17

NASA Technical Memorandum 78662

(NASA-TM-78662) OPTIMIZATION OF THE DESIGN PARAMETERS FOR A WIDE-BAND RADIOMETRIC SYSTEM (NASA) 25 p HC A02/MF A01 CSCL 14C

N78-18117

Unclas
G3/19 05950

OPTIMIZATION OF THE DESIGN PARAMETERS FOR A WIDE-BAND RADIOMETER SYSTEM

Pradeep K. Agrawal

January 1978

National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

Contents

OPTIMIZATION OF THE DESIGN PARAMETERS FOR A WIDE BAND RADIOMETRIC SYSTEM

Pradeep K. Agrawal

Joint Institute for Advancement of Flight Sciences
George Washington University
Hampton, Virginia 23665

1. Summary

The purpose of the study presented here is to find the optimum design parameters for a swept frequency wide band radiometric antenna system for spacecraft applications. Wide band antenna systems are needed to observe layered surfaces e.g. ice, sea foam, etc. which are frequency sensitive and require multiple measurements for interpretation. The lowest frequency band of interest is between 1.4 to 2.8 Ghz. Starting with a given size reflector fed in the offset mode by a corrugated horn located at the focus of the parabola, the primary performance indicies e.g. half power beamwidth, cross polarization level, and overall beam efficiency have been calculated over a wide frequency range (two to one) for different physical horn dimensions and for different values of f/D ratio. These data can be used to find the best design under given restrictions of reflector size and blockage.

2. Introduction

The aim of the study reported here is to find the optimum design parameters for a swept frequency wide band radiometric antenna system for spacecraft applications; the lowest frequency band of interest being between 1.4 to 2.8 GHz. The antenna system consists of a parabolic reflector fed in offset mode by a circular horn antenna located at the focus of the parabolic reflector as shown in Figure 1. The scanning of the reflected beam is achieved by mechanically rotating the entire system about an axis of choice. The most important performance requirements for the antenna system are:

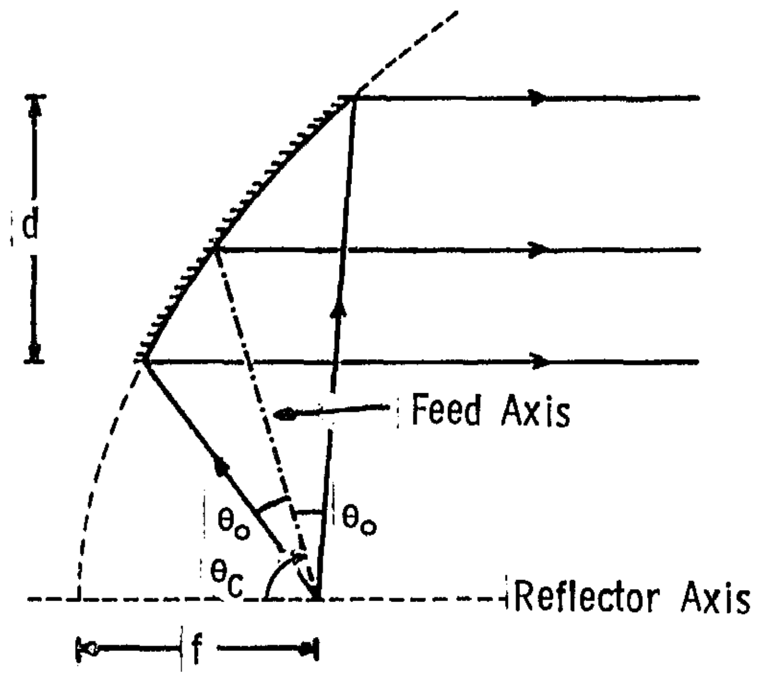


Figure 1 -- Parameters in an Offset Parabolic Reflector

1. Low level of cross polarized component in the secondary radiation pattern,
2. Low loss of energy due to spill over of the feed pattern over the boundary of the reflector, and,
3. A high overall beam efficiency. The overall beam efficiency includes the loss of energy due to spill over and therefore is a product of the conventional secondary beam efficiency and the efficiency with which the feed illuminates the reflector. Minor corrections are needed to incorporate the effect of loss of energy in the cross polarized component.

The size of the reflector (d) which is dictated by the room aboard the spacecraft is assumed to be 3 m. To further reduce the number of independent parameters of the system, θ_c is assumed to be equal to θ_o. But this causes a part of the reflected beam to be blocked by the feed. The blockage, however, can be minimized by choosing a feed with as narrow a semi flare angle and as small an aperture size as possible. If the fractional area of the reflected beam blocked by the horn is forced to be less than 2%, it is found that the horn semi flare angle must be about 20^o and the resulting aperture radius must be of the order of 0.25 m. A previous study of the cross polarized component level introduced in the secondary beam due to the curvature of the reflector [1] shows that the f/D ratio, D being equal to 2d, should be greater than 0.25 for the cross polarized component to be less than -20 db. Therefore, with the reflector size fixed to 3 m, and $\theta_c = \theta_o$, there are following three independent design parameters:

1. f/D ratio, which should be greater than 0.25 for maximum cross polarized component of the secondary beam to be less than -20 db w.r.t. the copolarized component,
2. Semi flare angle of the feed, which should be in the vicinity of 20^{o}, and
3. Aperture radius of the horn, which should be in the neighborhood of .25 m

} so that the blockage of the secondary beam is less than 2%. (applies to items 2 and 3)

The results presented throughout this report are in terms of parameters in wavelengths and therefore, can be scaled to other antenna sizes and frequency bands.

3. Feed Considerations

One system requirement not listed in the previous section is that the secondary beam should be approximately axially symmetric. To obtain such a beam, it is necessary that the radiation pattern of the feed be as symmetric about its own axis as possible. The best candidate feed which exhibits symmetrical radiation pattern over wide bandwidth is a corrugated horn. The magnitude and the phase of electric field in the aperture of a narrow flare angle circular corrugated horn are almost circularly symmetric. The magnitude is a cosine function of the radius and the phase is a quadratic variant [2]. The far field radiation pattern of such a corrugated horm therefore, can be numerically calculated by performing an aperture integration. Due to the circular symmetry, this aperture integration reduces to a line integral along a radius of the aperture. The calculated far field radiation patterns are found to agree very well with the ones given by Thomas [3].

For the horm dimensions outlined in the previous section, the maximum value of the phase taper over the horn aperture turns out to be 0.2 and 0.4 wavelengths at the lower and the upper ends of the frequency band, respectively. The far field pattern for such small values of phase taper has a rather broad main beam such that a part of the main beam alone illuminates the reflector.

For the system under consideration where the physical dimensions of the feed horn remain fixed, the change in the feed pattern due to a change in the operating frequency can be equivalently considered due to a corresponding change in the feed horn aperture size in wavelengths. Also, for a fixed reflector size, the part of the feed pattern that illuminates the reflector is determined by the f/D ratio, as shown in Figure 2. Consequently, the illumination properties of a corrugated feed horn are determined by:

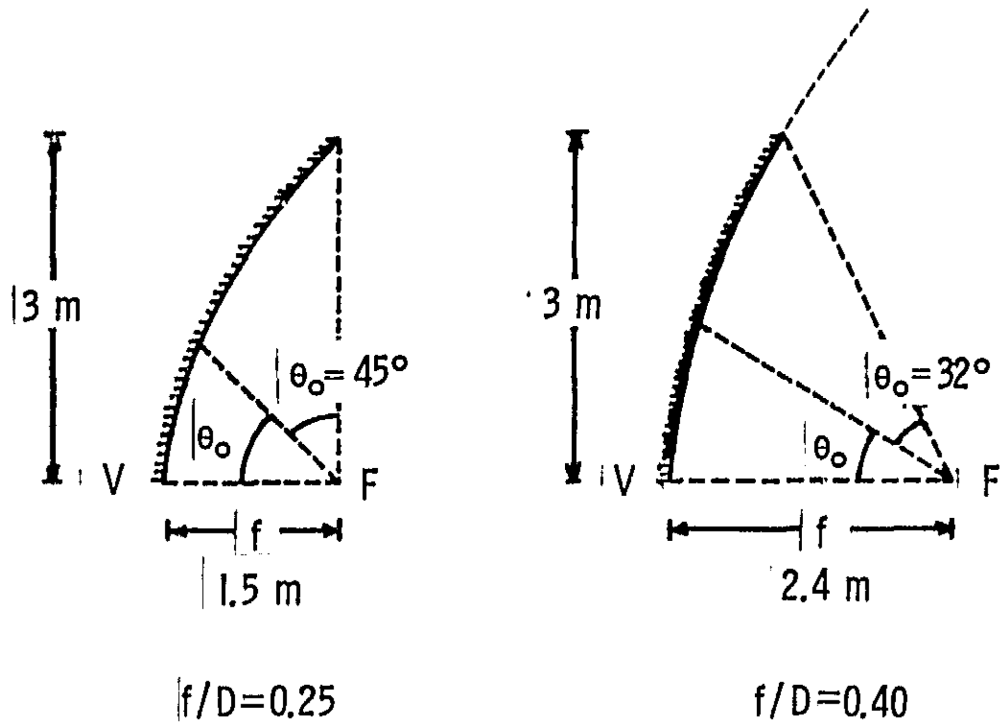


Figure 2 -- Effect of the f/D Ratio Over the Part of the Feed Pattern that Illuminates the Reflector

1. The semi flare angle of the horn, which as pointed out in the previous section is in the vicinity of 20^0,
2. The radius of the horn aperture in wavelengths, which is in the neighborhood of 1.15 wavelengths at 1.4 GHz (25 cm), or 2.30 wavelengths at 2.8 GHz, and
3. The f/D ratio, which should be between 0.25 and 0.40, the upper limit of which is set by mechanical limitations.

The most important illumination properties of the feed horn which are manifested in the properties of the secondary pattern are the level of the edge illumination of the reflector and the beam efficiency of the feed; the beam efficiency of the feed being defined as the energy received by the reflector expressed as the percent of the total power radiated from the horn. To make a parametric study of the feed, the beam efficiency of the feed and the edge illumination of the reflector are calculated and plotted in Figures 3 and 4, respectively, for a set of feed horns whose physical dimensions vary (say) about ±15% from the nominal values, i.e., (a) for the semi flare angle of the horn varying between 17 and 23°, and (b) for the horn aperture radius between 1.0 and 1.3 wavelengths at 1.4 GHz which corresponds to between 2.0 and 2.6 wavelengths at 2.8 GHz, and (c) for the f/D ratio of 0.25 and 0.40.

Notice that for f/D = 0.4, the beam efficiency of the feed and the reflector edge illumination are considerably poorer than for f/D = 0.25 case, as one would expect. Alongside the y-axis in Figure 3, data points for the intermediate values of f/D are plotted for a horn having a 17° semi flare angle and an aperture radius of 1.0 wavelengths. These can be used to estimate the beam efficiency of the feed for intermediate values of the f/D ratio.

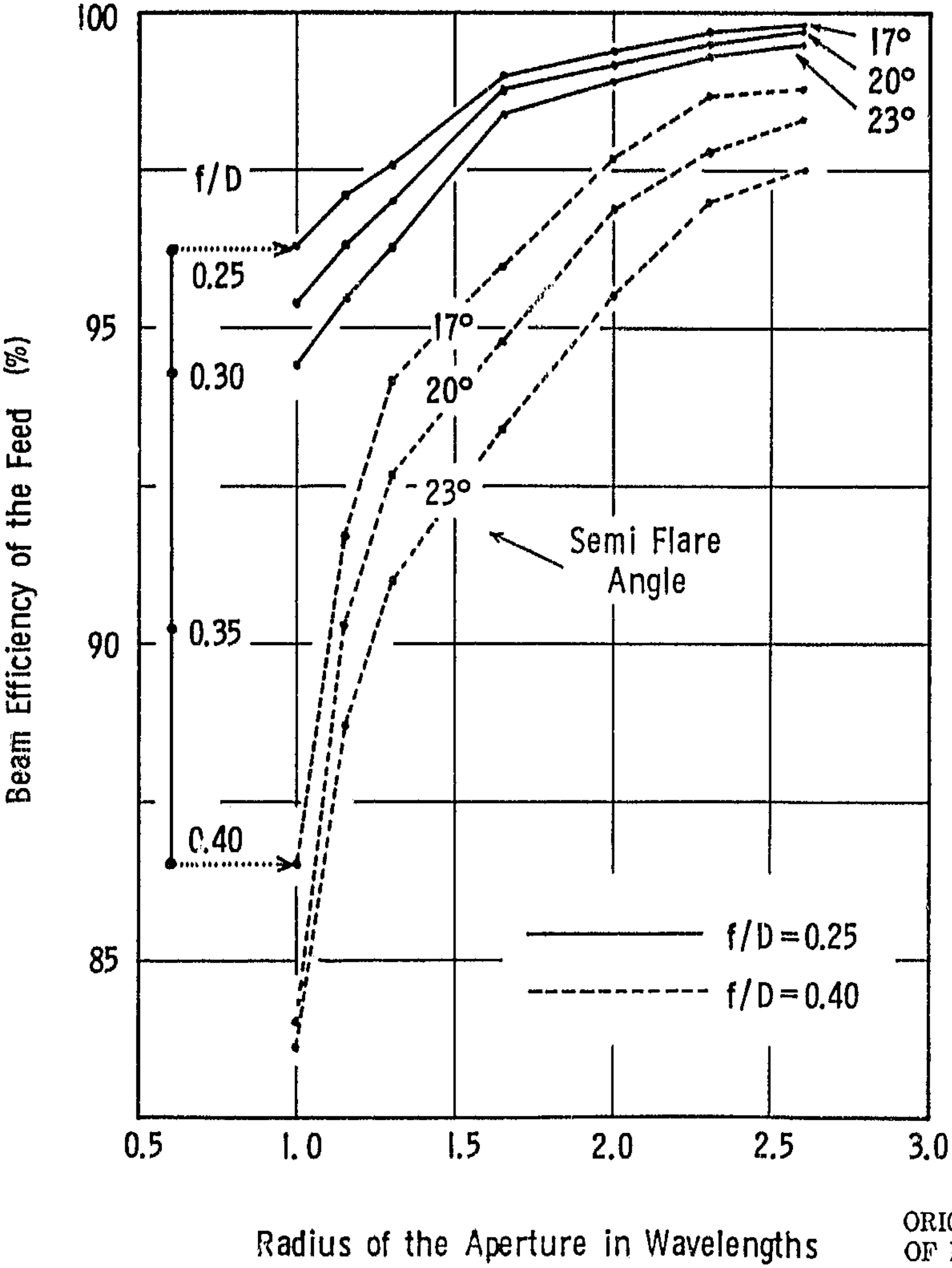


Figure 3 -- Beam Efficiency of the Feed as a Function of Aperture Radius

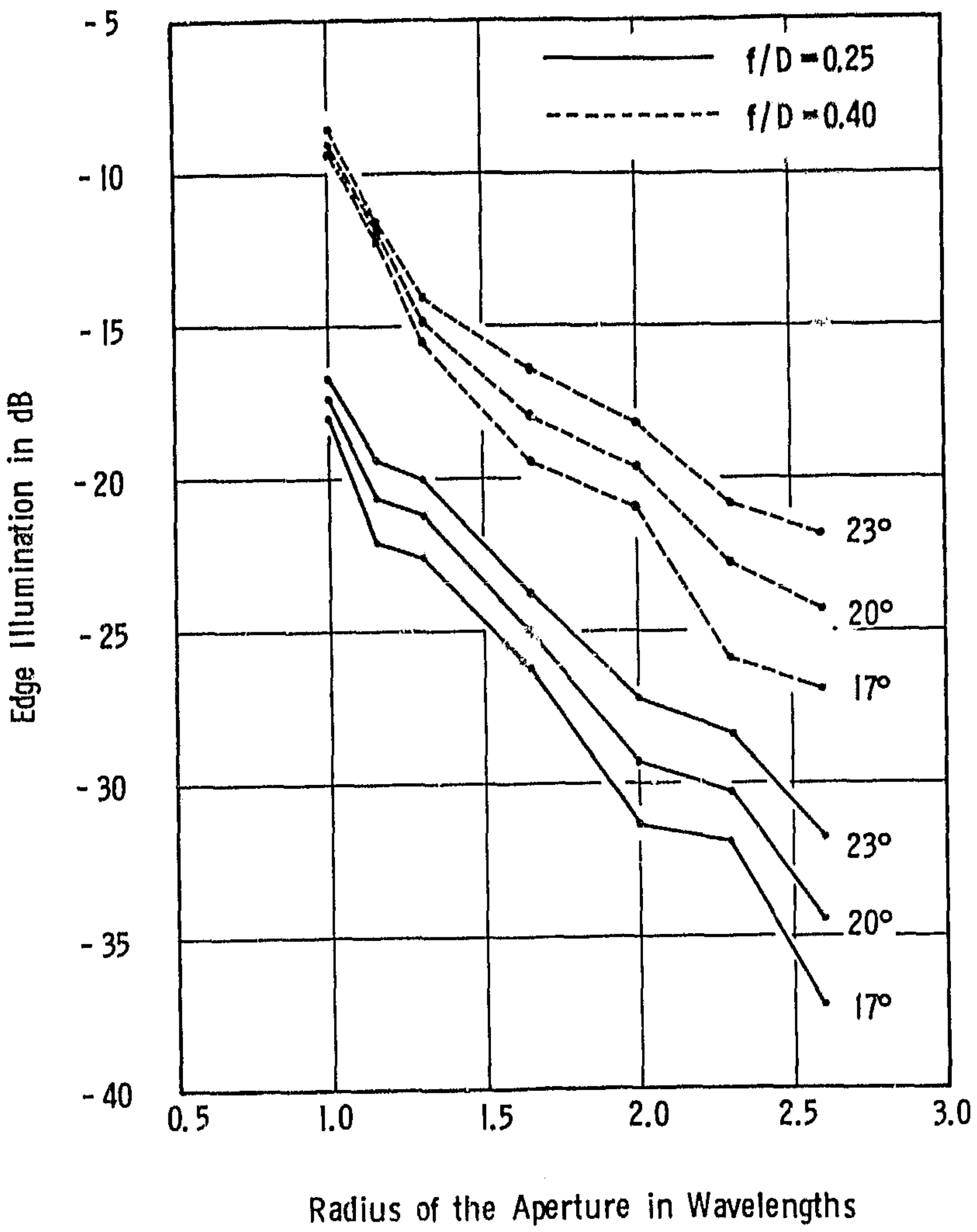


Figure 4 -- Edge Illumination of the Reflector as a Function of the Feed Horn Aperture Radius

4. Secondary Pattern

Consider the arrangement shown in Figure 5. The feed with known radiation pattern (calculated in the previous section) is located at the origin of the focus centered coordinate system. The reflector is defined by the curved surface of a frustum of the paraboloid of revolution. The aperture which is a projection of the reflector surface on a plane parallel to y-z plane, is thus, in general a circle. If a ray emanating from the feed strikes the reflector surface at (x_o, y_o, z_o), and after reflection it reaches the aperture plane at (x_a, y_a, z_a), then using the equations of geometric optics, the reflected electric field is calculated at (x_a, y_a, z_a) in the aperture plane. Considering many such rays, the reflected electric field is evaluated at many points in the aperture plane. In general, these points in the aperture plane are not uniformly distributed. Quantizing these points along equispaced y = constant lines in the aperture plane and then performing the double integration over the aperture plane, the far field radiation patterns are calculated [4].

The spacing between y = constant lines in the aperture plane is chosen by first obtaining a rough estimate of spacing of the data points in the aperture plane. The magnitude and phase of the electric field at each point are then arbitrarily assigned to a point on the nearest y = constant line in the aperture plane. Since the integration time depends upon the number of aperture data points which in turn is determined by the angular increment between the rays used in the feed pattern, the integration time is relatively insensitive to the absolute size of the aperture.

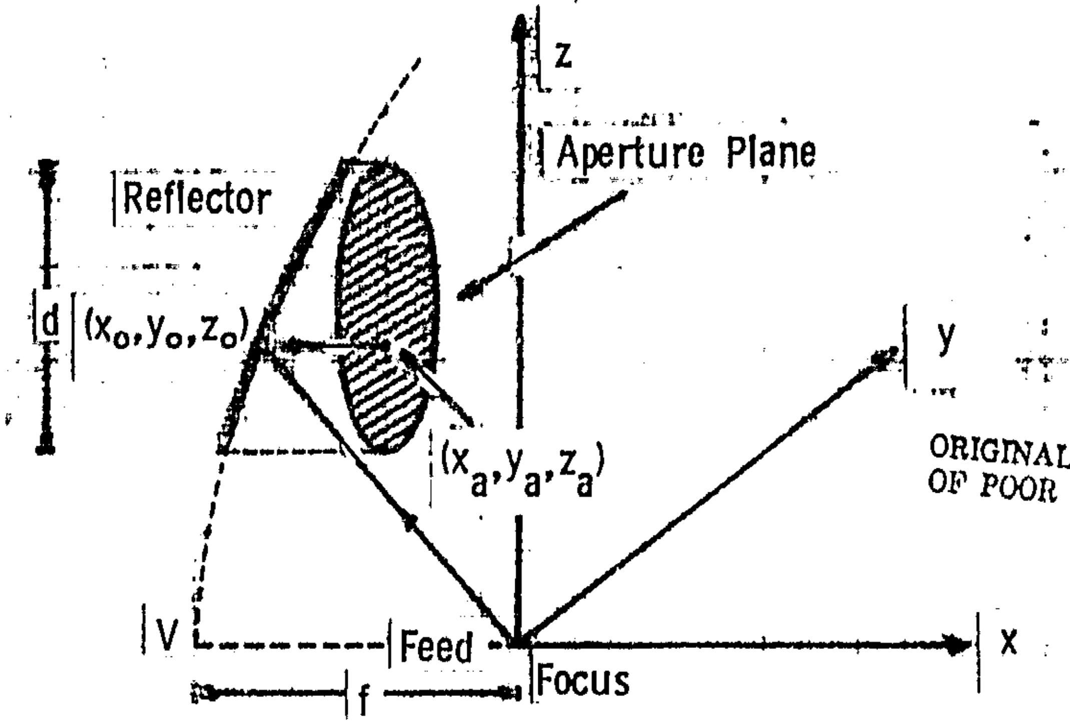


Figure 5 -- Antenna Geometry

The far field secondary radiation patterns are calculated using the technique outlined above for the ranges of horn dimensions and the f/D ratio (established in the previous section) over a frequency range of 1.4 to 2.8 GHz. Figure 6 is a computer generated plot showing (a) the typical locations of data points in the aperture plane before quantization and (b) the contours of constant electric field amplitude in steps of 3 dB. As pointed out earlier, observe that the data points in general, are not uniformly distributed. In Figure 7 (a) and (b) the calculated far field radiation patterns are shown for the copolarized and cross polarized components in the x-y plane. The maximum crosspolarized component is 27.90 dB below the copolarized component.

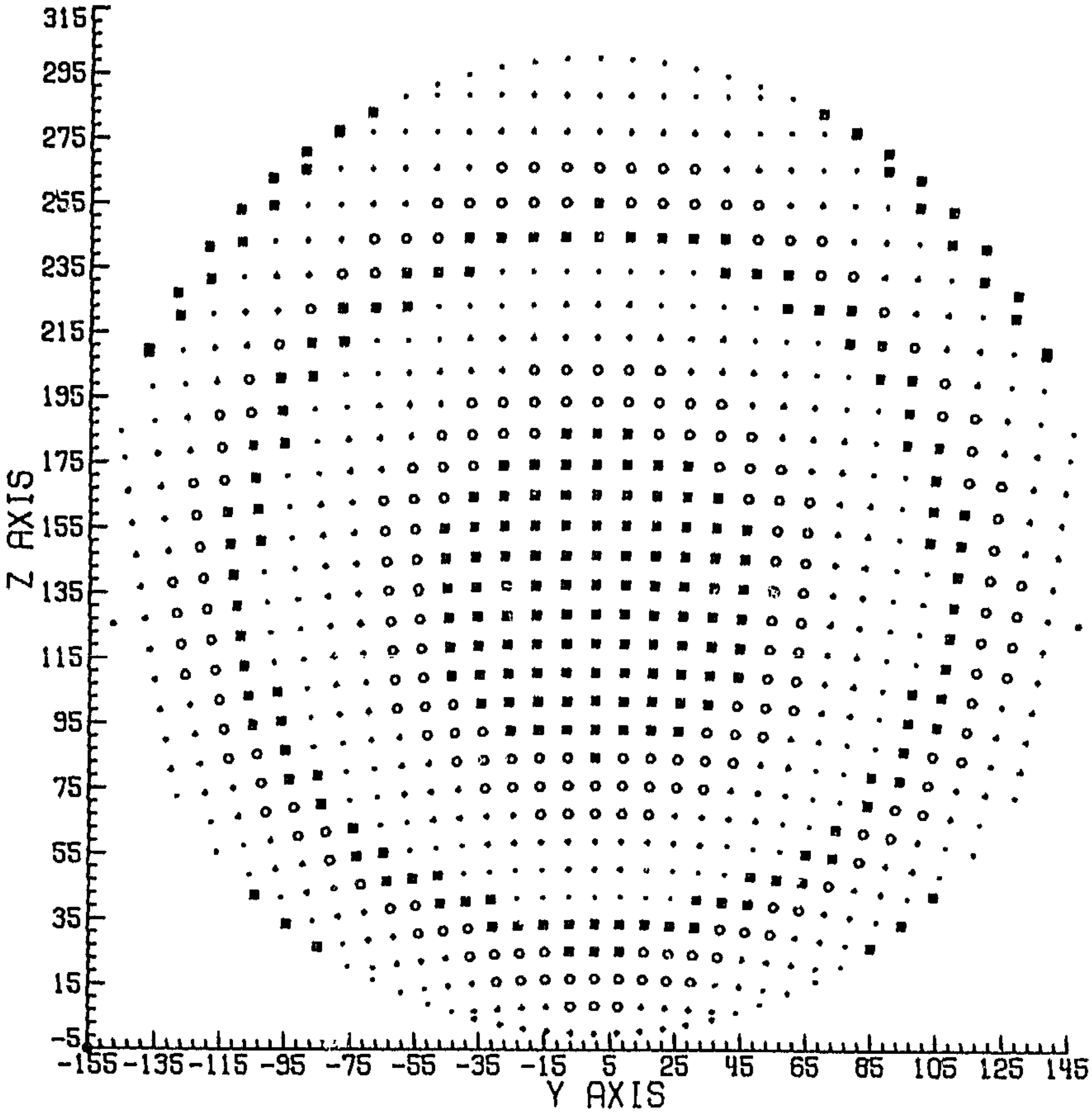
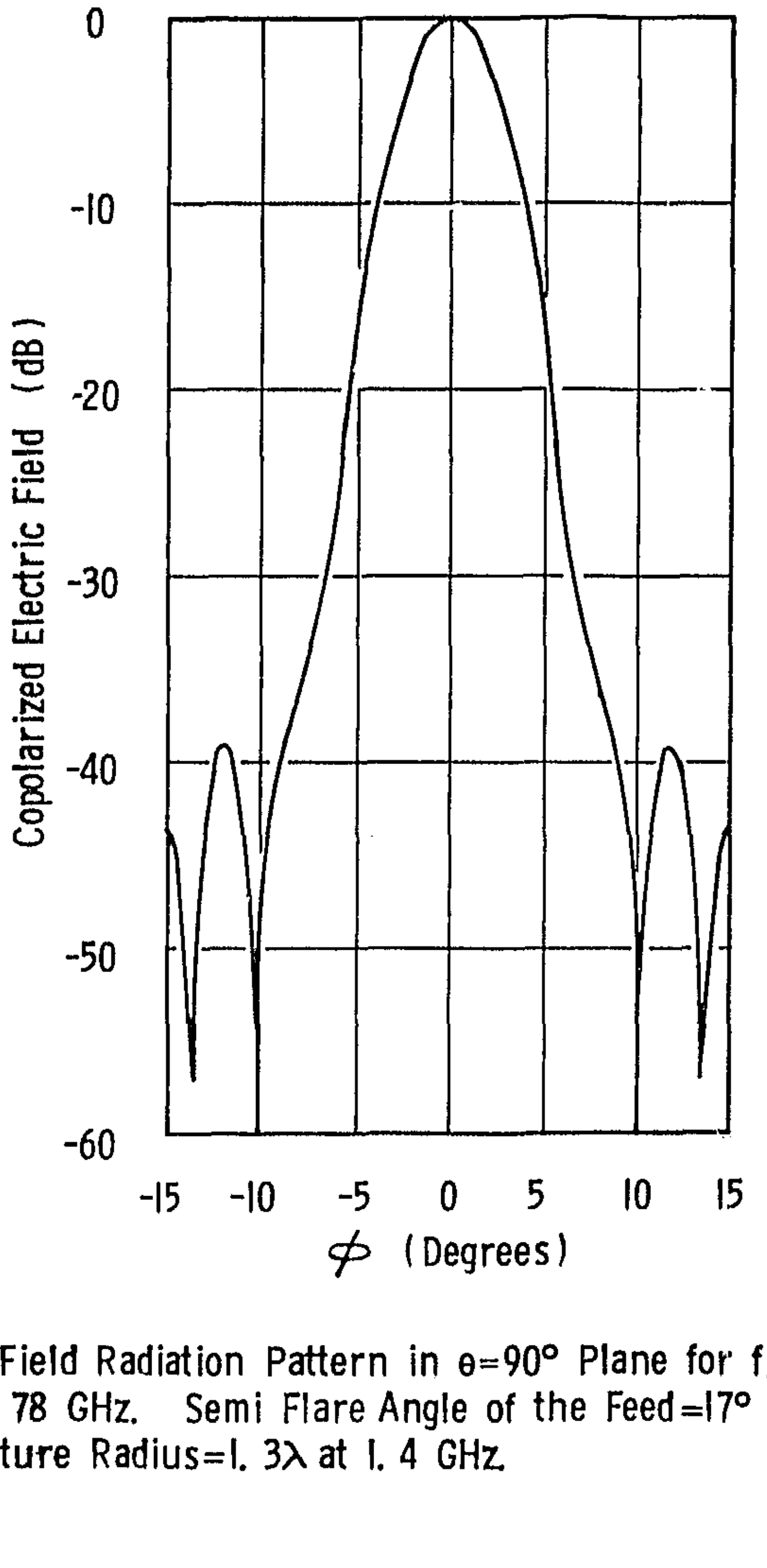
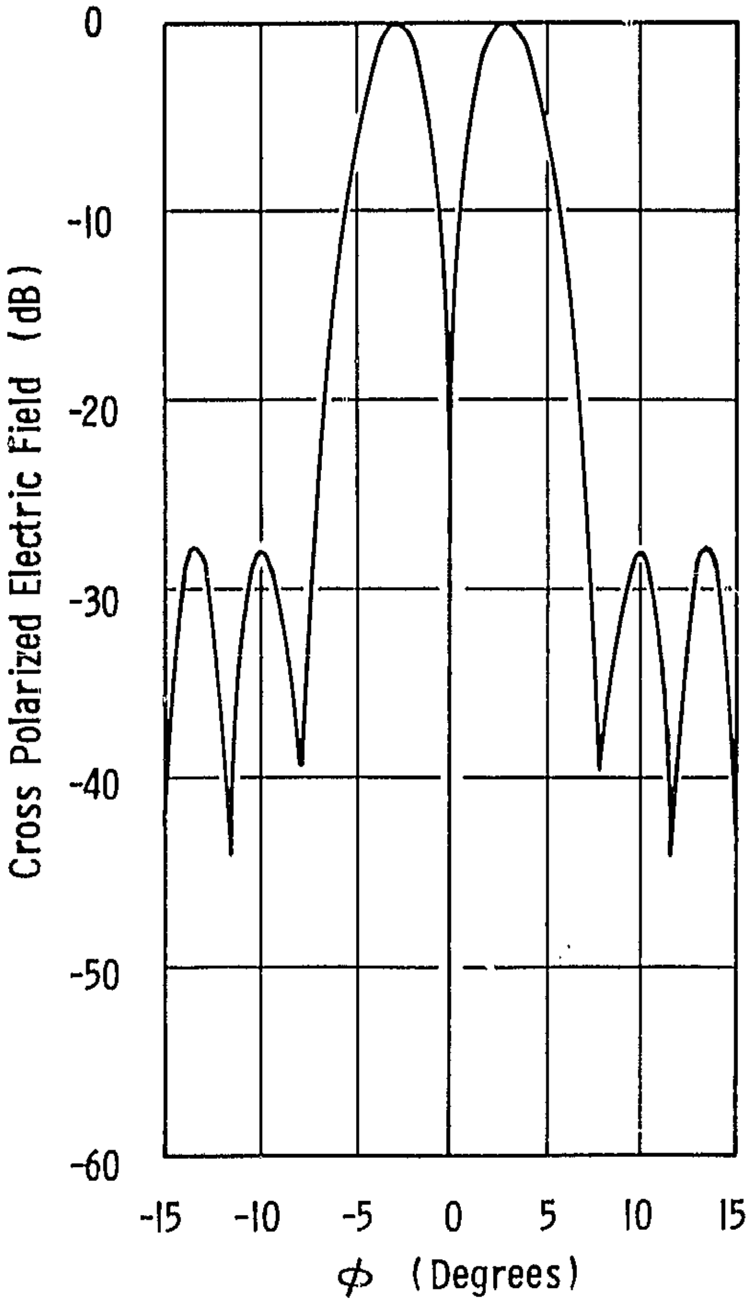


Figure 6 -- Data Point Locations in the Aperture Plane Before Quantization Showing the Contours of Constant Electric Field Amplitude at 1.78 GHz for f/D= 0.4 Using Feed with Semi Flare Angle of 17° and an Aperture Radius of 1.3λ at 1.4 GHz



ure 7(a) - Far Field Radiation Pattern in $\theta=90°$ Plane for $f/D=0.4$ at 1.78 GHz. Semi Flare Angle of the Feed=17° and the Aperture Radius=1.3λ at 1.4 GHz.



-e 7(b) - Far Field Radiation Pattern in θ=90° Plane for f/D=0. 4 at 1. 78 GHz. Semi Flare Angle of the Feed=17° and the Aperture Radius=1. 3λ at 1. 4 GHz.

5. Properties of the Secondary Pattern

The secondary far field radiation patterns were calculated in the previous section for the ranges of (a) the horn dimensions, (b) the f/D ratio, and (c) the operating frequency. The 3 dB beamwidth of the secondary pattern is found in each of the above cases and plotted as shown in Figure 8. As expected, since the edge illumination of the reflector for f/D = 0.40 is stronger than for f/D = 0.25 (Figure 4), the 3 dB beamwidth for f/D = 0.4 case is consistently smaller than f/D = 0.25 case.

Similarly in Figure 9 the maximum cross polarized component level is plotted as a function of frequency for the same variations in aperture size, semi flair angle, and the f/D ratio as in Figure 8. Observe that, as expected, for f/D = 0.25 where the reflector has more curvature than when f/D is 0.40, cross polarized component is consistently higher. In any event, the cross polarized component is always at least 21 dB below the copolarized component.

The beam efficiency of the secondary pattern which is defined as the fraction of the total reflected power contained within a cone of any given angle from the beam axis can be found by performing a double integration over the secondary pattern. Since the secondary pattern is nearly axially symmetric, the double integral simplifies to a single integral. The calculated beam efficiency at 2.5 half power beamwidths from the beam axis is plotted in Figure 10 as a function of the operating frequency. For the time being, the energy contained in the cross polarized component has not been included in the above calculations. Observe that higher beam efficiency occurs for higher f/D ratio.

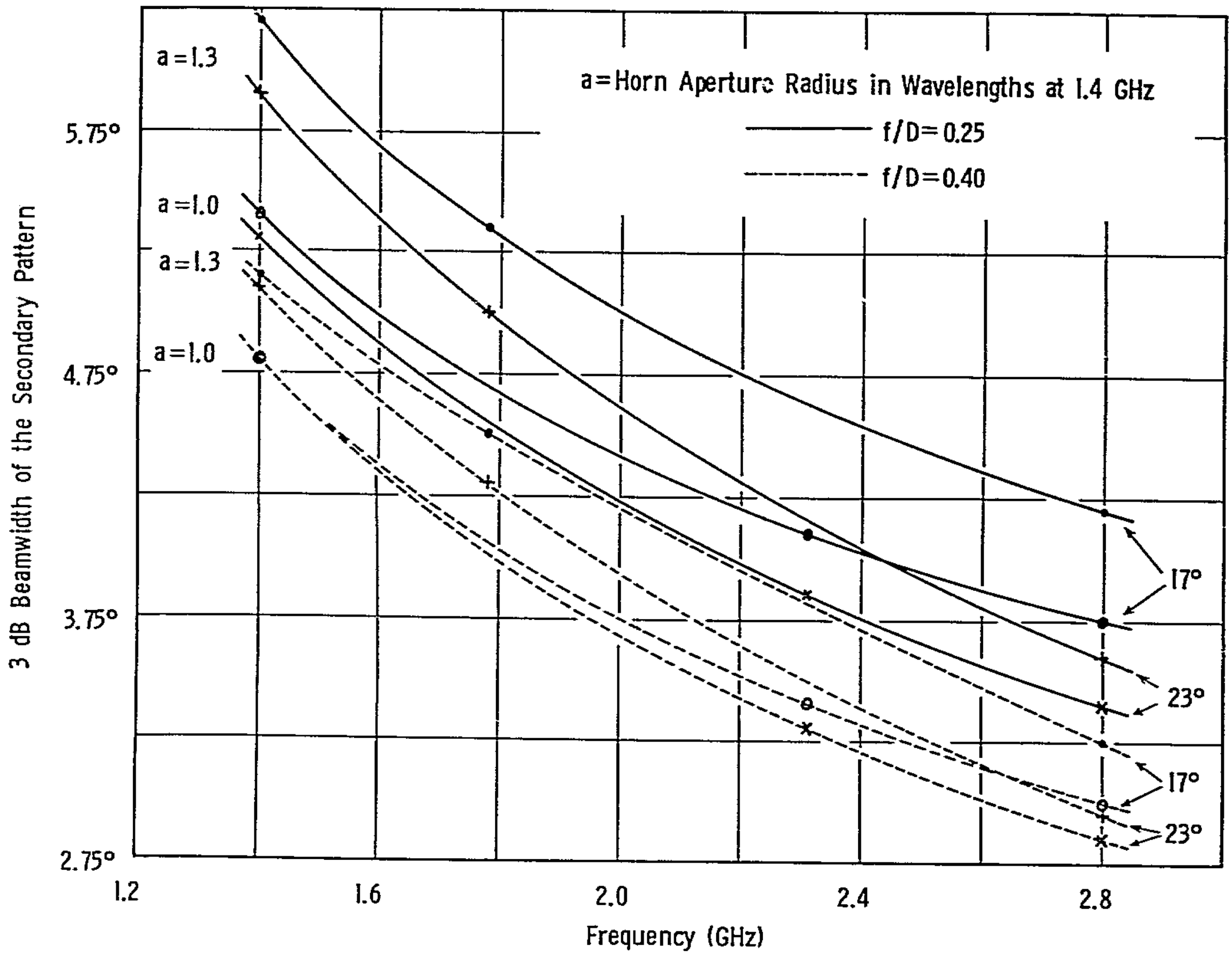


Figure 8 -- Half Power Beamwidth of the Secondary Pattern as a Function of the Operating Frequency

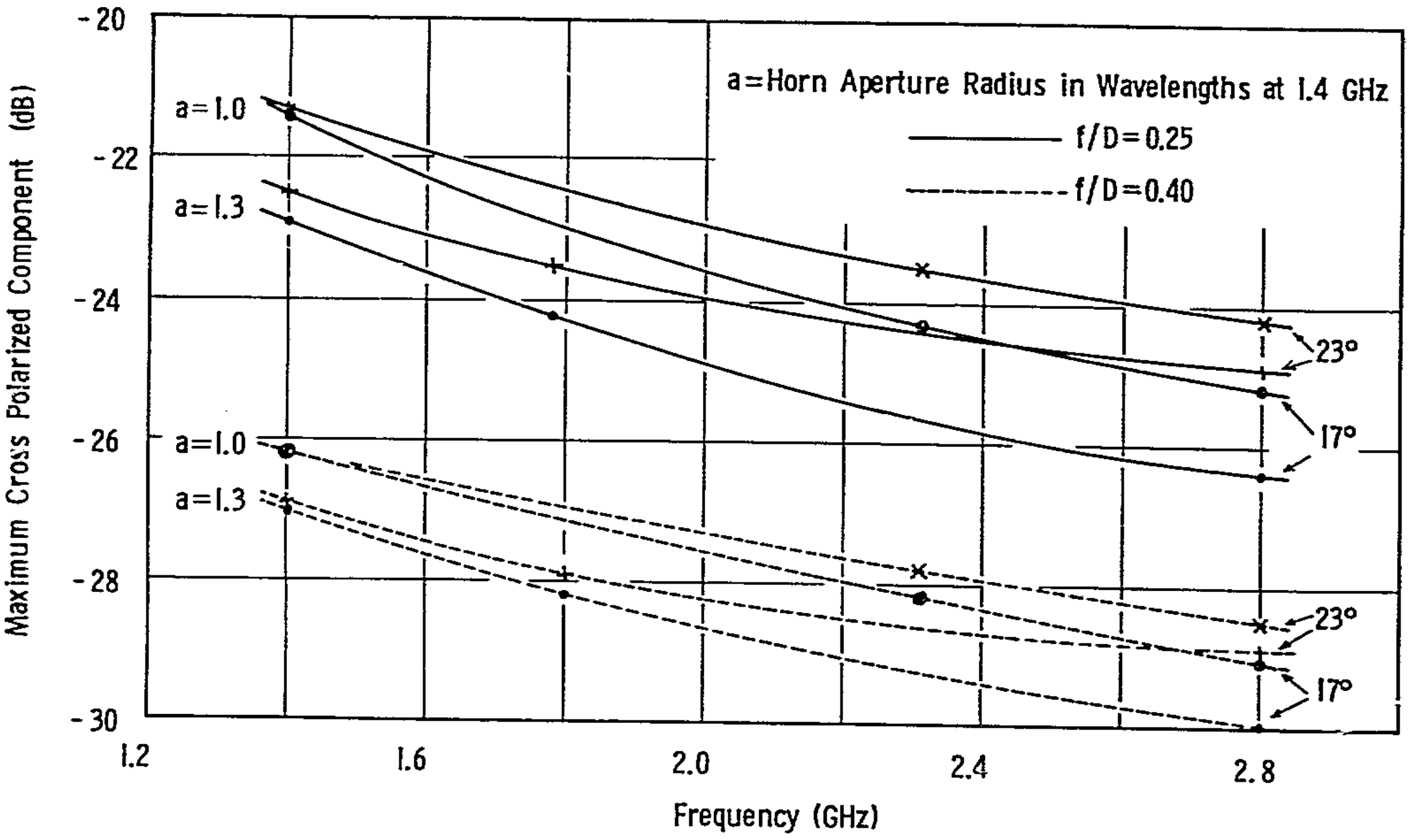


Figure 9 -- Maximum Cross Polarized Component Level in the Secondary Pattern as a Function of the Operating Frequency

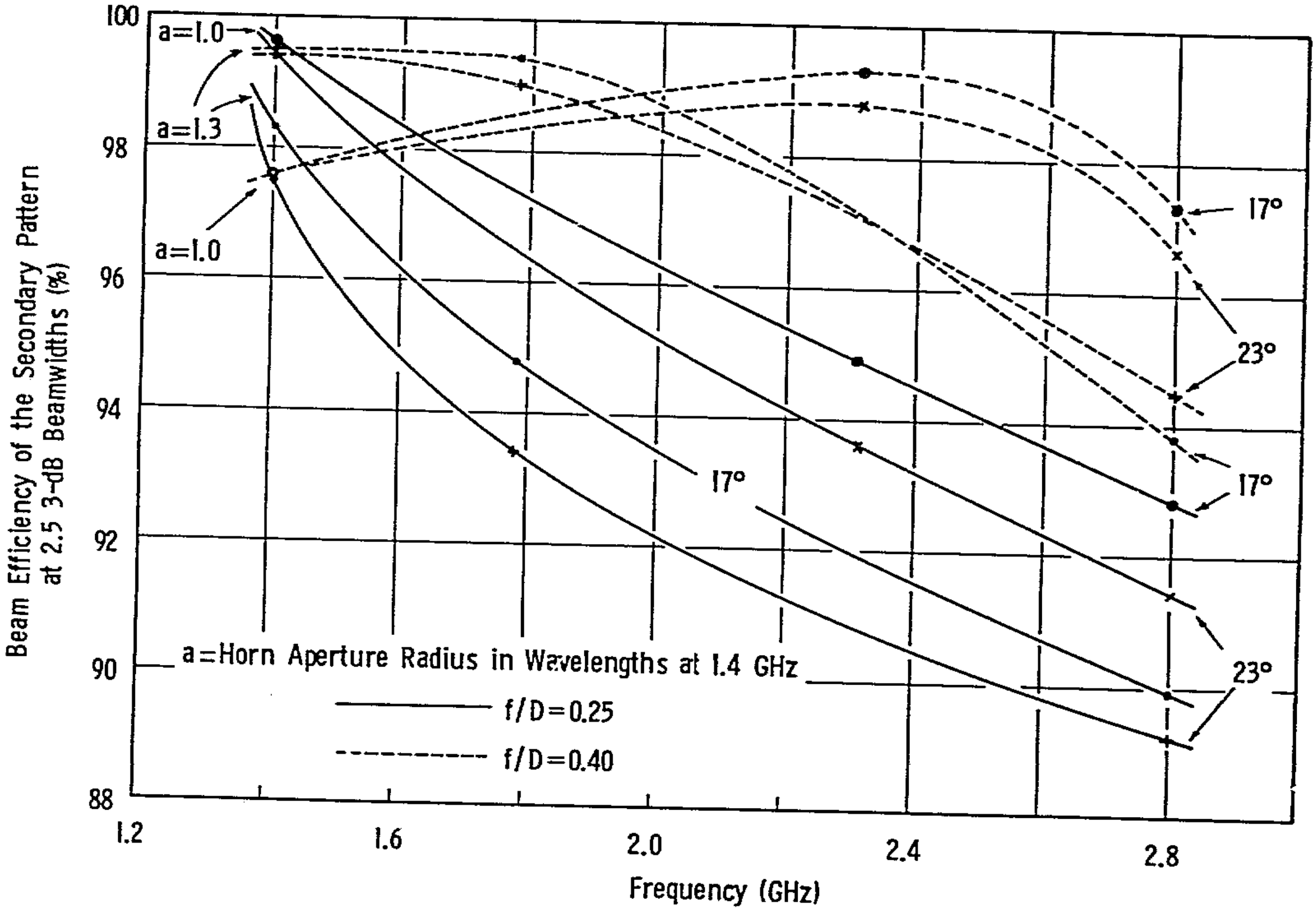


Figure 10 -- Beam Efficiency of the Secondary Pattern as a Function of the Operating Frequency

The beam efficiency of the secondary pattern discussed in the above paragraph, however, is not a performance index of the whole system because not all energy radiated from the horn strikes the reflector. Consequently, the overall beam efficiency is lower than shown in Figure 10. To incorporate the loss of the spilled over horn radiation, the beam efficiency of the secondary pattern must be multiplied by the ratio of the energy received by the reflector to the energy radiated by the horn. Such a ratio has been defined in section 2 as the beam efficiency of the feed. Thus, the overall beam efficiency of the system is calculated by carrying out a point by point multiplication of the beam efficiency of the secondary pattern (Figure 10) and the beam efficiency of the feed (Figure 3). The results of this multiplication are shown in Figure 11.

The overall beam efficiency data of Figure 11 still do not include the loss of energy in the cross polarized component. It is found that [5] for a cross polarization level of 22 dB below the copolarized, the power in cross polarized component is about 1.4% of the total power, the same at cross polarized level of 29 dB below the copolarized being only 0.6%. As a result for f/D = 0.25, the overall beam efficiency is about 1.4 to 1.1% less than the values shown in Figure 11 and for f/D = 0.4, the overall beam efficiency is about 0.8 to 0.6% less than values in Figure 11.

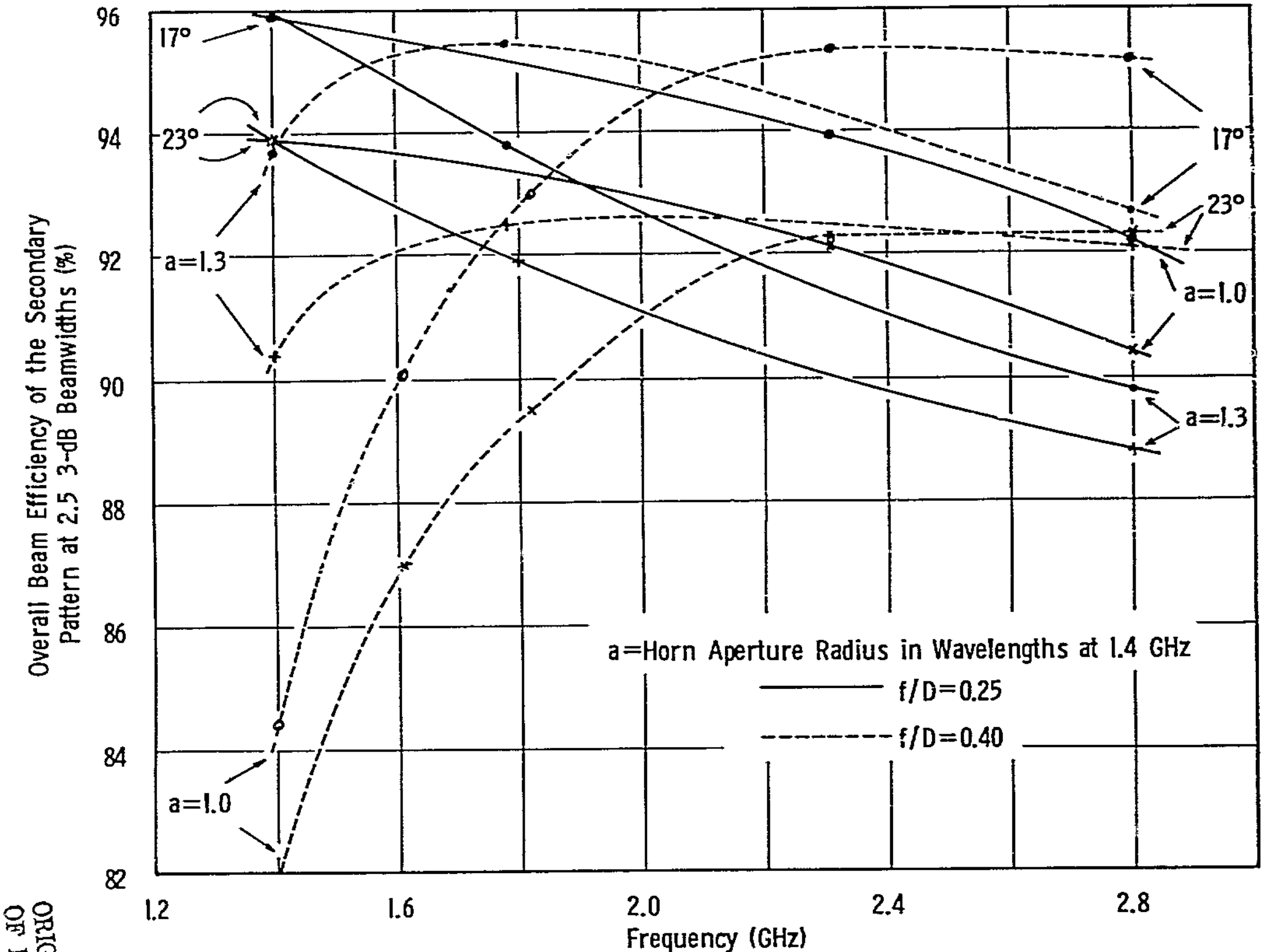


Figure 11 -- Overall Beam Efficiency of the Antenna System as a Function of the Operating Frequency

6. Conclusions and Remarks

Starting with a given size parabolic reflector which is fed in offset mode by a corrugated horn antenna located at the focus of the reflector, three performance indices viz., the half power beamwidth of the secondary pattern, the maximum cross polarized component level in the secondary pattern, and the overall beam efficiency have been calculated and plotted over a wide frequency band (1.4 to 2.8 GHz) for different physical horn dimensions and for different values of the f/D ratio. These data can be used to find the best design under given restrictions. Some important features of the optimization study presented here are as follows:

1. The performance over a full octave of operating frequency has been considered. If the requirements on the bandwidth were not so severe, a high gain feed with narrow bandwidth could be used to get better beamwidth and beam efficiency.

2. It is misleading to calculate the beam efficiency by considering the secondary pattern alone. The losses due to spill over must be included to calculate the overall beam efficiency. As pointed out in the last Section the true overall beam efficiency is found by multiplying the beam efficiency of the secondary pattern with the illumination efficiency of the feed horn at each frequency.

3. The study of the feed horn made here is all in terms of wavelengths. Therefore, with considerably less extra work, the results can be scaled to other frequency bands.

7. References

1. Chu, Ta-Shing, and Turrin, R. H., "Depolarization Properties of Offset Reflector Antennas", IEEE Trans. Antennas Propagat., Vol. AP-21, No. 3, May 1973, pp. 339-345.

2. Caldecott, R., Mentzer, C. A., Peters, L., and Toth, J., "High Performa[illegible] S-Band Horn Antennas for Radiometric Use," The Ohio State University ElectroScience Laboratory Report 3033-1, May 1972, pp. 4-9.

3. Thomas, B. MacA., "Design of Conical Corrugated Horns", IEEE Trans. Propagat., March 1978.

4. Kauffman, J. F., Croswell, W. F., and Jower, L. J., "Analysis of the Radiation Patterns of Reflector Antennas", IEEE Trans. Antennas Propagat., Vol. AP-24, No. 1, January 1976, pp. 52-65.

5. Caldecott, R., Mentzer, C. A., Peters, L., and Toth, J., "High Performance S-Band Horn Antennas for Radiometric Use," The Ohio State University ElectroScience Laboratory Report 3033-1, May 1972, pp. 67-77.

1. Report No.
NASA Technical Memorandum 78662

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
OPTIMIZATION OF THE DESIGN PARAMETERS FOR A WIDE-BAND RADIOMETRIC SYSTEM

5. Report Date
February 1978

6. Performing Organization Code

7. Author(s)
Pradeep K. Agrawal

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, VA 23665

10. Work Unit No.
750-01-23-04

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics & Space Administration
Washington, DC 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
The author is affiliated with the Joint Institute for Advancement of Flight Sciences, George Washington University, Hampton, VA 23665.

16. Abstract
The purpose of the study presented here is to find the optimun design parameters for a swept frequency wide-band radiometric antenna system for spacecraft applications. Wide-band antenna systems are needed to observe layered surfaces; e.g., ice, sea foam, etc. which are frequency sensitive and require multiple measurements for interpretation. The lowest frequency band of interest is between 1.4 to 2.8 Ghz. Starting with a given size reflector fed in the offset mode by a corrugated horn located at the focus of the parabola, the primary performance indicies; e.g., half power beamwidth, cross polarization level, and overall beam efficiency have been calculated over a wide frequency range (two to one) for different physical horn dimensions and for different values of f/D ratio. These data can be used to find the best design under given restrictions of reflector size and blockage.

17. Key Words (Suggested by Author(s))
Reflector antenna
Beam efficiency
Corrugated horn

18. Distribution Statement
Unclassified - Unlimited
Subject Category 07

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	22	$4.00

* For sale by the National Technical Information Service, Springfield Virginia 22161