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Technical Memorandum 80705

Multi-Mode Horn Antenna Simulation

(NASA-TM-80705) MULTI-MODE HORN ANTENNA
SIMULATION (NASA) 19 p HC A02/MF A01

N81-12298

CSCCL 20N

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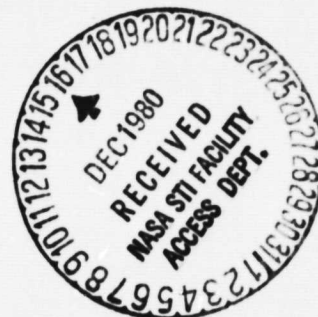
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MAY 1980

National Aeronautics and
Space Administration

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TM 80705

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MULTI-MODE HORN ANTENNA SIMULATION

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ABSTRACT

Radiation patterns have been computed for a circular multi-mode horn antenna using waveguide electric field radiation expressions. The circular multi-mode horn is being considered as a possible reflector feed antenna for the Large Antenna Multi-frequency Microwave Radiometer (LAMMR). This horn antenna uses a summation of the TE_{11}^o and TM_{11}^o modes to generate far field primary radiation patterns with equal E and H plane beamwidths and low sidelobes. A computer program for the radiation field expressions using the summation of waveguide radiation modes is described. The sensitivity of the multi-mode horn antenna radiation patterns to phase variations between the two modes is given. Sample radiation pattern calculations for a reflector feed horn for LAMMR are shown. The multi-mode horn antenna will provide a low-noise feed suitable for radiometric applications.

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MULTI-MODE HORN ANTENNA SIMULATION

INTRODUCTION

The multi-mode horn antenna is being considered as a feed antenna for an offset parabolic reflector for the Large Antenna Multifrequency Microwave Radiometer (LAMMR). A computer model for the radiation expressions of the multi-mode conical horn has been developed and is described in this memo. The computer model is based upon the electric field radiation expressions for the TE_{MN}° and TM_{MN}° modes as described in Silver (ref. 1). The computer model allows the summation of any number of modes, both TE_{MN}° and TM_{MN}° , with arbitrary phases and amplitude weighting. The special case of the dual mode conical horn (ref. 2) composed of TE_{11}° and TM_{11}° modes is modeled. Computed primary radiation patterns for the dual-mode horn demonstrate equal E and H plane beamwidths and low sidelobes.

MULTI-MODE HORN ANTENNA

The dual mode conical horn was first described by Potter in 1963 (ref. 2). Potter showed that the summation of the TE_{11}° and TM_{11}° modes in a conical horn produced improved radiation patterns over a single mode TE_{11}° horn. The radiation pattern improvements are: (1) equal E and H plane beamwidths, and (2) reduced E plane sidelobes. These improvements in the radiation characteristics are obtained by adding the E_θ components of the TE_{11}° and TM_{11}° modes in the E plane to broaden the E plane beamwidth and reduce the E plane sidelobes from -17dB to greater than -30dB. These improvements in the horn radiation patterns give low spillover when the horn is used as a reflector feed.

The radiated field components for the conical waveguide modes are given in Silver (ref. 1). The derivation of the radiation modes is based upon a modified Kirchoff formula initially derived by Chu (ref. 3). The derivation is based upon the radiation due to waveguide modes in cylindrical pipe. The coordinate system for the spherical electric field components, E_θ and E_ϕ are shown in Figure 1.

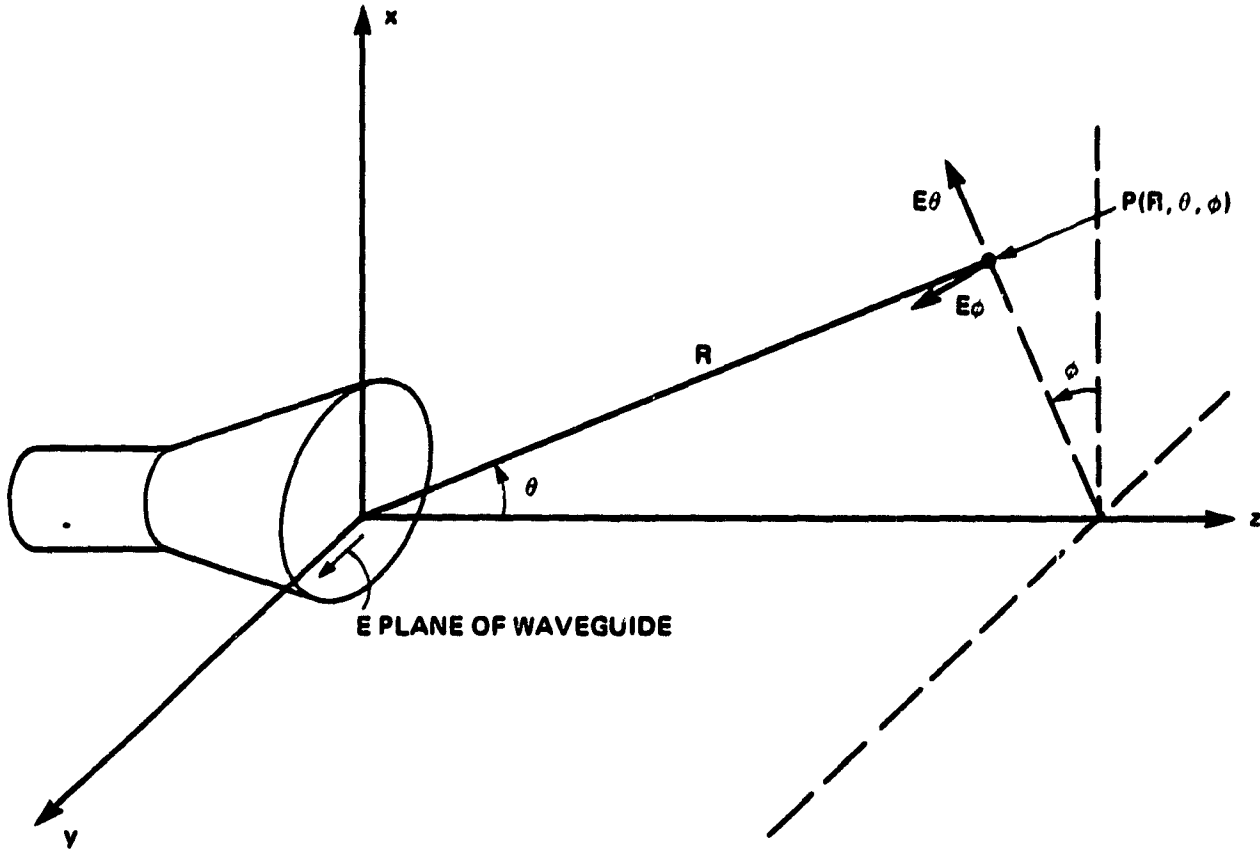


Figure 1. Antenna Geometry

The radiation electric fields due to a transverse electric (TE) waveguide mode in a circular aperture are:

TE_{MN}°

$$E_{\theta} = j^{m+1} \frac{mwu}{2R} \left[1 + \frac{\beta_{mn}}{k} \cos \theta + \Gamma \left(1 - \frac{\beta_{mn}}{k} \cos \theta \right) \right] J_m(k_{mn}a) \frac{J_m(k a \sin \theta)}{\sin \theta} \sin m\phi e^{-jkR} \quad (1)$$

$$E_{\phi} = j^{m+1} \frac{kawu}{2R} \left[\frac{\beta_{mn}}{k} + \cos \theta - \Gamma \left(\frac{\beta_{mn}}{k} - \cos \theta \right) \right] \frac{J_m(k_{mn}a) J'_m(k a \sin \theta)}{1 - \left(\frac{k \sin \theta}{k_{mn}} \right)^2} \cos m\phi e^{-jkR} \quad (2)$$

The radiation electric fields due to a transverse magnetic (TM) waveguide mode are:

TM_{MN}°

$$E_{\theta} = -j^{m+1} \frac{ka k_{mn}}{2R \sin \theta} \sin m\phi \left[\frac{\beta_{mn}}{k} + \cos \theta + \Gamma \left(\frac{\beta_{mn}}{k} - \cos \theta \right) \right] \frac{J_m(ka \sin \theta) J'_m(k_{mn}a)}{1 - \left(\frac{k_{mn}}{k \sin \theta} \right)^2} e^{-jkR} \quad (3)$$

$$E_{\phi} = 0$$

The TE_{11}° and TM_{11}° modes have the following form:

TE_{11}°

$$E_{\theta} = j^2 \frac{wu}{2R} \left[1 + \frac{\beta_{11}}{k} \cos \theta + \Gamma \left(1 - \frac{\beta_{11}}{k} \cos \theta \right) \right] J_1(k_{11}a) \frac{J_1(ka \sin \theta)}{\sin \theta} \sin \phi e^{-jkR} \quad (4)$$

$$E_{\phi} = j^2 \frac{kawu}{2R} \left[\frac{\beta_{11}}{k} + \cos \theta - \Gamma \left(\frac{\beta_{11}}{k} - \cos \theta \right) \right] \frac{J_1(k_{11}a) J'_1(ka \sin \theta) \cos \phi}{1 - \left(\frac{k \sin \theta}{k_{11}} \right)^2} e^{-jkR} \quad (5)$$

TM_{11}°

$$E_{\theta} = -j^2 \frac{ka k_{11}}{2R \sin \theta} \sin \phi \left[\frac{\beta_{11}}{k} + \cos \theta + \Gamma \left[\frac{\beta_{11}}{k} + \cos \theta + \Gamma \left(\frac{\beta_{11}}{k} - \cos \theta \right) \right] \right] \frac{J_1(ka \sin \theta) J'_1(k_{11}a)}{1 - \left(\frac{k_{11}}{k \sin \theta} \right)^2} e^{-jkR} \quad (6)$$

$$E_{\phi} = 0$$

where

$$j = \sqrt{-1}$$

m, n = mode numbers for waveguide

β_{mn} = phase constant for a given m, n waveguide mode

k = free space wave number

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- Γ = waveguide reflection coefficient
- R = distance from aperture center to far-field observer point
- θ, ϕ = spherical coordinate angles
- k_{mn} = electric or magnetic characteristic value
- a = radius of aperture
- ω = angular frequency = $2\pi f$
- μ = permeability

It should be noted that the expression (equation 13) given in Silver (ref. 1) for the E_θ component of the TM_{mn}° case has a typographical error which reads $\cos m\phi$ rather than $\sin m\phi$. If the equations (4) and (6) for the E_θ components of the TE_{11}° and TM_{11}° are added with proper amplitude the beam in the E plane will broaden to the same value as the H plane beamwidth and the E plane sidelobes will reduce. This pattern improvement for a dual mode horn over a conventional TE_{11}° conical horn will be shown in a following section for computed results of the program. The following section describes the computer program for the computation of the spherical field components.

COMPUTER MODEL

The radiation patterns for the TE_{11}° and TM_{11}° modes are simulated by a program named Prime Feed (ref. 4). The function of the program is to simulate the radiation electric fields on a spherical locus of observation for various types of antennas. The program can simulate single or multiple antennas with any number of waveguide modes. The following discussion will be limited to pattern simulation of cylindrical waveguide modes and will not treat other options of the Prime Feed program.

The program calculates the spherical E_θ and E_ϕ components of each electric field for a given waveguide mode and then does a summation of these components to produce the resultant field.

The TE_{11}° radiation fields, E_θ and E_ϕ , as given in equations (4) and (5) are modified by amplitude and phase multiplier terms so that the summation may be completed with any desired amplitude or phase difference between modes.

The TE_{11}° radiation fields, E_{θ} and E_{ϕ} , as given in equations (4) and (5) are modified in the program to yield

$$E_{\theta \text{comp.}} = S_1(E_{\theta}) e^{j\psi_0}$$

and

$$E_{\phi \text{comp.}} = S_1(E_{\phi}) e^{j\psi_0}$$

where S_1 = amplitude weighting function

and ψ_0 = phase angle

Similarly the TM_{11}° mode E_{θ} expression given in equation (6)

$$E_{\theta \text{comp.}} = S_0(E_{\theta}) e^{j\psi_0}$$

The flow chart for the circular waveguide subroutine of the Prime Feed Program is shown in Figure 2 and the flow chart for the far-field pattern computation is given in Figure 3. The inputs to the program are

m, n = mode order

TE, TM = mode type

κ_{mn} = mode characteristic value

κ = wave number

a = radius of aperture

Γ = reflection coefficient

The Bessel Functions in expressions (4), (5), and (6) are calculated in the computer program using the IBM Scientific Subroutine Package. Care must be taken however, when

$$ka \sin \theta = \kappa_{mn} a$$

because

$$\frac{J'_m(ka \sin \theta)}{1 - \left(\frac{k \sin \theta}{\kappa_{mn}}\right)^2} = \frac{0}{0}$$

for the TE mode because $J'_m(\kappa_{mn} a) = 0$.

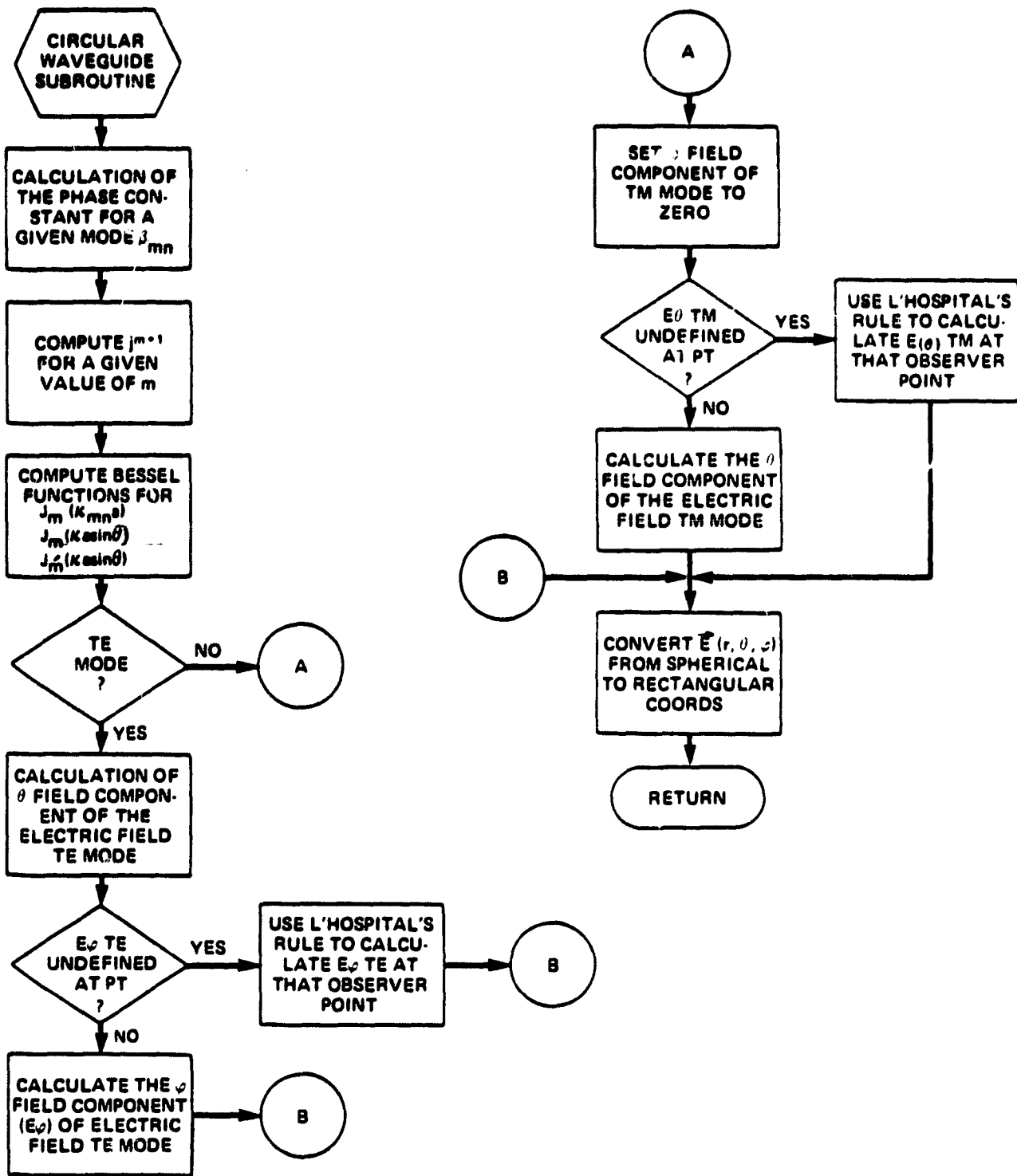
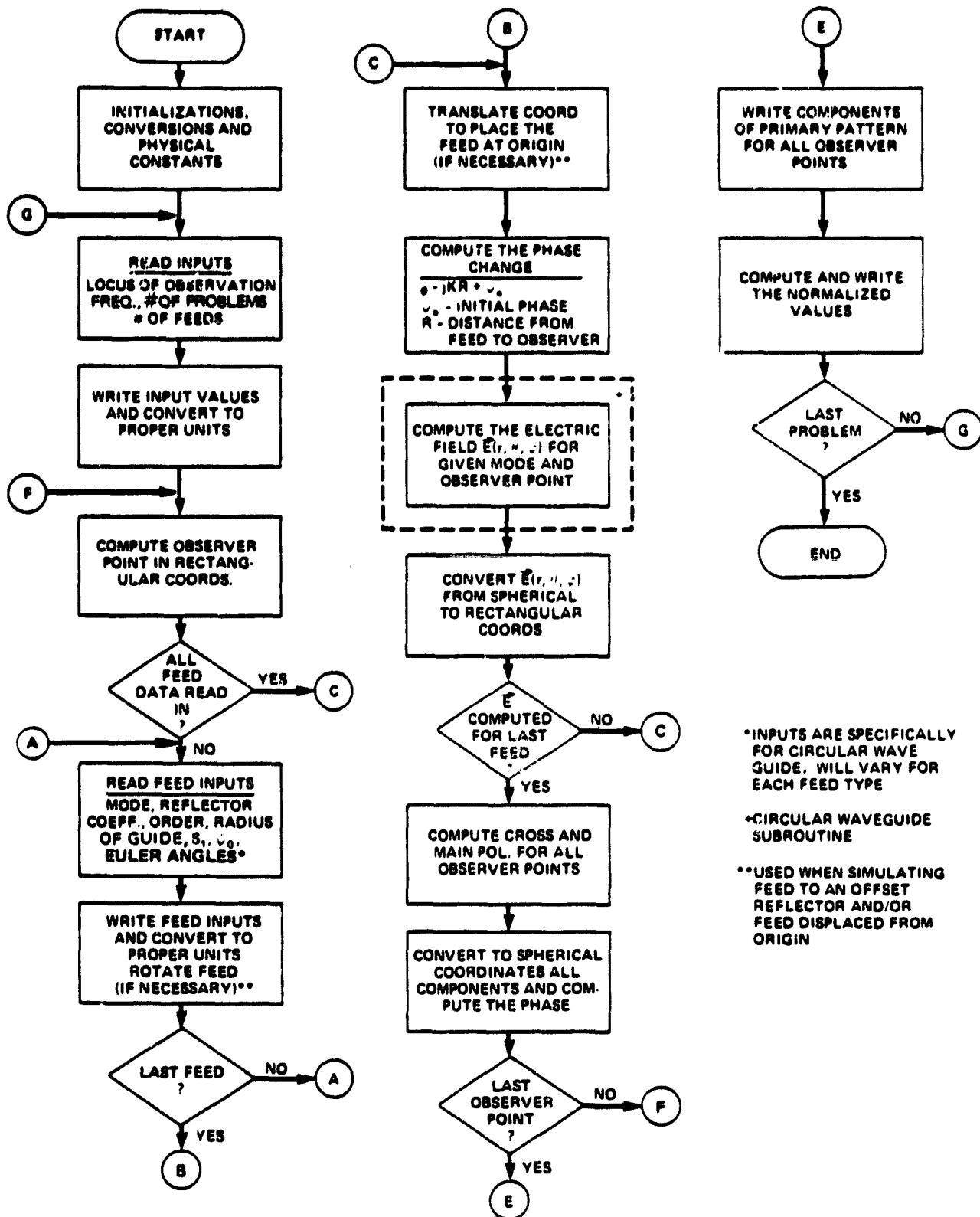


Figure 2



*INPUTS ARE SPECIFICALLY FOR CIRCULAR WAVE GUIDE. WILL VARY FOR EACH FEED TYPE

*CIRCULAR WAVEGUIDE SUBROUTINE

**USED WHEN SIMULATING FEED TO AN OFFSET REFLECTOR AND/OR FEED DISPLACED FROM ORIGIN

Figure 3

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and

$$\frac{J_m(ka \sin \theta)}{1 - \left(\frac{\kappa_{mn}}{k \sin \theta}\right)^2} = \frac{0}{0}$$

for the TM mode because $J_m(\kappa_{mn}a) = 0$ which makes E_ϕ for the TE mode and E_θ for the TM mode undefined at that observer point. This situation may be alleviated by applying L'Hospital's rule to the equations above and replacing them by the following:

$$\frac{m-1}{u} J_{m-1}(u) - \frac{mJ'_m(u)}{u} - \left(1 - \frac{1}{u^2}\right) J_m(u)$$

and

$$\frac{-\frac{m}{u} J_m(u) + J_{m-1}(u)}{\frac{2(\kappa_{mn}a)^2}{u^3}} \quad \text{where } u = ka \sin \theta$$

The functional flowchart in Figure 2 will provide an overall view of the way the field components are calculated.

RESULTS

Several computer runs were made for a TE_{11}° mode conical horn, a TM_{11}° mode simulation which shows the twin lobes of this mode in the E plane, and a dual mode horn that uses the TE_{11}° and TM_{11}° modes. The results of these computer runs are shown in Figures 4, 5, and 6. These figures show the $\theta - \phi$ contour plots of the radiation expressions for the electric fields given in equations 5, 6, and 7. The coordinate system is given in Figure 1. The radiation pattern contour plot in Figure 4 shows the TE_{11}° mode with narrow E plane beamwidth and high E plane sidelobes ($\phi = 90^\circ, 270^\circ$). The aperture diameter for this series of patterns is 2.5 wavelengths. Figure 5 shows a contour plot of a TM_{11}° mode with twin lobes occurring in the E plane. The addition of these two modes results in Figure 6 for the dual mode horn. This radiation pattern exhibits good circular symmetry and low sidelobes. Figure 7 shows the effects on the radiation

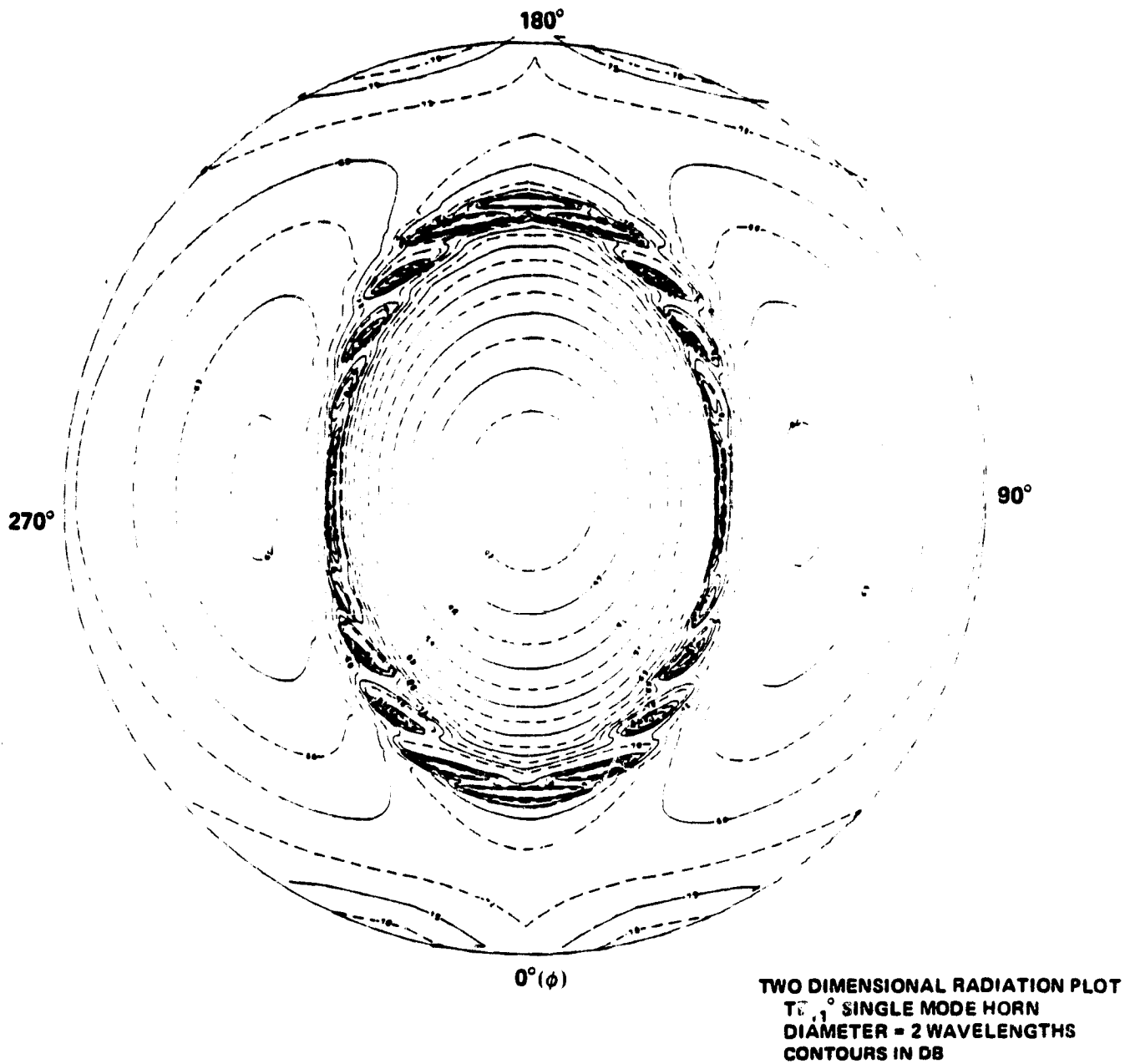


Figure 4

pattern for phase differences of 5° and 10° between the TE_{11} and TM_{11} modes. It can be seen that the radiation pattern is extremely sensitive to phase error and thus the dual mode antenna is limited in bandwidth as reported by Potter (ref. 2).

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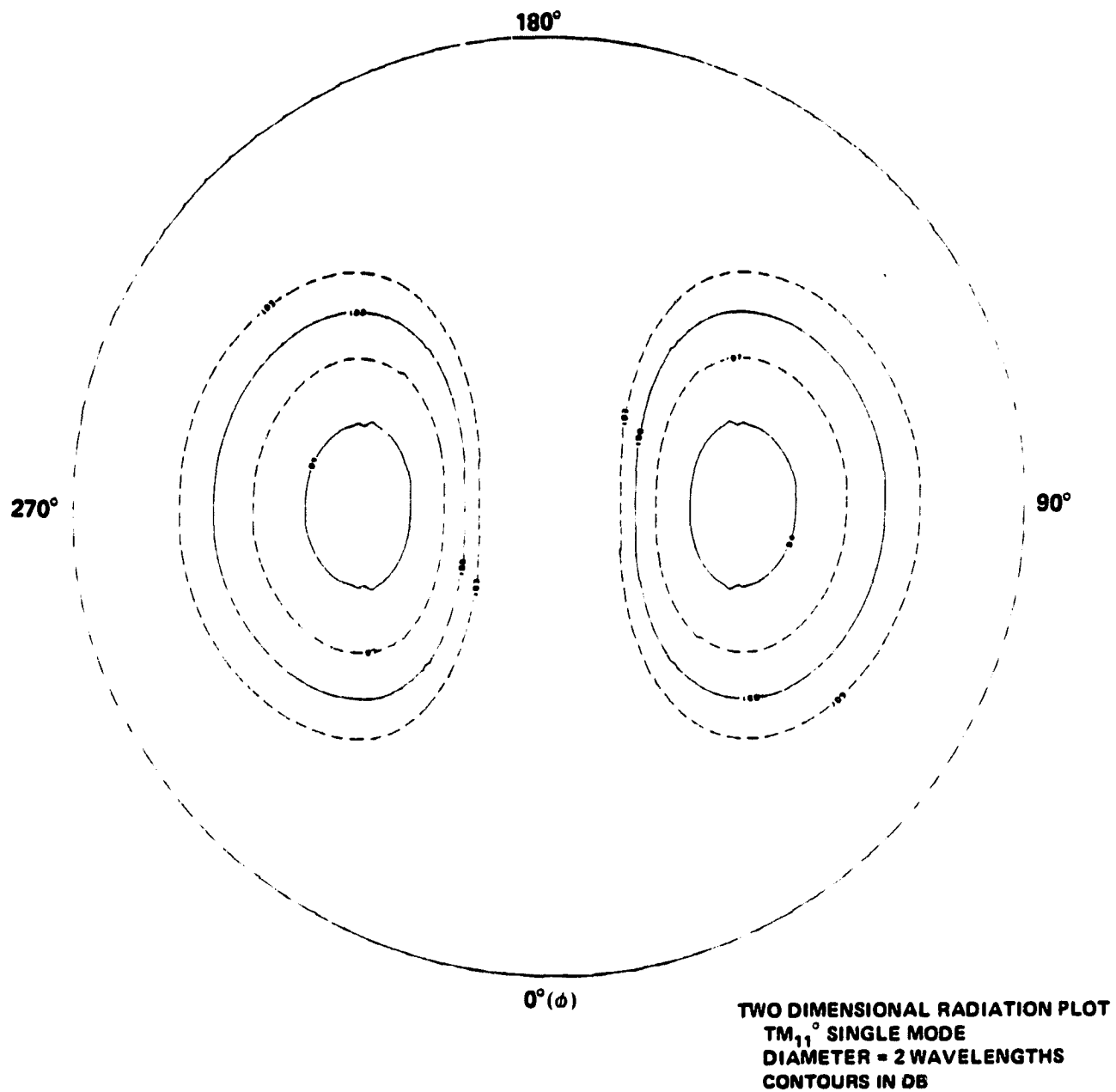


Figure 5

CONCLUSIONS

The dual mode horn antenna has been simulated for application as a feed for a microwave radiometer antenna. The antenna offers improved symmetry and lower sidelobes than a conventional single-mode TE_{11}° horn. Reduced spillover loss results when the dual mode horn antenna is used as a reflector feed. The bandwidth of the antenna is limited due to the amplitude

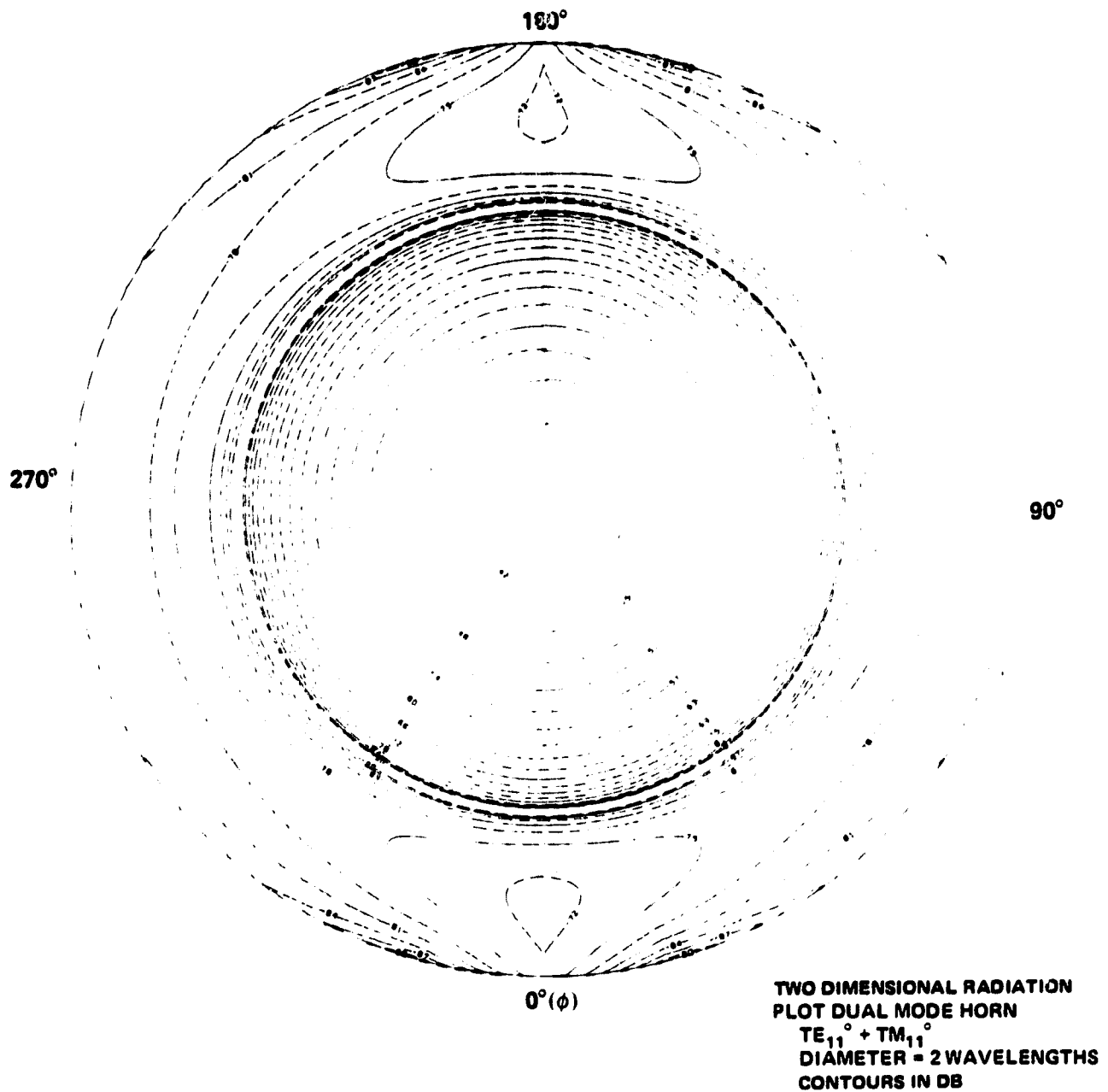


Figure 6

and phase sensitivity of the mode addition. Further work is proceeding on simulation of secondary radiation patterns of offset reflector antenna with dual-mode feeds.

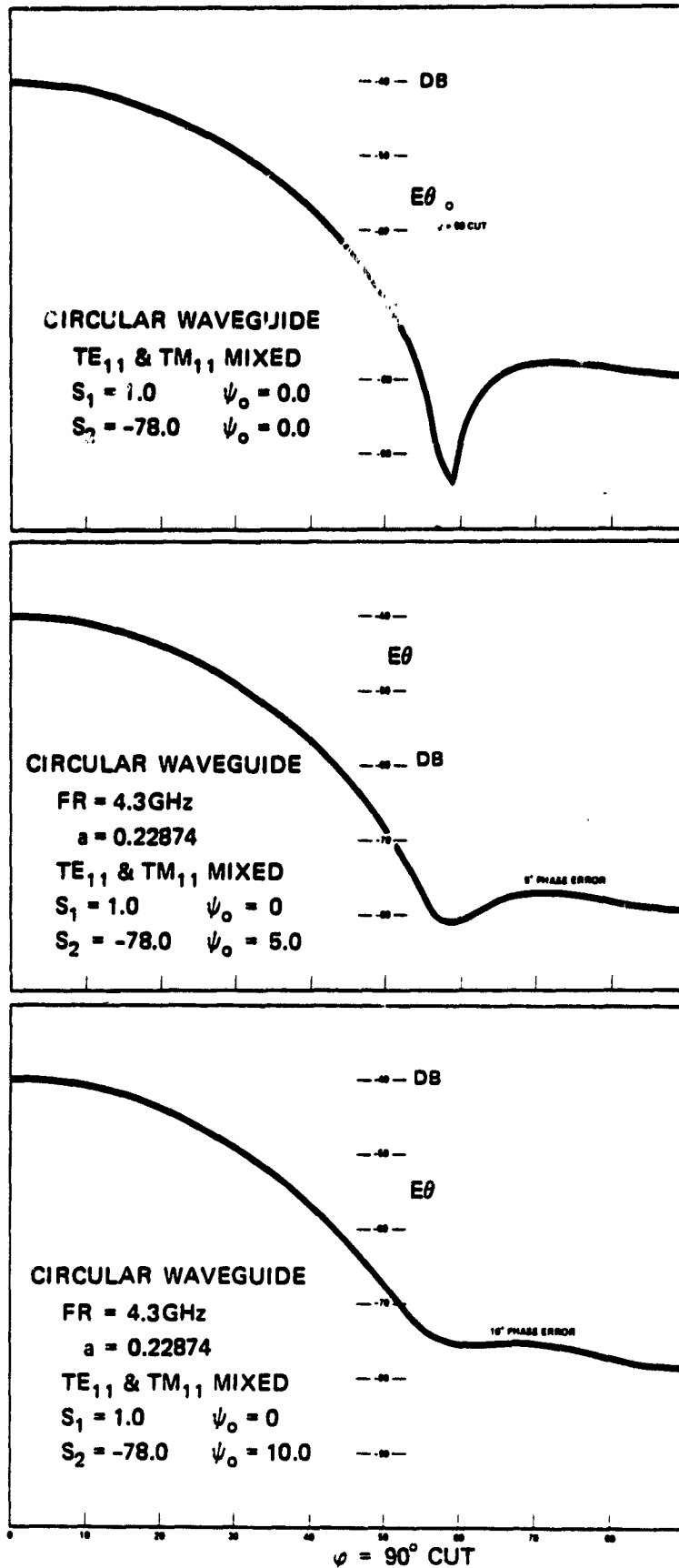


Figure 7. Dual Mode Horn, Diameter = 2 Wavelengths

ACKNOWLEDGMENTS

Our grateful acknowledgment to Richard F. Schmidt of Goddard for his guidance and advice on this problem. Also Ramon Miezis and Jack Healy of Sigma Data Services provided valuable comments and support for our effort.

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BIBLIOGRAPHIC DATA SHEET

1. Report No. TM 80705	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle MULTI-MODE HORN ANTENNA SIMULATION		5. Report Date May, 1980	
		6. Performing Organization Code 946.0	
7. Author(s) Louis R. Dod & Jane D. Wolf		8. Performing Organization Report No.	
9. Performing Organization Name and Address Microwave Sensors Branch Code 946		10. Work Unit No.	
		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address NASA Goddard Space Flight Center Greenbelt, Maryland 20771		14. Sponsoring Agency Code	
		15. Supplementary Notes	
16. Abstract <p style="margin: 0;">Radiation patterns have been computed for a circular multi-mode horn antenna using waveguide electric field radiation expressions. The circular multi-mode horn is being considered as a possible reflector feed antenna for the Large Antenna Multifrequency Microwave Radiometer (LAMMR). This horn antenna uses a summation of the TE_{11}° and TM_{11}° modes to generate far field primary radiation patterns with equal E and H plane beamwidths and low sidelobes. A computer program for the radiation field expressions using the summation of waveguide radiation modes is described. The sensitivity of the multi-mode horn antenna radiation patterns to phase variations between the two modes is given. Sample radiation pattern calculations for a reflector feed horn for LAMMR are shown. The multi-mode horn antenna will provide a low-noise feed suitable for radiometric applications.</p>			
17. Key Words (Selected by Author(s)) Microwave Antenna, Computer Simulation, Multi-Mode Horn Antenna		18. Distribution Statement	
19. Security Classif. (of this report) NC	20. Security Classif. (of this page)	21. No. of Pages	22. Price *