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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}° 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.

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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 $TE_{MN}{}^{\circ}$ and $TM_{MN}{}^{\circ}$ modes as described in Silver (ref. 1). The computer model allows the summation of any number of modes, both $TE_{MN}{}^{\circ}$ and $TM_{MN}{}^{\circ}$, with arbitrary phases and amplitude weighting. The special case of the dual mode conical horn (ref. 2) composed of $TE_{11}{}^{\circ}$ and $TM_{11}{}^{\circ}$ 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 $TE_{11}{}^{\circ}$ and $TM_{11}{}^{\circ}$ modes in a conical horn produced improved radiation patterns over a single mode $TE_{11}{}^{\circ}$ 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 $TE_{11}{}^{\circ}$ and $TM_{11}{}^{\circ}$ 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.

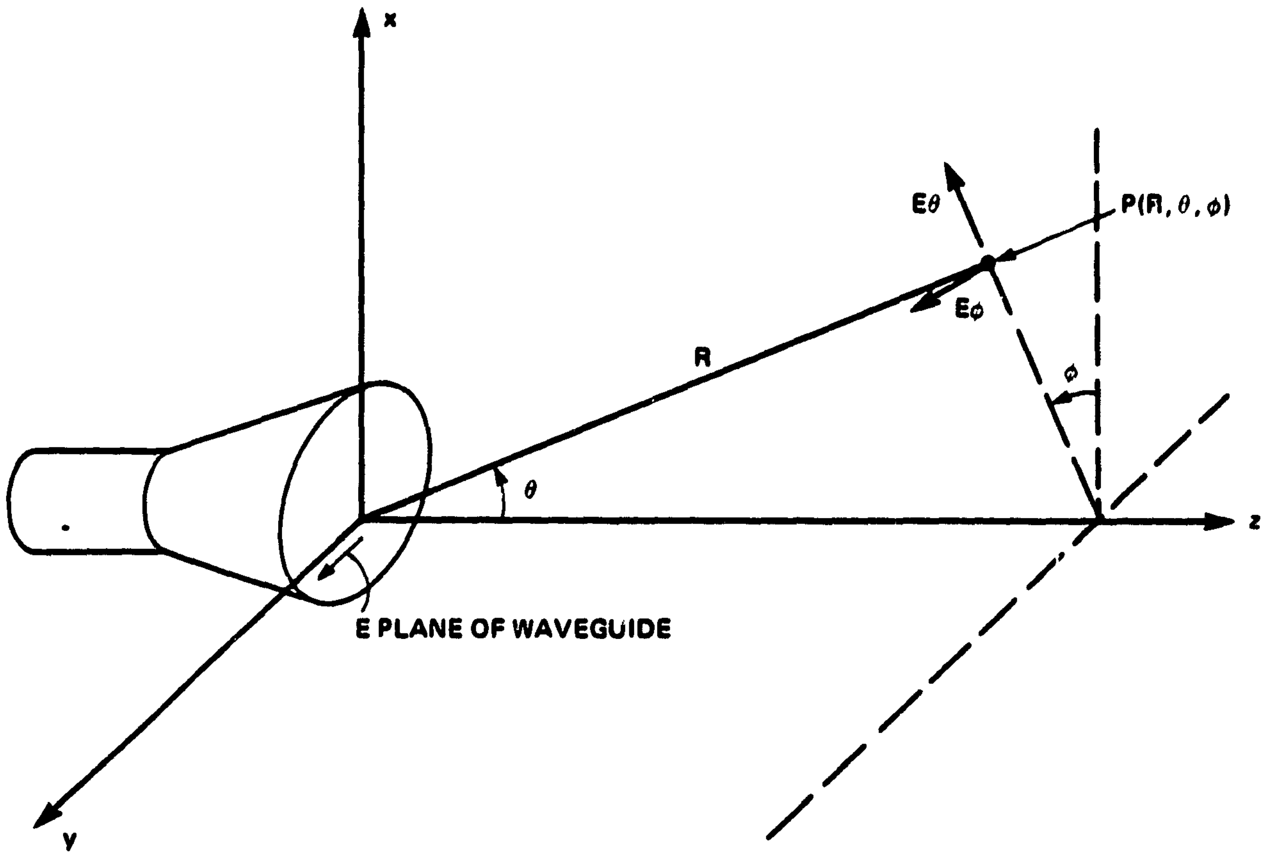


Figure 1. Antenna Geometry

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

$TE_{MN}°$

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

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

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

$TM_{MN}°$

$$E_\theta = -j^{m+1}\ \frac{ka\, k_{mn}}{2R \sin\theta}\ \sin m\phi \left[\frac{\beta_{mn}}{k} + \cos\theta + \Gamma\left(\frac{\beta_{mn}}{k} - \cos\theta\right)\right] \cdot$$

$$\frac{J_m\ (ka \sin\theta)\ J_m'\ (k_{mn} a)}{1 - \left(\frac{k_{mn}}{k \sin\theta}\right)^2}\ e^{-jkR} \qquad (3)$$

$$E_\phi = 0$$

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

$TE_{11}°$

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

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

$TM_{11}°$

$$E_\theta = -j^2\ \frac{ka\, k_{11}}{2R \sin\theta}\ \sin\phi\left[\frac{\beta_{11}}{k} + \cos\theta + \Gamma\left[\frac{\beta_{11}}{k} + \cos\theta + \Gamma\left(\frac{\beta_{11}}{k} - \cos\theta\right)\right]\right] \cdot$$

$$\frac{J_1 (ka \sin\theta)\ J_1' (k_{11} a)}{1 - \left(\frac{k_{11}}{k \sin\theta}\right)^2}\ e^{-jkR} \qquad (6)$$

$$E_\phi = 0$$

where

ORIGINAL PAGE IS OF POOR QUALITY

$j = \sqrt{-1}$

m, n = mode numbers for waveguide

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

k = free space wave number

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

$$E_{\theta comp.} = S_1 [E_\theta] \, e^{j\psi_o}$$

and

$$E_{\phi comp.} = S_1 [E_\phi] \, e^{j\psi_o}$$

where S_1 = amplitude weighting function

and ψ_o = phase angle

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

$$E_{\theta comp.} = S_o [E_\theta] \, e^{j\psi_o}$$

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

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

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

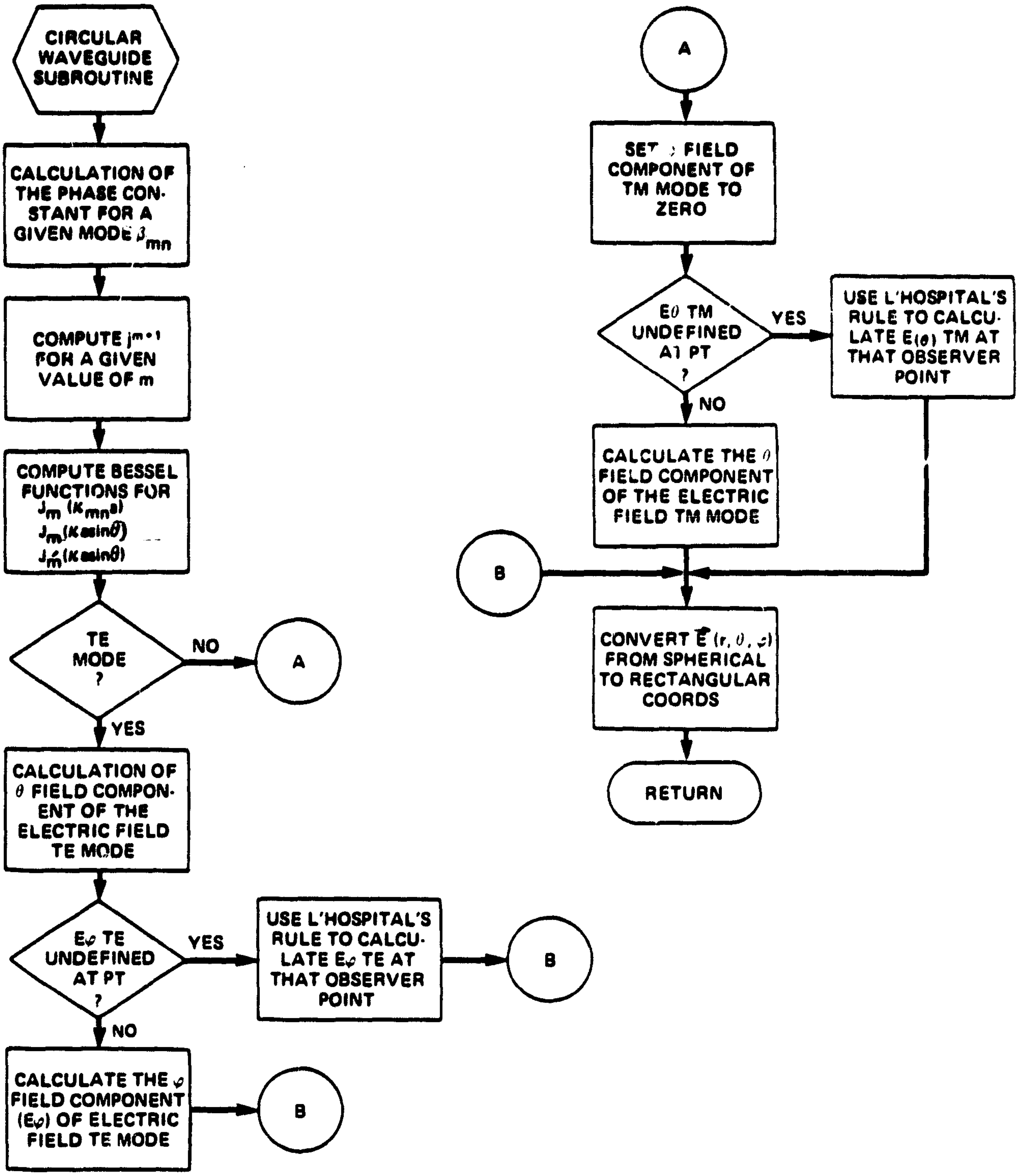

CIRCULAR WAVEGUIDE SUBROUTINE
CALCULATION OF THE PHASE CONSTANT FOR A GIVEN MODE β_{mn}
COMPUTE j^{m+1} FOR A GIVEN VALUE OF m
COMPUTE BESSEL FUNCTIONS FOR $J_m(K_{mn}a)$ $J_m(Ka\sin\theta)$ $J_m'(Ka\sin\theta)$
TE MODE ?
NO
A
YES
CALCULATION OF θ FIELD COMPONENT OF THE ELECTRIC FIELD TE MODE
E_φ TE UNDEFINED AT PT ?
YES
USE L'HOSPITAL'S RULE TO CALCULATE E_φ TE AT THAT OBSERVER POINT
B
NO
CALCULATE THE φ FIELD COMPONENT (E_φ) OF ELECTRIC FIELD TE MODE
B
A
SET φ FIELD COMPONENT OF TM MODE TO ZERO
$E\theta$ TM UNDEFINED AT PT ?
YES
USE L'HOSPITAL'S RULE TO CALCULATE $E_{(\theta)}$ TM AT THAT OBSERVER POINT
NO
CALCULATE THE θ FIELD COMPONENT OF THE ELECTRIC FIELD TM MODE
B
CONVERT $\vec{E}(r, \theta, \varphi)$ FROM SPHERICAL TO RECTANGULAR COORDS
RETURN

Figure 2

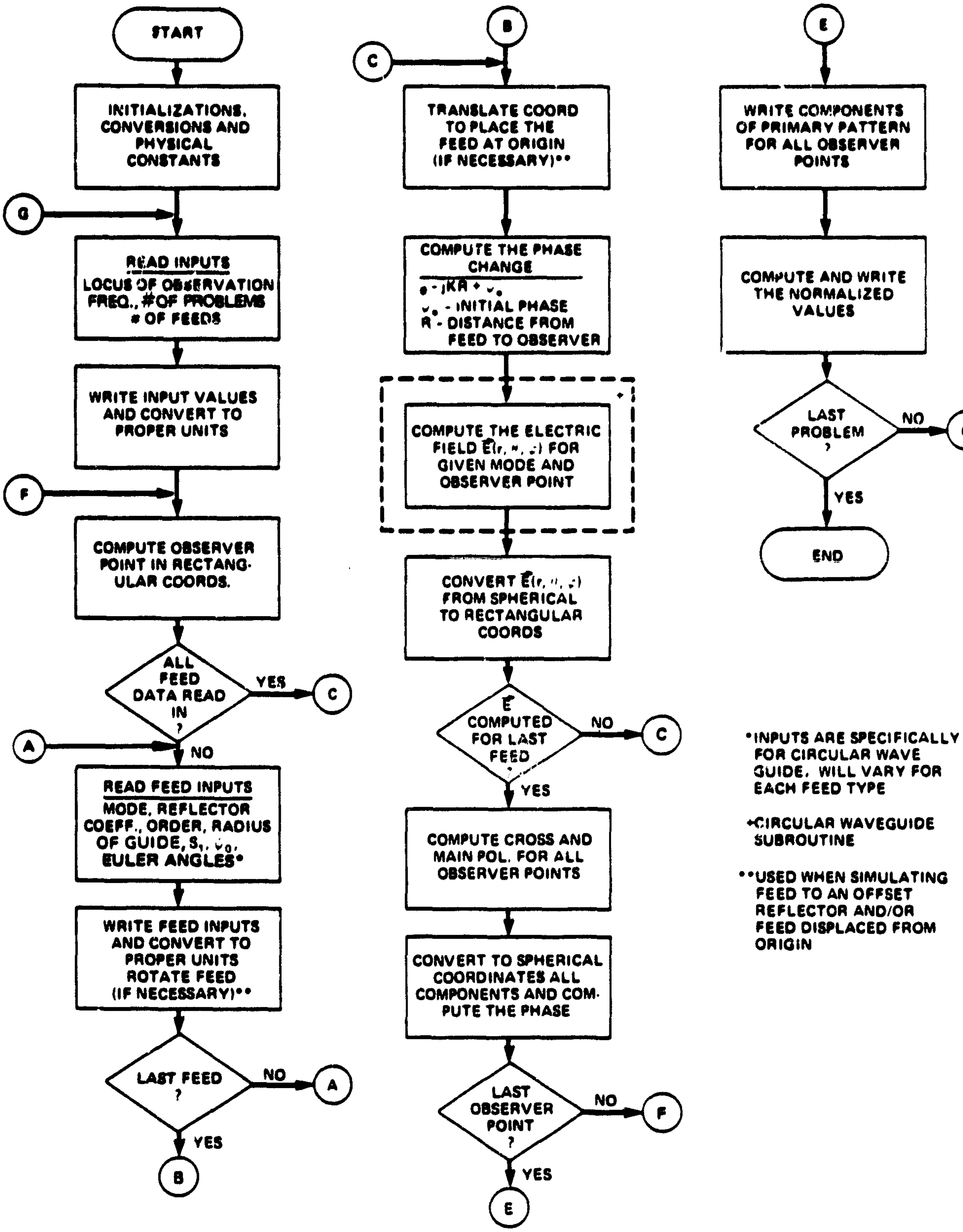

START
INITIALIZATIONS, CONVERSIONS AND PHYSICAL CONSTANTS
G
READ INPUTS
LOCUS OF OBSERVATION FREQ., # OF PROBLEMS # OF FEEDS
WRITE INPUT VALUES AND CONVERT TO PROPER UNITS
F
COMPUTE OBSERVER POINT IN RECTANGULAR COORDS.
ALL FEED DATA READ IN ?
YES
C
A
NO
READ FEED INPUTS
MODE, REFLECTOR COEFF., ORDER, RADIUS OF GUIDE, EULER ANGLES*
WRITE FEED INPUTS AND CONVERT TO PROPER UNITS ROTATE FEED (IF NECESSARY)**
LAST FEED ?
NO
A
YES
B
B
C
TRANSLATE COORD TO PLACE THE FEED AT ORIGIN (IF NECESSARY)**
COMPUTE THE PHASE CHANGE
- INITIAL PHASE
R - DISTANCE FROM FEED TO OBSERVER
+
COMPUTE THE ELECTRIC FIELD FOR GIVEN MODE AND OBSERVER POINT
CONVERT FROM SPHERICAL TO RECTANGULAR COORDS
COMPUTED FOR LAST FEED
NO
C
YES
COMPUTE CROSS AND MAIN POL. FOR ALL OBSERVER POINTS
CONVERT TO SPHERICAL COORDINATES ALL COMPONENTS AND COMPUTE THE PHASE
LAST OBSERVER POINT ?
NO
F
YES
E
E
WRITE COMPONENTS OF PRIMARY PATTERN FOR ALL OBSERVER POINTS
COMPUTE AND WRITE THE NORMALIZED VALUES
LAST PROBLEM ?
NO
G
YES
END
*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

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:

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

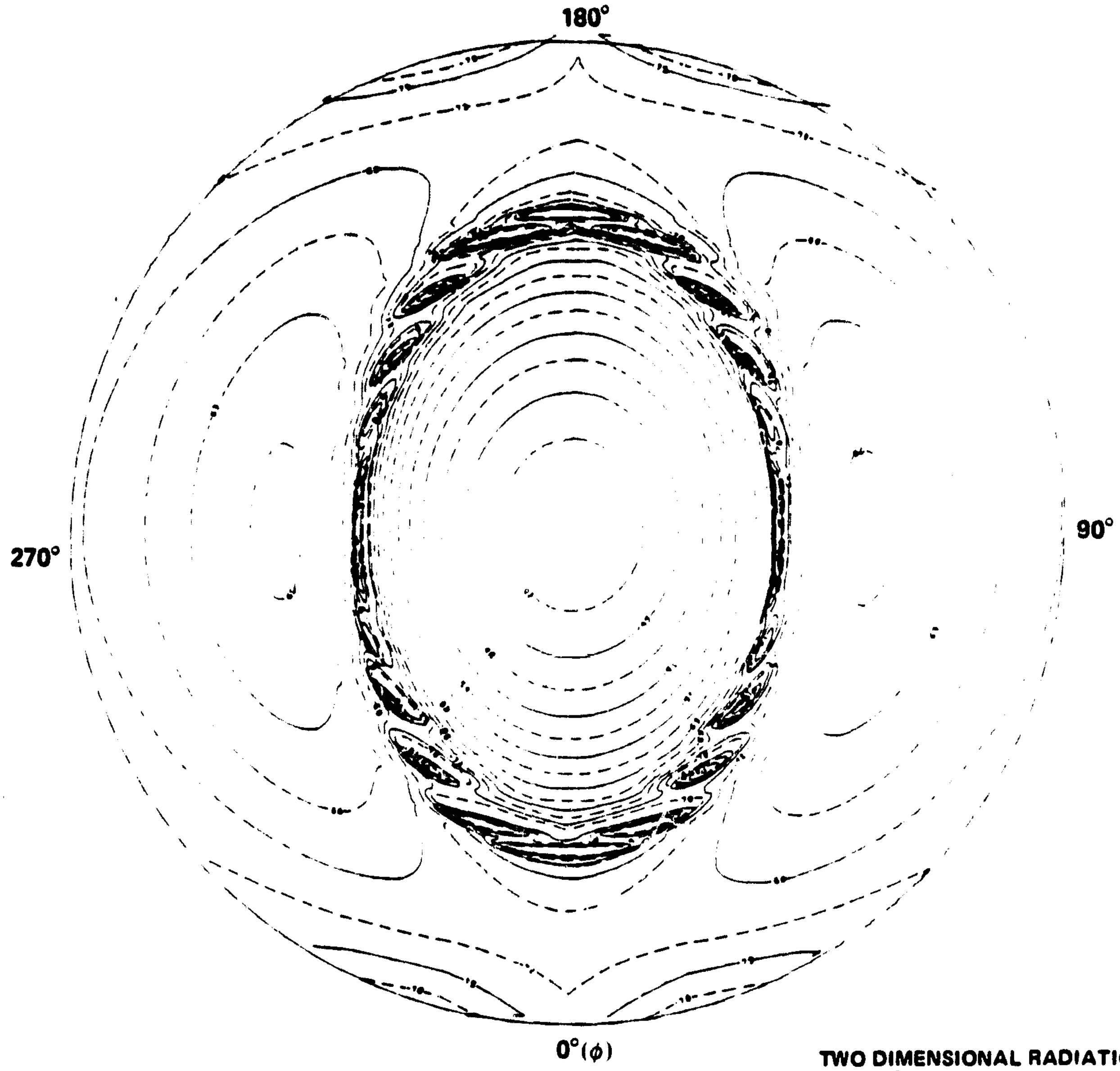
and

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

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

RESULTS

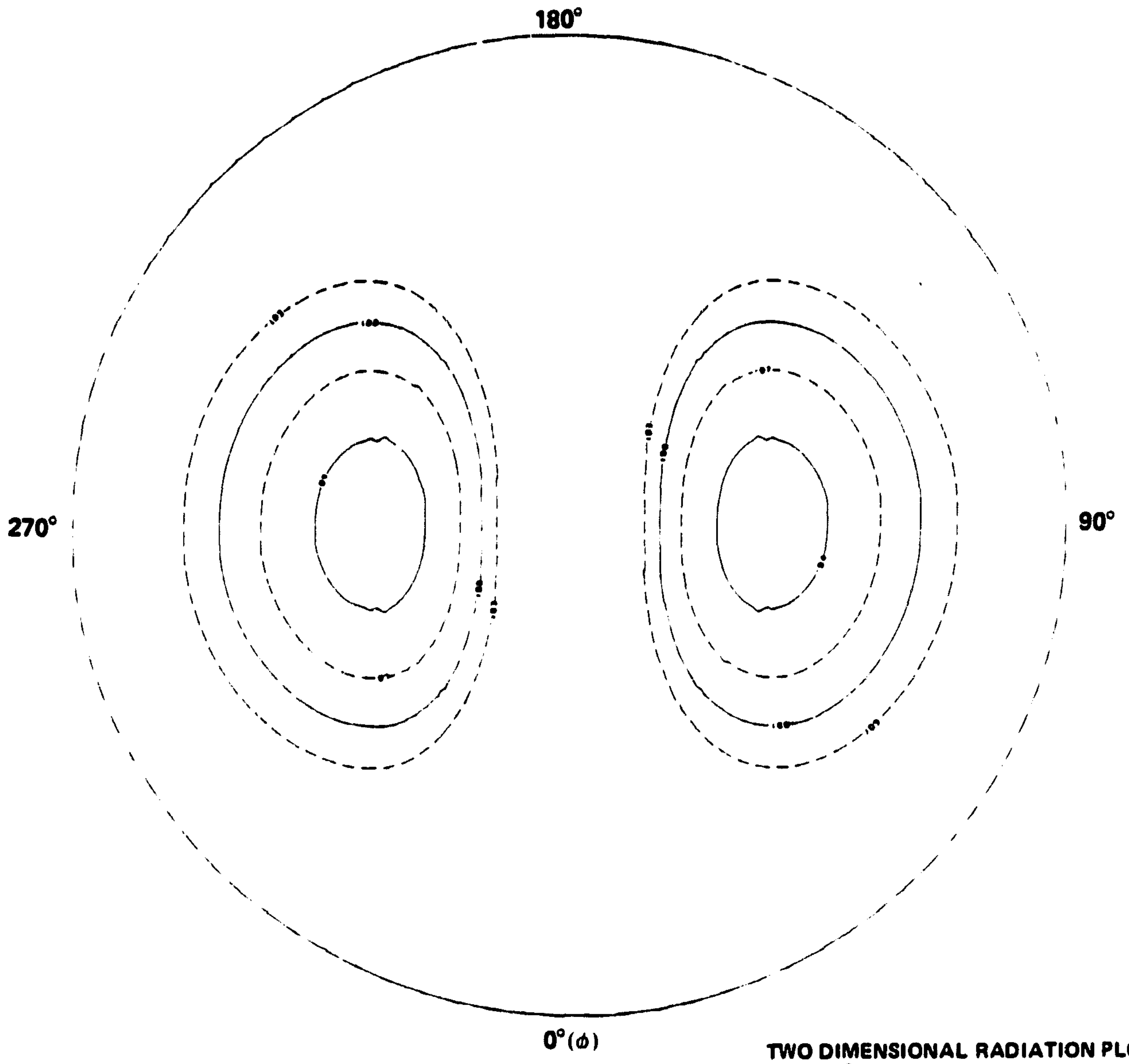
Several computer runs were made for a $TE_{11}°$ mode conical horn, a $TM_{11}°$ mode simulation which shows the twin lobes of this mode in the E plane, and a dual mode horn that uses the $TE_{11}°$ and $TM_{11}°$ modes. The results of these computer runs are shown in Figures 4, 5, and 6. These figures show the θ-ϕ 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 ($\phi = 90°, 270°$). 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



TWO DIMENSIONAL RADIATION PLOT
TE_{11}° SINGLE MODE HORN
DIAMETER = 2 WAVELENGTHS
CONTOURS IN DB

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).



TWO DIMENSIONAL RADIATION PLOT
$TM_{11}°$ SINGLE MODE
DIAMETER = 2 WAVELENGTHS
CONTOURS IN DB

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

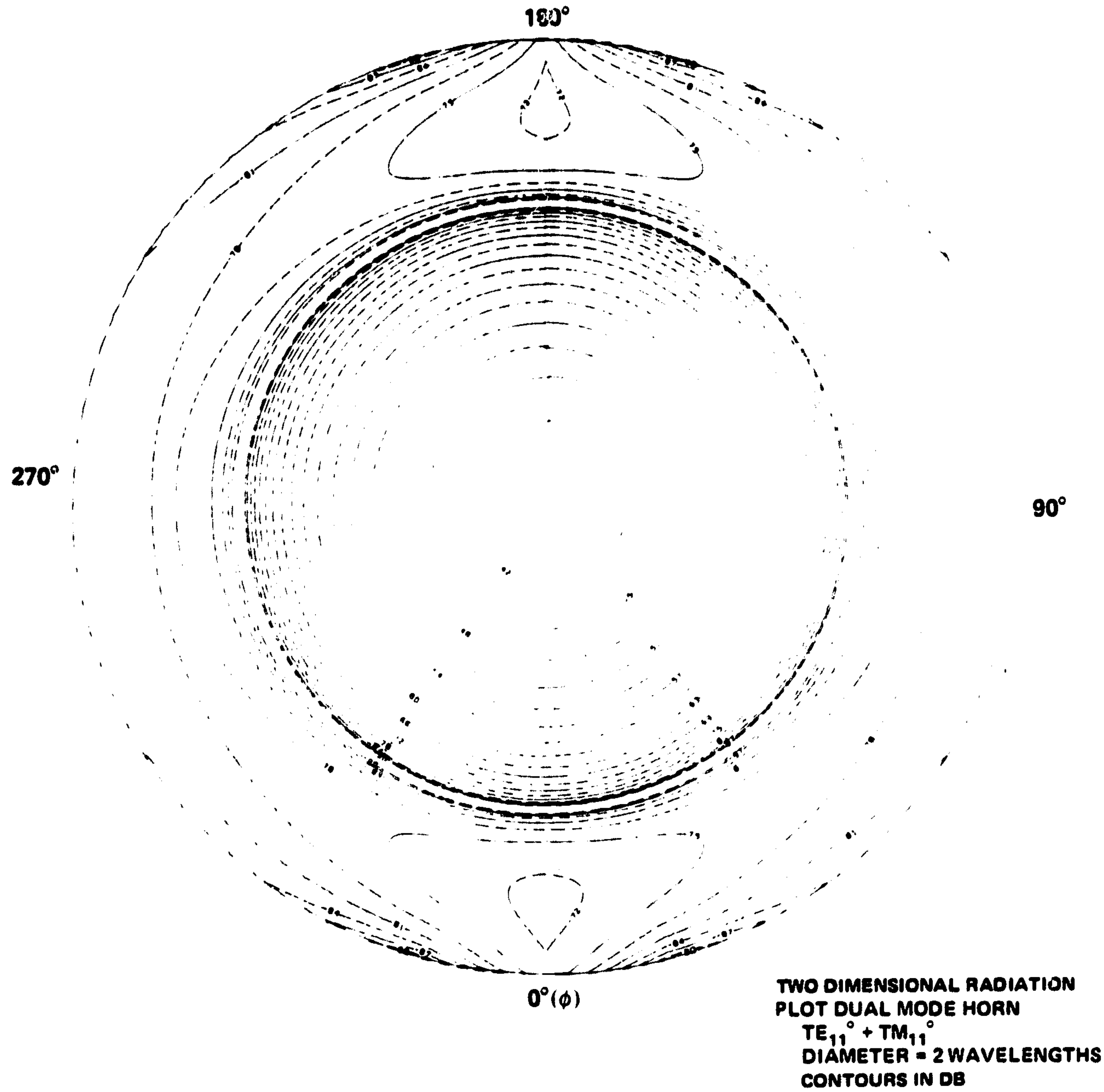


Figure 6

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.

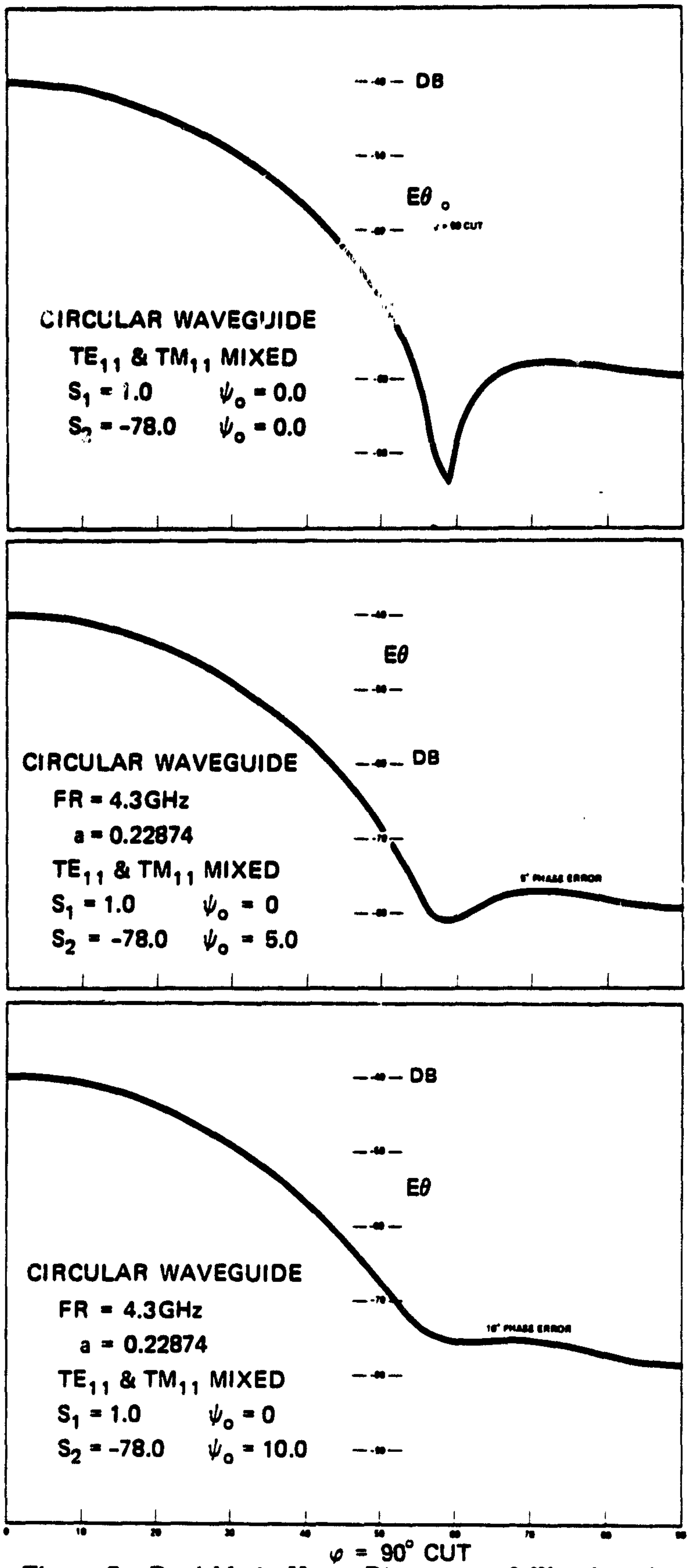


Figure 7. Dual Mode Horn, Diameter = 2 Wavelengths

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2. Potter, P. D., "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," Microwave Journal, Vol. VI, pp. 71–78, June, 1963.

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BIBLIOGRAPHIC DATA SHEET

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15. Supplementary Notes

16. 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 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.

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