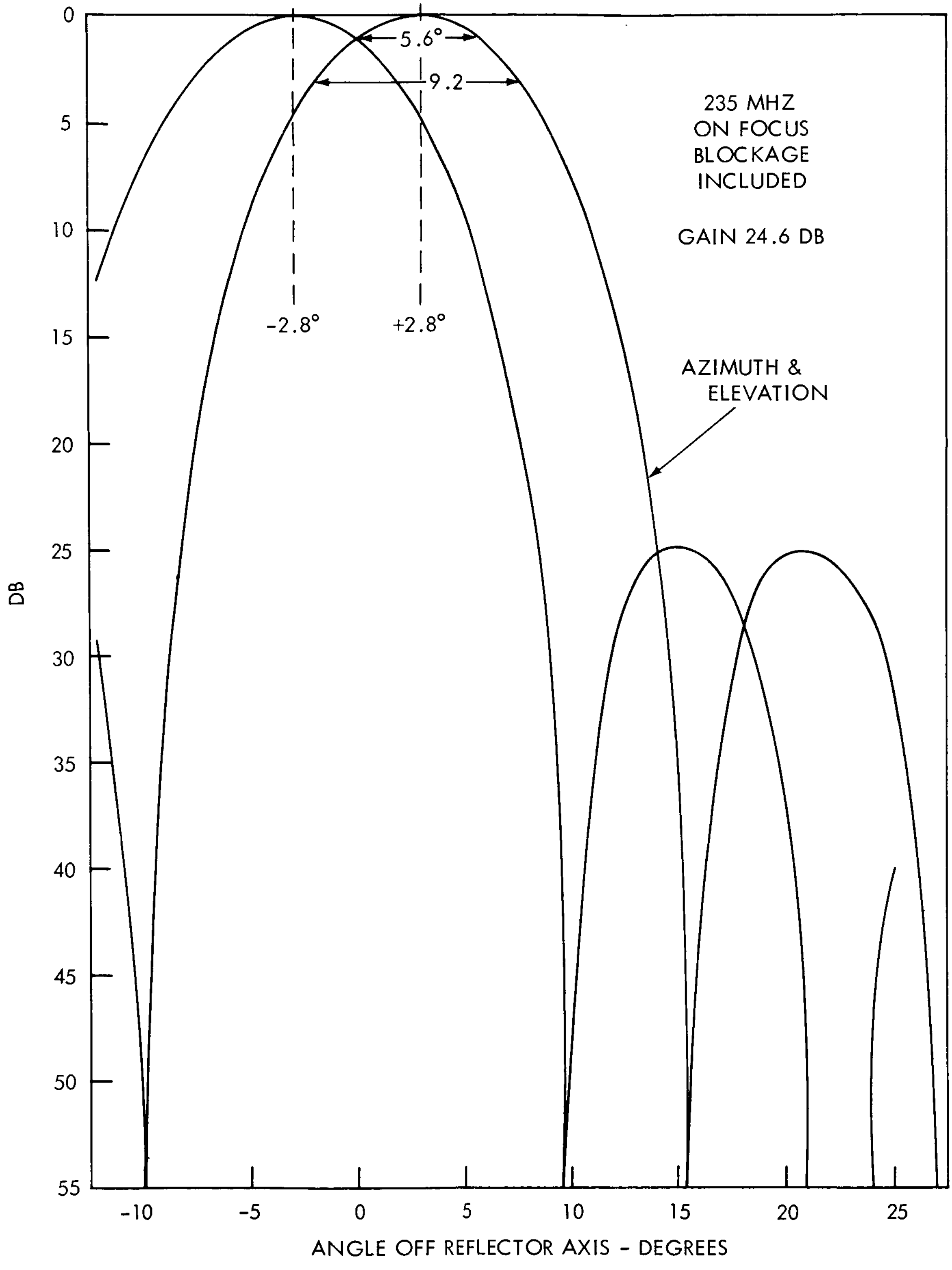


Figure 7. Calculated Secondary Pattern With Scanning Action (Cavity-Backed Turnstile)

reflector as well as the primary pattern. Hansen[5] shows the beam-deviation factor for a reflector with f/d = 0.3 to be 0.81. It is required that the conical-scan beam crossover level be 1 db down from the peak intensity of the beam. Figures 5 and 6 show the half width of the secondary pattern at the 1-db level to be 2.8 degrees. This information makes it possible to compute the required displacement of the feed from the reflector axis of symmetry. Figure 8 shows that the angular feed displacement, β, is

$$\beta = \frac{\text{1-db beamwidth}}{\text{beam deviation factor}} = \frac{2.80}{0.81} = 3.46 \text{ deg.} \tag{2}$$

This angular displacement, d, for the 9-foot focal length, is shown to be

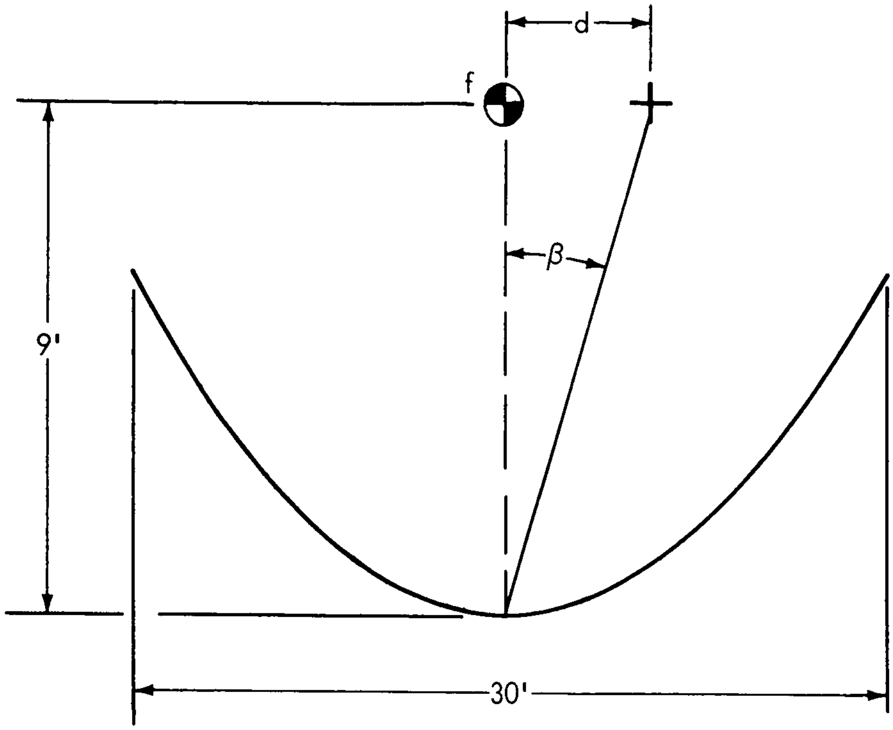
$$\begin{aligned} d &= f \tan \beta \\ &= 9(0.06045) \\ &= 0.5440 \text{ feet} \\ &= 6.529 \text{ inches,} \end{aligned} \tag{3}$$

and will cause the peak of the beam to fall 2.8 degrees off the reflector axis of symmetry.

Gain and Efficiency Calculations

The overall radiation efficiency of a reflector antenna is the product of the aperture efficiency and the spillover efficiency, less the sum of the system losses. The aperture efficiency of a circular aperture with rotationally symmetric illumination can be approximated accurately by computing the ratio of the average tapered illumination to the average illumination for uniform distribution. If the radius of the aperture is normalized to unity, area integration is simplified, and the area of the circular aperture πr^2 becomes simply π. The average illumination for

[5]Hansen, op cit, p. 140



f/D = 0.30
BEAM DEVIATION FACTOR = 0.81
1-db BEAMWIDTH = 2.80°

$$\beta = \frac{2.80}{0.81} = 3.46°$$

$$d = f \tan\beta = 9\ (0.06045)$$
$$= 0.544 \text{ FEET}$$
$$= 6.529 \text{ INCHES}$$

Figure 8. Geometric Analysis of Feed Offset

the tapered distribution is then

$$I = \frac{1}{\pi(1)^2}\int_0^1 2\pi r I(r) dr \tag{4}$$

$$I = 2\int_0^1 r\,I(r)\,dr. \tag{5}$$

The average illumination for the uniform distribution is

$$I_0^2 = \frac{1}{\pi(1)^2}\int_0^1 2\pi r\,I^2(r)\,dr \tag{6}$$

$$I_0^2 = 2\int_0^1 r\,I^2(r)\,dr. \tag{7}$$

The aperture efficiency is then the ratio of I^2 to I_0^2 or

$$\xi_A = \frac{I^2}{I_0^2} = \frac{4\left[\int_0^1 r\,I(r)\,dr\right]^2}{2\int_0^1 r\,I^2(r)\,dr} = \frac{2\left[\int_0^1 r\,I(r)\,dr\right]^2}{\int_0^1 r\,I^2(r)\,dr} \tag{8}$$

The numerical values for the parameters of $I^2 r$ were shown earlier (Figure 4) to be

$$I(r) = 0.195 + 0.805(1 - r^{1.51})^2. \tag{9}$$

Substituting in (8) and performing the integration

$$\xi_A = \frac{0.0813}{0.1052} = 0.7731, \tag{10}$$

hence the aperture efficiency is 77.31 percent. Aperture blocking reduces this efficiency to 68.97 percent. The spillover efficiency was computed from a relative power plot of the primary pattern (Figure 9). The total field strength impinging on the reflector is

$$E = \sum_{n=1}^{N} I_n^2 r \sin \theta \tag{11}$$

where $I^2 r$ is the relative power at any point in the field and θ is angular displacement off axis in degrees. Using (11) to analyze the primary power pattern, the relative power on the reflector and the relative power lost over the reflector edge can be computed. From Figure 9, then, the spillover efficiency is

$$\xi_s = \frac{\text{total power on reflector}}{\text{total power lost over edge}} \tag{12}$$

$$= \frac{1.2815}{1.4005} = 0.915 \text{ or } 91.5\%.$$

The antenna overall efficiency can now be computed:

Aperture efficiency, 68.97 percent	1.62 db
Spillover efficiency, 91.50 percent	0.38
Hybrid coupler loss	0.25
Dipole loss	0.20
VSWR loss (for 1.5:1)	0.20
Coaxial cable loss (4-ft RG9B/U)	0.15
	2.80 db or 52.5 percent.

Overall efficiency of the conical scan antenna system is therefore 52.5 percent. No correction is necessary for the fact that the feed is displaced off-axis, because the displacement is so small (less than 0.1 beamwidths).

The directivity gain is

$$G = k \frac{4\pi A}{\lambda^2} \tag{13}$$

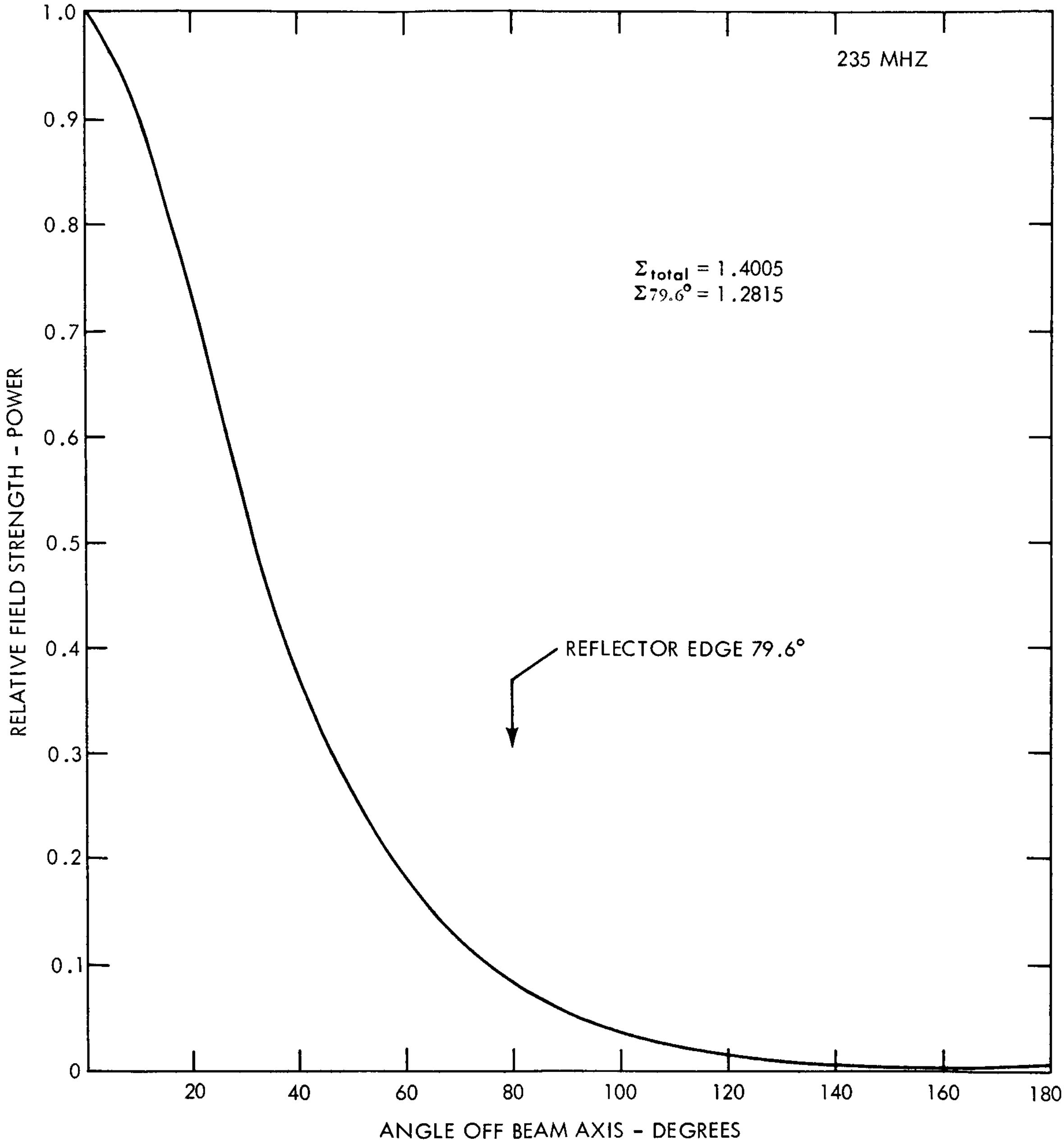


Figure 9. Primary Pattern Adjusted To Include Space Attenuation

where A is aperture area, and k is efficiency. For 52.5-percent efficiency, the decibel equivalent gain at 235 Mhz is

$$G = \left[20 \log 0.525 \frac{4\pi A}{\lambda^2}\right]$$

$$= 24.2 \text{ db.} \tag{14}$$

Defocusing Effects

The feed-drive assembly of the antenna for which the turnstile feed is designed is adjusted to focus the existing conical logarithmic spiral feed elements at 2300 Mhz. If the turnstile feed is installed without moving the entire feed-drive assembly to refocus, the phase center of the turnstile will be approximately 2 feet outside the focal point of the reflector. It is interesting to note how the performance is degraded by this out-of-focus illumination.

The directivity pattern of an area distribution is, simply stated,[6]

$$E = Eo\, e^{j\phi} \tag{15}$$

and

$$E_0\, e^{j\phi} = Eo(\cos\phi - j\,\sin\phi). \tag{16}$$

The real and imaginary components of this pattern were plotted (Figure 10), and the illumination functions were determined which most closely fit these curves. (Note in Figure 10 that the angle subtended by the edge of the reflector for a feed 2 feet outside of focus is 72 degrees, instead of 79.61 degrees as for an on-focus feed.) The illumination functions were used to compute the far-field pattern of each component (Figure 11), and addition of the far-field components yields the far-field pattern for the off-focus feed (Figure 12). Comparison with Figure 6 shows that the sidelobe level has come up from 25 to 12 db, and that the half-power beamwidth has increased from 9.2 to 9.4 degrees.

[6]Wolff, E. A., "Antenna Analysis," John Wiley, 1966, p. 289

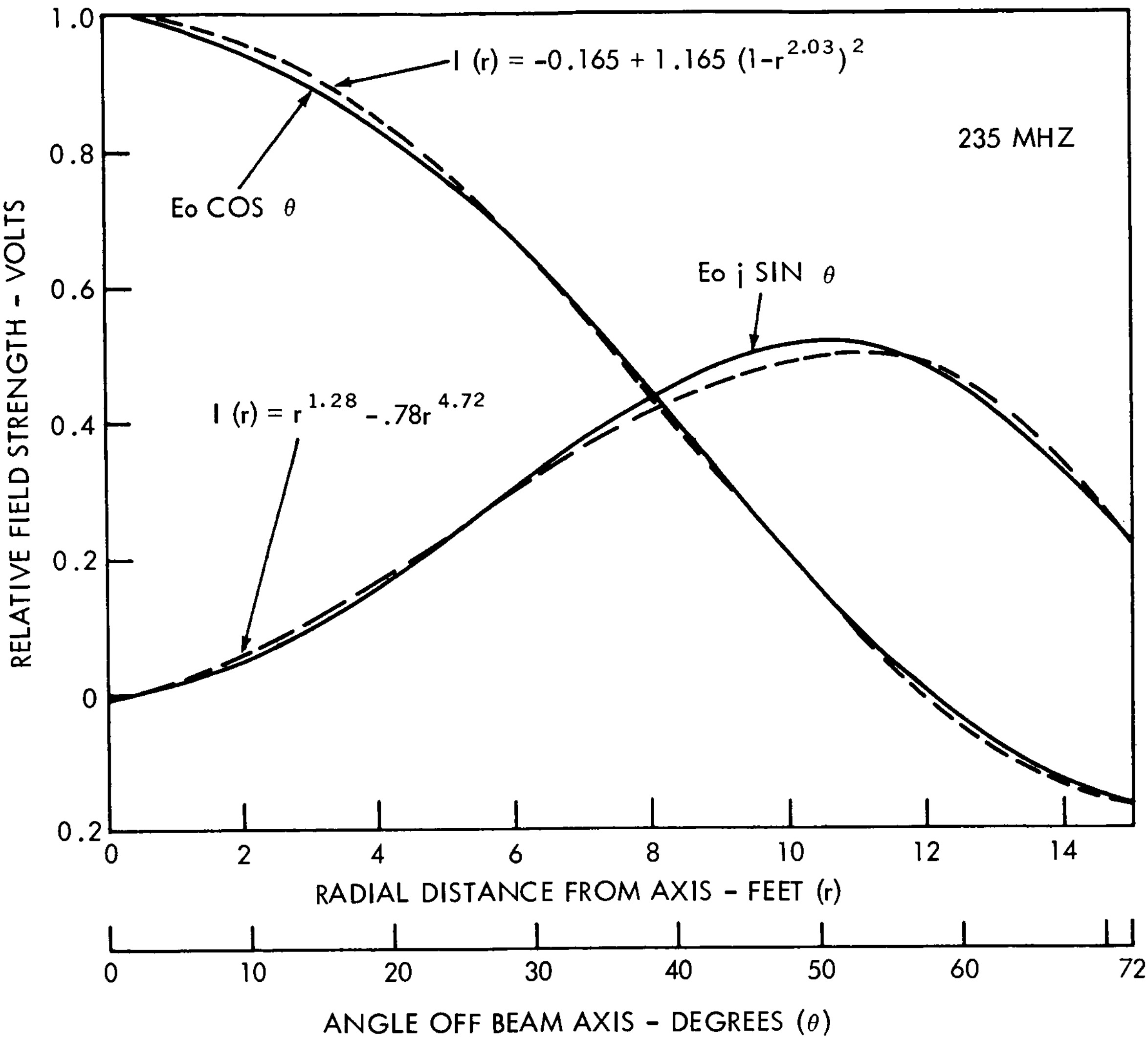


Figure 10. Primary Pattern Field Components (Feed 2 Feet Outside Focus)

Analysis of gain and efficiency in the same manner as for the on-focus feed indicates an efficiency of 21.1 percent and a directivity gain of 20.2 db for the off-focus feed. This represents a gain loss of 4.0 db.

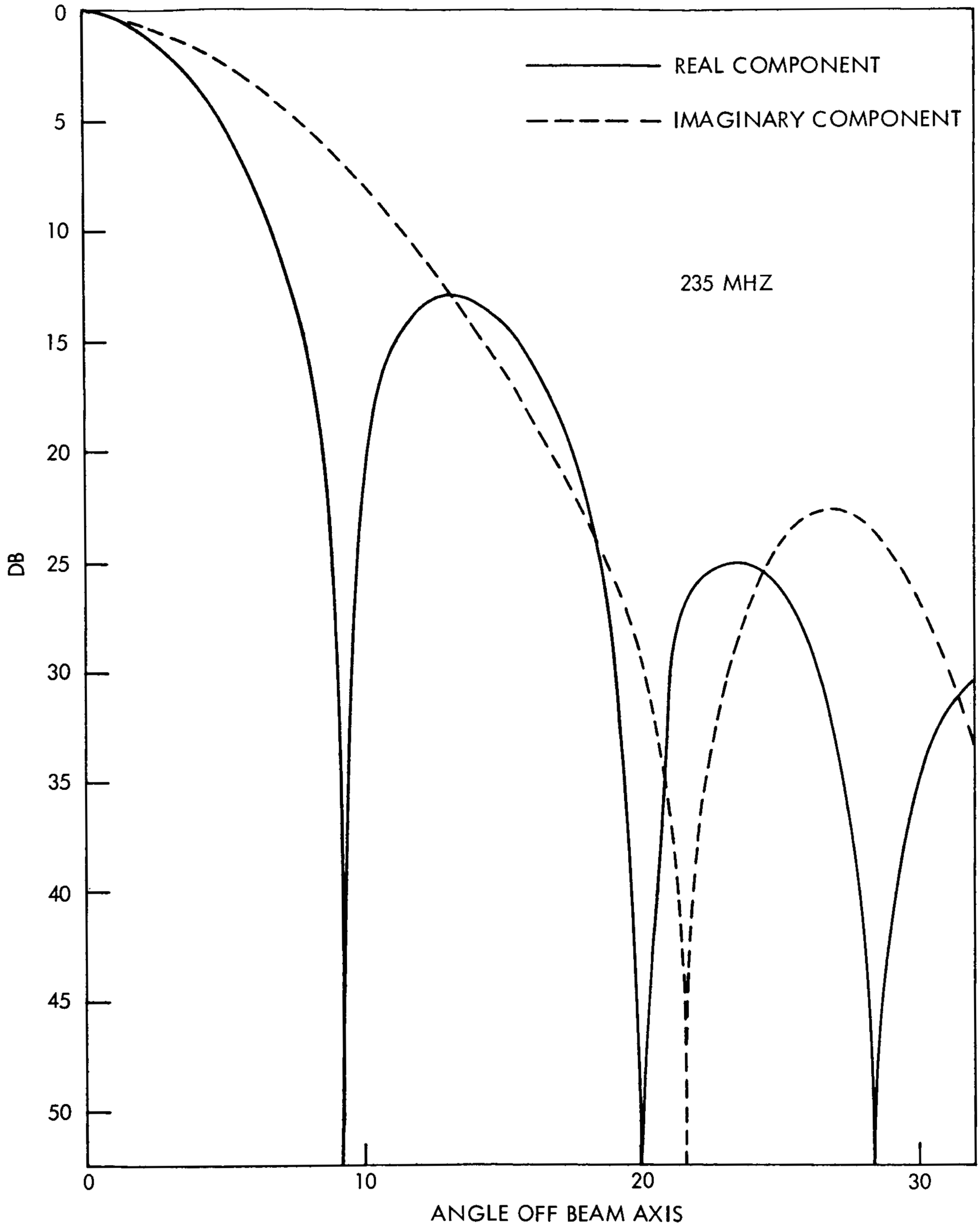


Figure 11. Secondary Pattern Field Components (Feed 2 Feet Outside Focus)

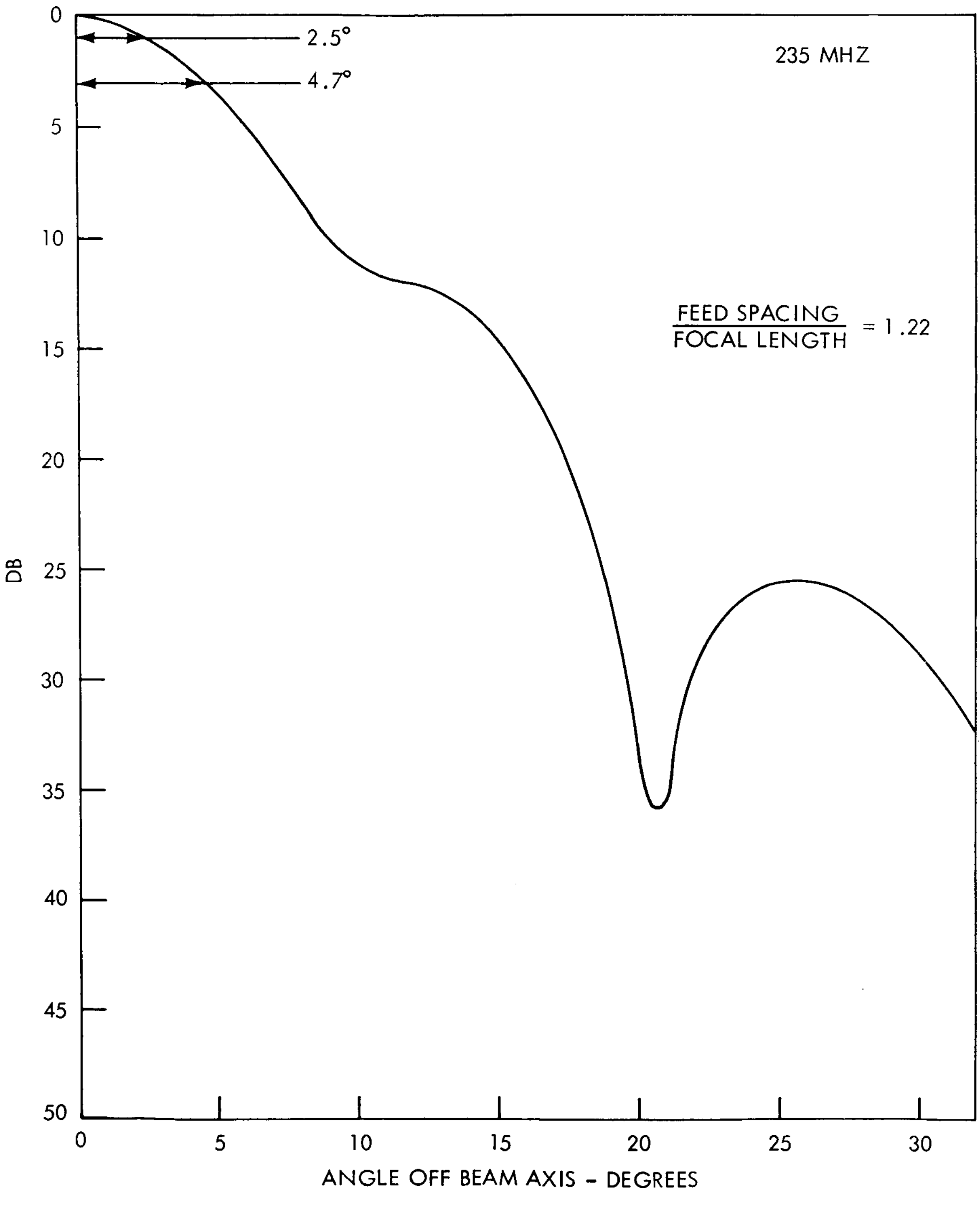


Figure 12. Calculated Secondary Pattern (Feed 2 Feet Outside Focus)

MECHANICAL DESIGN

Size Limitations

It was necessary that the feed be small enough to fit inside the conical fiberglass radome, shown in Figure 1, which has an inside height of 59 inches and an inside maximum diameter of 56.82 inches at the base. Moreover, it was required that the feed fit on to the motor drive shaft protruding through an aluminum ground plane which forms a mounting plate for the radome. A Radiation Systems, Inc., turnstile (Cat. No. 1623-03) modified to meet the electrical requirements was mounted on a suitable conical-scan rotation arm; Figure 13 shows the turnstile mounted in a cavity for the purpose of equalizing the E- and H-plane beamwidth. In this configuration, the cavity is excited in the TE_{11} mode and the aperture distribution across the cavity is uniform. Rotationally symmetric radiation results, and the RF analysis for design was based on this feed configuration. The vanes seen in Figure 13 beneath the dipoles, and attached to the sides of the support balun, serve to suppress TM modes in the cavity.

Feed Rotation Drive

The feed is driven by a Reliance Model Y178231 2-horse-power 3-phase 1740-rpm induction motor. Notched drive belts connect the motor shaft to the feed drive shaft. When the feed was rotated to accomplish dynamic balancing, it was found that 3.9 horsepower was required to spin the structure at the required 600 rpm. The available drive motor produces only 2 horsepower, and could rotate the feed, with cavity backing, at only 430 rpm.

Aerodynamic Drag Resistance

The excessive power required to drive the feed at 600 rpm was attributed to drag from the cavity surrounding the dipole and the TM-mode-suppressing vanes. When these were removed, and the mounting arm was streamlined somewhat, the feed rotated in free space at 600 rpm with no apparent heating of the 2-hp motor. The power required at this point to drive the feed at 600 rpm was measured to be 1.4 hp. Figure 14 shows the final version of the feed, with cavity removed. The stainless steel driveshaft seen in Figure 14 has the proper internal taper to fit the feed driveshaft. Lines connecting the turnstile to the coaxial hybrid coupler mounted under the feed are

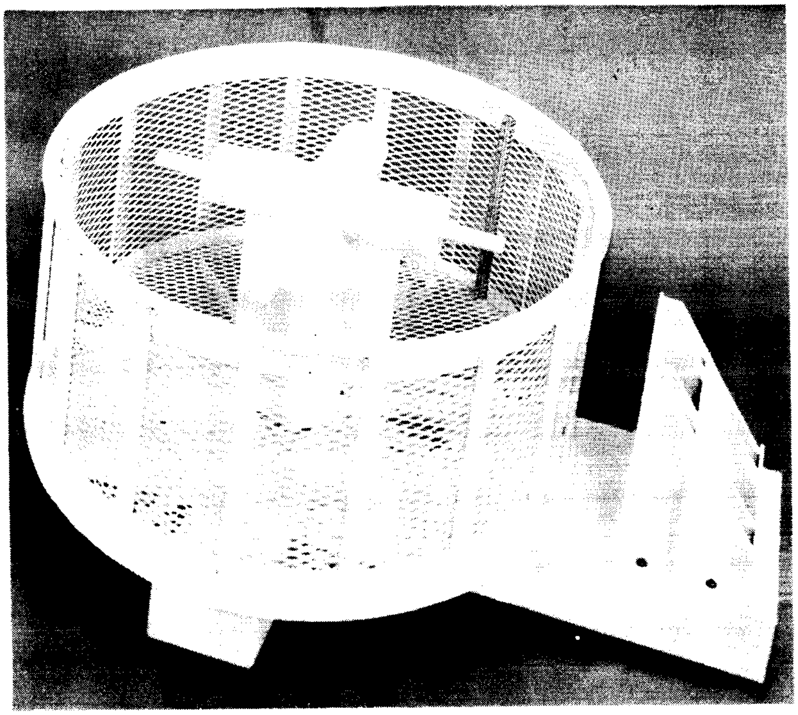


Figure 13. Turnstile Feed With Cavity Backing

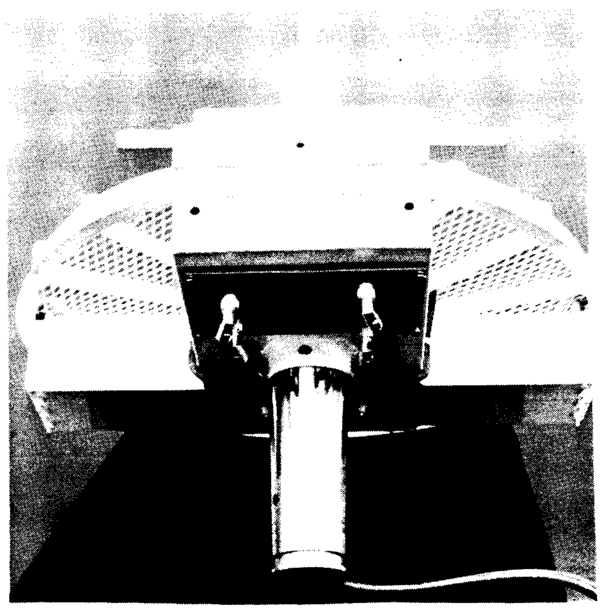


Figure 14. Turnstile Feed, Final Configuration
Cavity Removed

RG-9B/U, and the outputs from the coupler are fed down through the hollow shaft to mate with existing Type N connectors on the two-channel rotary joint.

Measured Weights

Weights of various components of the feed assembly, measured on a platform scale, are as follows;

Turnstile element	5.5 pounds
Ground plane	8.0
Support structure	27.5
Drive shaft	15.5
Hybrid coupler	1.5
Counterweights	15.0
Cables and hardware	3.5
Radome spacing ring	10.9
Total weight	87.4 pounds

This weight is 12.6 pounds less than the existing dual conical logarithmic spiral feed, which weighs 100 pounds.

Dynamic Balance

The feed was mounted and rotated on a dynamic balancing machine (Figures 15 and 16), at Keystone Electric Company, 2807 Annapolis Road, Baltimore, Maryland. For the balancing, the feed was mounted in a dual-bearing housing. The forward bearing of the rotating feed was clamped so that the bearing was free to move laterally in the presence of any dynamic unbalance, and the amount of this movement was measured by a dial indicator which showed the displacement at the bearing. After balancing, the vibration was found to be extremely small: maximum vibration displacement on the feed structure was measured to be approximately 1.9×10^{-5} inches peak-to-peak. This vibration appears as an extremely smooth balance on the vibration severity chart (Figure 17). Figure 17 also shows the vibration frequency to be 500 cycles per minute (83.3 cps).

Installation Procedure

The feed is designed and fabricated as a direct replacement of the existing dual balanced bifilar conical logarithmic spiral element. It is installed by removing the fiberglass radome, presently secured to

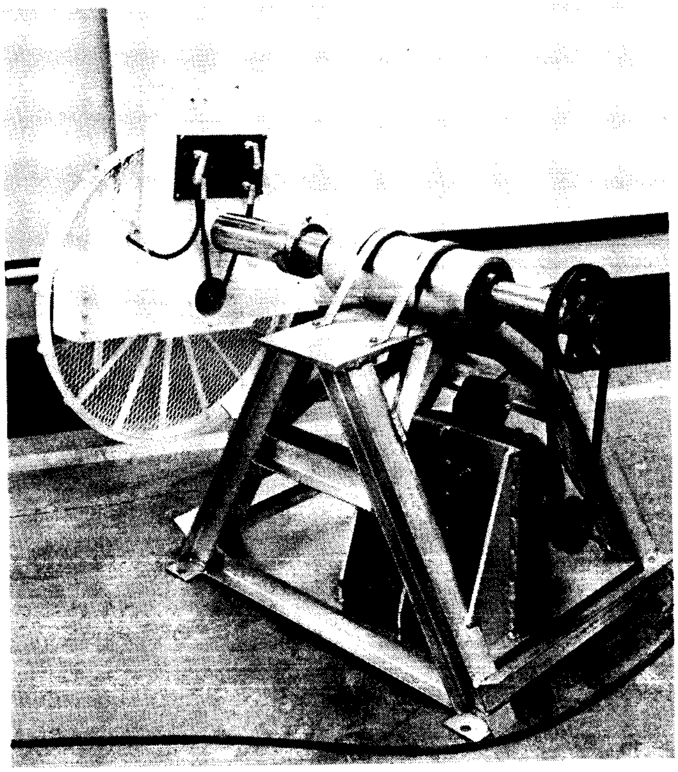


Figure 15. Feed In Dynamic Balancing Machine, (Rear View)

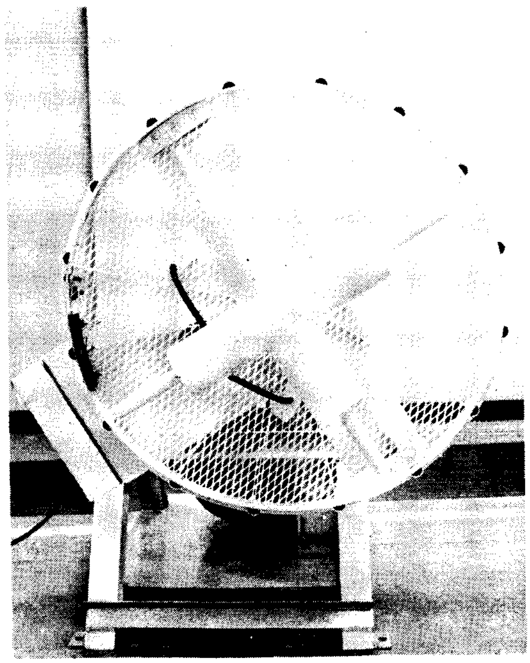


Figure 16. Feed In Dynamic Balancing Machine, (Front View)

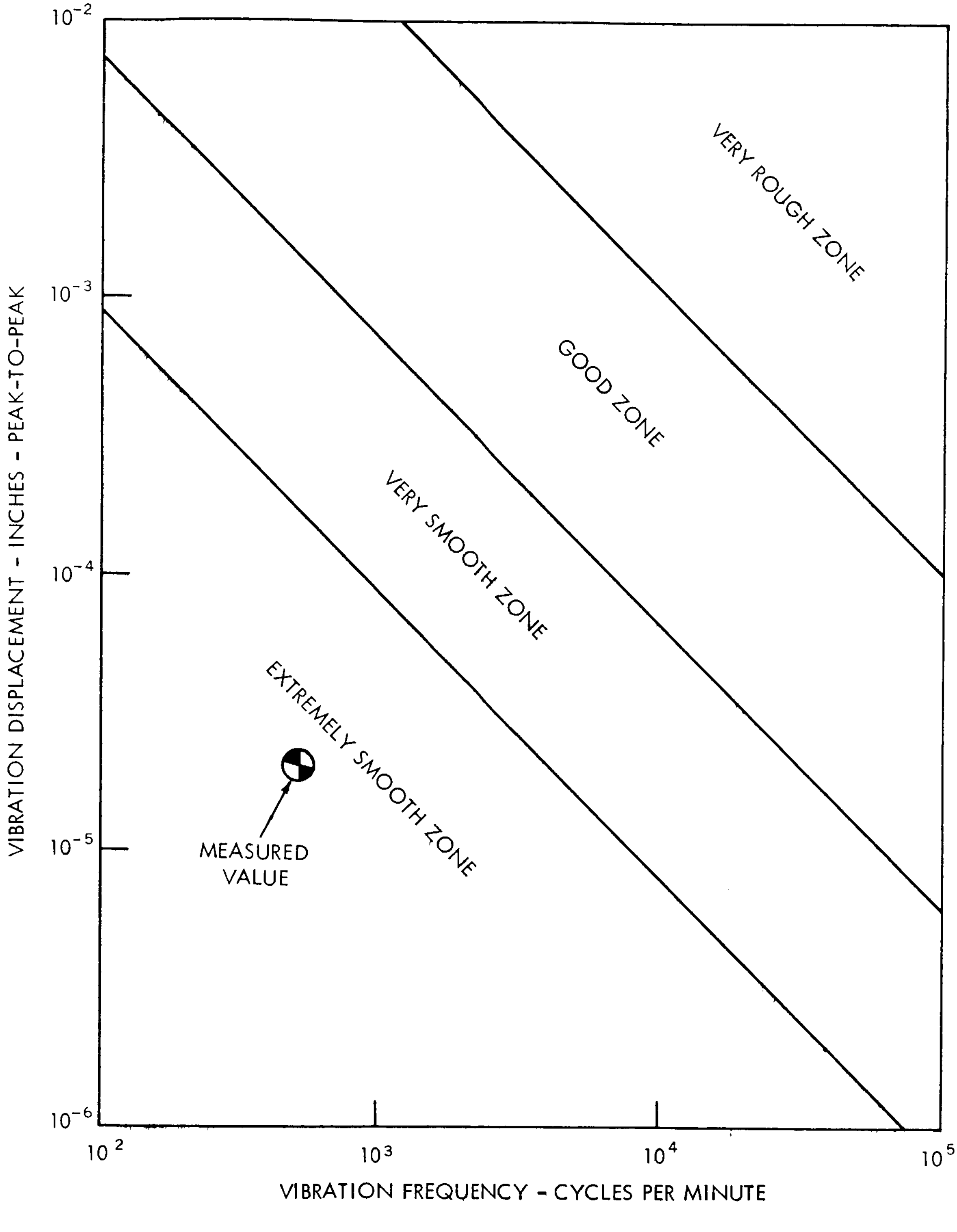


Figure 17. Vibration Severity Nomograph

a metal plate which serves as a reflecting plane for the conical spiral and also forms the end closure to the drive-assembly housing. Thirty 1/4-20 stainless steel cap screws hold the radome in place. The radome weighs 70 pounds. It is necessary to open the drive-assembly housing cover and remove the cover plates on the rotating drive shaft to obtain access to two Type N connectors on the end of the rotary joint. These connectors must be disconnected. The hollow shaft of the feed is drawn down over a tapered drive shaft by means of a 4.8-inch takeup nut, secured with three 3/8-inch cap screws in the side. When the nut is loosened, the existing feed is removable. The existing feed weighs 100 pounds. The replacement feed is installed in the reverse order, being careful that a locating pin through the drive shaft seats properly in a fork groove in the feed shaft. The replacement feed weighs 76.5 pounds.

Because the tangential velocity of the replacement feed is 69.8 miles per hour, adequate clearance should be provided from the inside wall of the radome. Although spacing between the feed and the radome inside surface is only one-half inch with the radome in place, a 2.5-inch spacer ring used under the radome increases this clearance to 2.5 inches on the radius. Replacement gaskets maintain the 0.5-psig internal pressure in the radome, although a pressurized environment is not necessary to operate the feed. The spacer ring weighs 10.9 pounds. The terminal marked J-2 is the right circular polarized terminal, and the terminal marked J-3 is the left circular polarized terminal for the feed installed in the reflector.

PERFORMANCE RESULTS

Primary Pattern Measurements

Primary patterns of the final version of the feed (cavity removed) were measured at each end of the Apollo operating band as well as at midband. Figure 18 is the coordinate system used in labeling patterns; Figures 19, 20, and 21 show primary patterns at 225, 237.8, and 260 Mhz. The patterns include the edges of the reflector (f/D = 0.3). Table 1 lists measured reflector-edge illumination. The 4.7 db-space attenuation to the edges of a reflector with f/D = 0.3 has been added to primary-pattern levels read from Figures 19, 20, and 21.

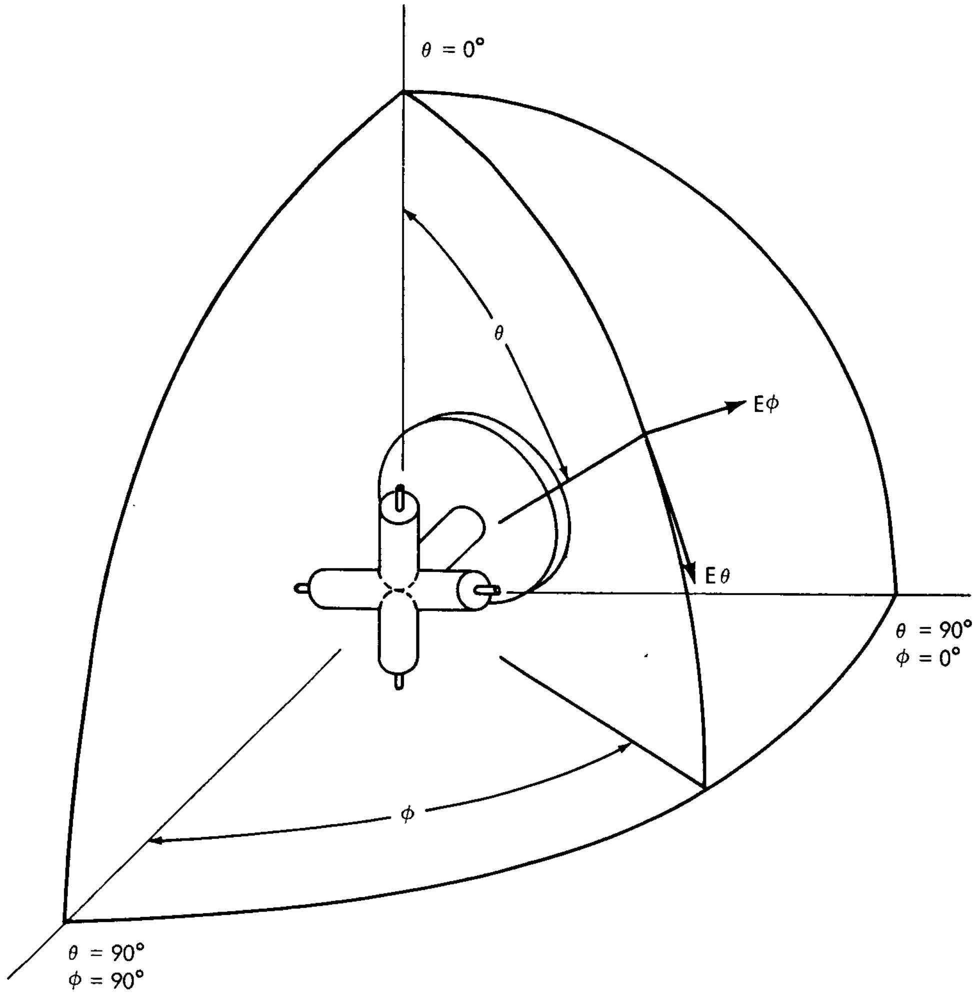


Figure 18. Coordinate System For Primary Patterns

Table 1

Reflector Edge Illumination

Frequency (Mhz)	Plane	Edge Illumination
225	E (ϕ)	23.5 db
225	H (θ)	11.2
237.8	E (ϕ)	7.7
237.8	H (θ)	20.7
260	E (ϕ)	10.2
260	E (θ)	19.3

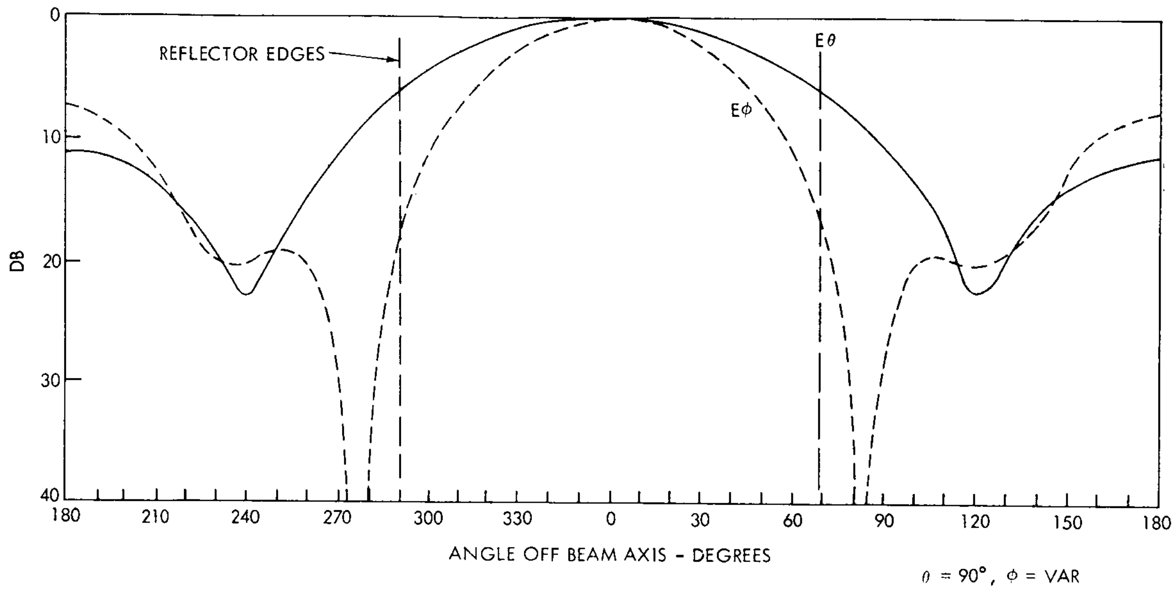


Figure 19. 225-Mhz Measured Primary Pattern

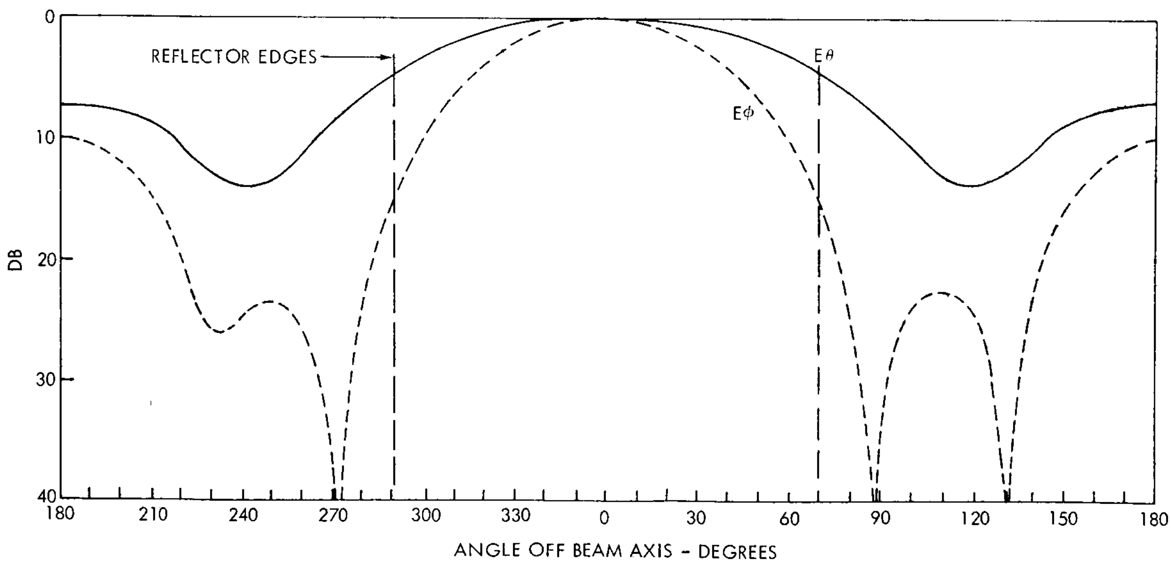


Figure 20. 237-8-Mhz Measured Primary Pattern

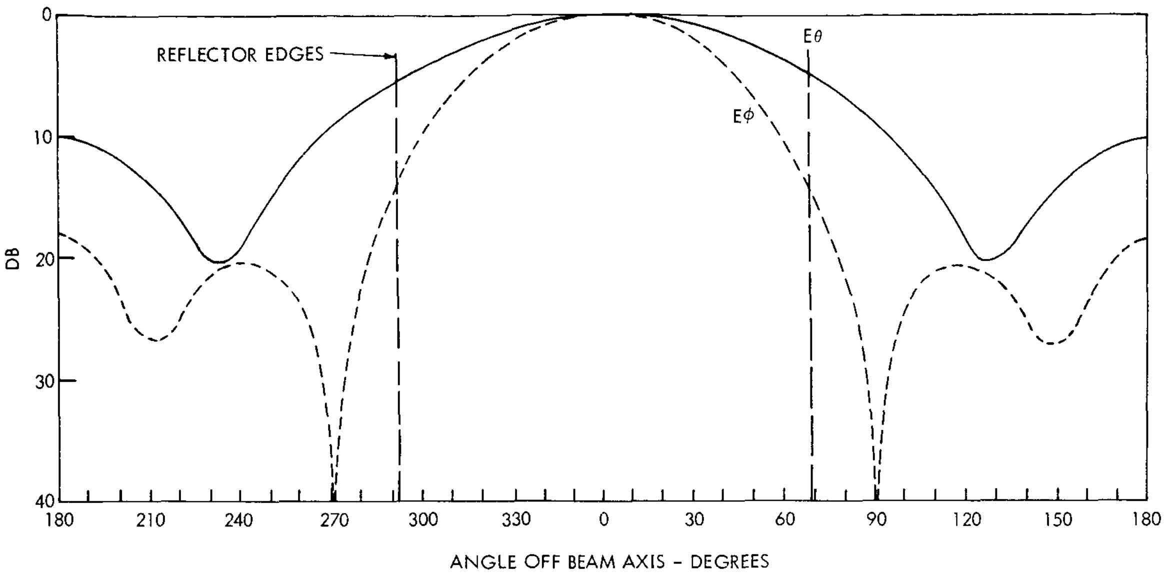


Figure 21. 260-Mhz Measured Primary Pattern

The wide variation between E- and H-plane edge illumination is the result of removing the cavity surrounding the turnstile, in an effort to reduce wind drag. Good axial ratio is preserved on-axis, however, as described below.

Axial Ratio

The axial ratio of the polarization ellipse measured on the axis of the turnstile was found to be acceptable, despite removal of the beam equalizing cavity. The cavity has no effect on axial ratio on the axis of the reflector, and preserves axial ratio only for angles of observation off the axis of the reflector. The measured on-axis axial ratios are:

Frequency	Ellipticity
225.0 Mhz	0.4 db
237.8	0.5
260.0	0.5

VSWR

The voltage standing-wave ratio was measured through the hybrid coupler and is referred to the input terminals of the coupler. Table 2 lists the measured VSWR.

Table 2

Measured VSWR

Frequency	VSWR		Insertion Loss
	RCP (J2)	LCP (J3)	
225 MHz	1.08	1.13	0.08
237.8	1.20	1.09	0.05
260	1.05	1.08	0.05

Isolation

The isolation between on-axis left-circular and right-circular incoming signals can be calculated by knowing the measured axial ratio. This relationship is

$$I = 20 \log \left[\frac{A+1}{A-1}\right] \tag{17}$$

where I is the isolation in db and A is the measured axial ratio. The list of on-axis axial ratios, shows the maximum to be 0.5 db, which corresponds to a voltage ratio of 1.059. Substituting in Expression (17)

$$I = 20 \log \left[\frac{1.059+1}{1.059-1}\right] \tag{18}$$

$$I = 20 \log 34.90 \tag{19}$$

$$I = 30.9 \text{ db.} \tag{20}$$

This isolation level is considerably better than that necessary to assure good tracking.

Predicted Secondary Pattern

Figure 22 is the secondary pattern of the final version of the feed shown in Figure 14 with cavity removed, and was computed for the Apollo

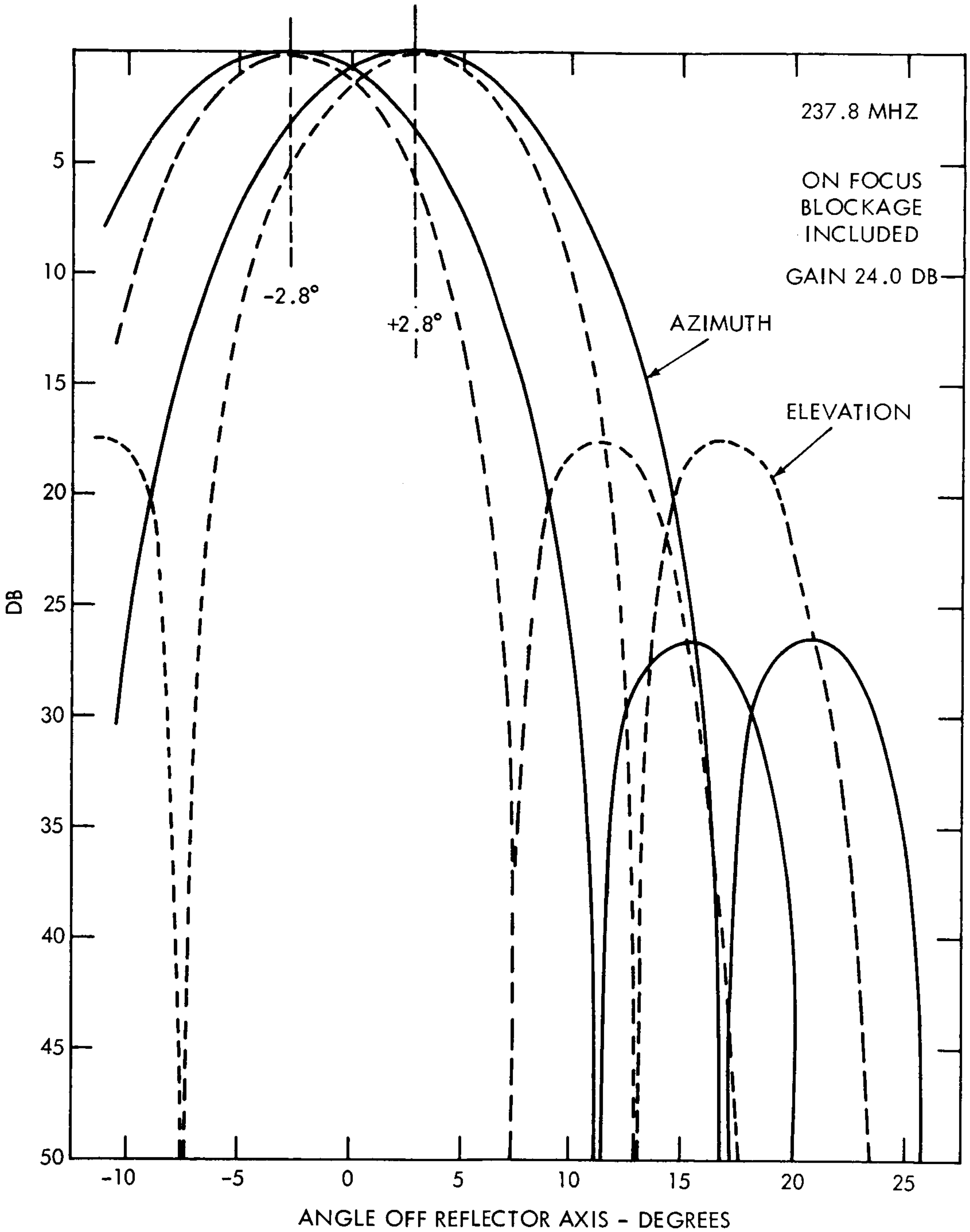


Figure 22. Calculated Secondary Pattern With Scanning Action
(Cavity Removed From Turnstile)

real-time telemetry frequency only (237.8 Mhz). This pattern was computed on a GE model T-35 computer in the manner previously described. The primary pattern for 237.8 Mhz (Figure 20) was used in computing this secondary pattern, and aperture-blockage effects have been included in the computation. As in Figure 7, the pattern is plotted for two positions of the feed; comparison of Figures 22 and 7 indicates the degradation resulting from removal of the cavity backing from the turnstile. The most significant change is the fact that the pattern has lost rotational symmetry: this is shown by the fact that the pattern is different for azimuth and elevation plane cuts in Figure 22, whereas Figure 7 is representative of any cut through the rotationally symmetric pattern. As a result, the beam crossover level is no longer constant at 1 db, but varies between 0.7 and 1.3 db, depending on the plane of cut through the pattern. The 1-db beamwidth is 5.0 and 6.6 degrees for the elevation and azimuth planes respectively; the 3-db beamwidth is 8.4 and 10.4 degrees in the elevation and azimuth planes respectively. As a consequence, the axial ratio has degraded; however, it is still only 0.7 db on the axis-of-symmetry of the reflector. Sidelobes are 17.5 db down in the elevation plane, and 26.5 db down in the azimuth plane. As a result of the increase in elevation-plane sidelobes, gain has gone down 0.6 db, to 24.0 db. Overall efficiency of the turnstile feed, without the cavity backing, is:

Aperture efficiency, 66.5 percent	1.76 db
Spillover efficiency, 90.0 percent	0.36
Hybrid coupler loss	0.25
VSWR loss (for 1.5:1)	0.20
Dipole loss	0.20
Coaxial cable Loss (4-ft RG-9)	0.15
TOTAL	2.95 db or 50.5 percent

The 50.5-percent efficiency yields an antenna-directivity gain of 24.0 db.

SUMMARY

A crossed-sleeve dipole (turnstile) feed designed, developed, and fabricated as a feed for the Apollo instrumentation ships tracking telemetry antenna will operate at P-band frequencies only, and does not cover L-band or S-band frequencies. A hybrid coupler forming a part of the feed provides simultaneous right-circular and left-circular polarization in two coaxial channels which may be attached to the existing dual coaxial rotary joint. The turnstile is mounted on a drive arm which locates it off the axis of the reflector, and drives it so as to provide conical scanning with a nominal 1-db crossover level. The turnstile assembly is designed to be a direct replacement for the existing conical log spiral feed installed in the antenna reflector. It is necessary only to modify the antenna feed structure by inserting a 2.5-inch spacer provided for use under the radome, and to focus the feed by moving the entire feed package 21.5 inches toward the reflector. Feed mounting rails provided for this purpose are a part of the antenna structure. Table 3 compares performance characteristics of the turnstile feed and the conical log spiral feed.

Table 3

Comparison of Turnstile and Conical Log Spiral Feeds
(237.8 Mhz)

	Turnstile	Log Spiral
Gain	24.0 db	19.6 db
Axial ratio	0.5 db	3.1 db
VSWR	1.20	1.80
Efficiency	50.5%	19.0 %
Sidelobe level	17.5 db	15.0
Crossover level	0.7-1.3 db	1.0-3.0 db
Beamwidth	9.4°	10.0°
Weight	87.4 lbs*	100.0 lbs
Drive power	1.4 HP	2.0 HP

*including 10.9lb, radome spacing ring

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