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Antennas of Circular Waveguides

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***Abstract*—The design of the circular waveguide antenna is proposed for displacement reflector antennas. For them, we use the frequencies of operation so that our waveguide generates the mode, (Transversal Electric), resulting in a high impedance bandwidth. The results obtained from the radiation pattern of the fabricated antenna give excellent results according to the numerical data. Used as a primary feed-in compensation, reflector decreases cross-polarization.**

Keywords—Circular waveguide antenna; mode; microwave oven

I. INTRODUCTION

The circular waveguide antenna is a conductive cylinder, through which the electromagnetic waves are transferred, radiating within it. The waveguides operate in the frequency range of (300 MHz and 30 GHz), being its manufacture mostly of metallic components. The transmission of signals in waveguides reduces the dissipation of energy. The signal goes along the guide, limiting its borders. Also, to no loss in the dielectric, because this is air. They are most often used in equipment such as radars, which need a rotating antenna and microwave.

The article shows a circular waveguide mode TE_{11}, as seen in Fig. 1. The antenna designed in the mode TE_{11}, that produces a cutoff frequency f_c, on which the antenna will operate. The first and second index of the modes refers to the azimuthal and radial variations, respectively. The simulated and measured results are finalized by comparing, demonstrating an excellent agreement. The numerical results are carried through the Ansoft HFSS program. The presented antenna is very compact, and the mode TE_{11} it reduces cross-polarization, being able to be used in reflecting antennas. This situation is so because the mode cancels or minimizes cross-polarization [1].

II. METHODOLOGY

The geometry of the circular waveguide antenna is shown in Fig. 1. The desired operating mode is the TE_{11}. The desired radius is r = 14mm, the distance between the dielectric and the metal is th = 2mm, the length of the waveguide is L = 70mm to meet the criteria of the cutoff frequency f_c 6.3 GHz. To simplify the understanding of each mode in the far field region, formulas are used, which will be mentioned below.

A. Equations

The circular waveguides are used in waveguides, which are a hollow conductor, which is filled with a dielectric material. The solution of the wave equation in cylindrical coordinates, for electric and magnetic fields, is done with maxwell equations for variable fields in time [2]:

$$\vec{\nabla} x \vec{H} = j\omega e\vec{E} \tag{1}$$

$$\vec{\nabla} x \vec{E} = -j\omega\mu\vec{H} \tag{2}$$

$$\nabla^2\vec{H} = \gamma^2\vec{H} \tag{3}$$

$$\nabla^2\vec{E} = \gamma^2\vec{E} \tag{4}$$

One uses equations 3 and 4, and one gets the Laplacian wave function [3]:

$$\nabla^2\psi = \gamma^2\psi \tag{5}$$

From where one obtains the Helmholtz scalar equation in cylindrical coordinates to solve it by the method of separation of variables [4]:

$$\psi = \psi(r,\phi,z) \tag{6}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\psi}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2\psi}{\partial\phi^2}+\frac{\partial^2\psi}{\partial z^2}=\gamma^2\psi \tag{7}$$

One simplifies by separating variables:

$$\Psi = R(r)\Phi(\phi)Z(z) \tag{8}$$

Substitute in z and divide in equation (7) for the functionψ, resulting:

$$\frac{1}{rR}\frac{d}{dr}\left(r\frac{dR}{dr}\right)+\frac{1}{r^2\Phi}\frac{d^2\Phi}{d\phi^2}+\frac{1}{Z}\frac{d^2Z}{dz^2}=\gamma^2 \tag{9}$$

Being the sum of the terms in terms of z:

$$\frac{d^2Z}{dz^2}=\gamma^2 z \tag{10}$$

Being γ^2, the propagation constant in air, being the solution of the homogeneous linear partial differential equation:

$$Z(z)=Ae^{-\gamma_g z}+Be^{\gamma_g z} \tag{11}$$

One replaces equation (8) in (9):

$$\frac{r}{R}\frac{d}{dr}\left(r\frac{dR}{dr}\right)+\frac{1}{\Phi}\frac{d^2\Phi}{d\phi^2}-\left(\gamma^2-\gamma_g^2\right)r^2=0 \tag{12}$$

Now one operates according to z:

$$\frac{\partial^2\Phi}{\partial\phi^2}=-k_\phi^2\Phi \tag{13}$$

Being your solution:

$$\Phi(\phi)=A\sin(k_\phi\phi)+B\cos(k_\phi\phi) \tag{14}$$

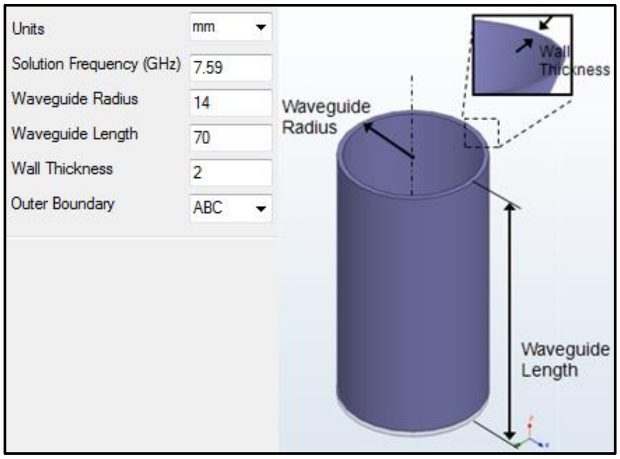
Units mm
Solution Frequency (GHz) 7.59
Waveguide Radius 14
Waveguide Length 70
Wall Thickness 2
Outer Boundary ABC

Fig. 1. Geometry of the Antenna Operating in Mode TE_{11}.

One replaces in the equation (8):

$$r\frac{d}{dr}\left(r\frac{dR}{dr}\right)+\left[(k_c r)^2-k_\phi^2\right]R=0 \qquad (15)$$

Equation (13) is a Bessel equation, where one has the cutoff wave number:

$$k_c^2=k^2-\beta^2 \qquad (16)$$

Being the constant of propagation in the air:

$$\beta^2=\pm\sqrt{\omega^2\mu\varepsilon-k_c^2} \qquad (17)$$

$$\gamma_g=\alpha_g+j\beta_g \qquad (18)$$

Being the function of Bessel in function of R (r):

$$R(r)=C.J_n(k_c r)+D.Y_n(k_c r) \qquad (19)$$

So $J_n(x)$ y $Y_n(x)$, are functions of bessel of first and second class of order n, being of the longitudinal magnetic field formed by the multiplication of R (r) and $\Phi(\phi)$, however, we do not use the second-class Bessel function, because when evaluated at the origin it takes an infinite value, because it does not reflect the electromagnetic field at the origin of the waveguide [5]:

$$\psi(r,\phi)=\left(A\sin(k_\phi\phi)+B\cos(k_\phi\phi)\right)J_n(k_c r) \qquad (20)$$

Evaluating the electric field direction of ϕ when r = a:

$$\left(E_\phi(r,\phi)|_{r=a}\right)=0 \qquad (21)$$

In order for this condition to be fulfilled, a cut wave number will be chosen that causes the derivative of the Bessel function to be canceled, so that there is a zero of the function when r = a. We will find this cut wave number, from the radius of the circular waveguide and also the cutoff frequency [5]:

$$k_c=\frac{\Phi'_{nm}}{a} \qquad (22)$$

n: It's the order of Bessel's function

m: Ordinal number of zeros of the Bessel function

Being the cutting frequency of the circular waveguide:

$$f_{c_{nm}}=\frac{k_c}{2\pi a\sqrt{\mu\varepsilon}} \qquad (23)$$

$$\beta_{nm}=\sqrt{k^2-k_c^2} \qquad (24)$$

The impedance of the wave is [5]:

$$Z_{TE}=\frac{E_x}{H_y}=\frac{k\eta}{\beta} \qquad (25)$$

B. *Operation Tables*

Below are the tables for the operating modes of our circular waveguide.

The first four first-class Bessel Functions are shown in Fig. 2, as mentioned in the second-class or Newman functions because it tends to infinity, and one will only be left with the first-class Bessel function J_n, of the graph [6].

The oscillation of Bessel's functions allows tabulating the arguments for which they are worth zero, that is, when the axis of the abscissa is crossed. These roots give rise to the frame for the Transversal Electric TE and Transversal Magnetic TM [7], modes shown in Table I and Table II, respectively.

For the handling of circular waveguides, standards such as the IEC system (Electronic Industry Association, United States) have been established, classifying the guides with letter C followed by a number, Table III provides data on these standards, such as Cutoff frequency of operating modes, such as hypothetical levels of dominant mode attenuation, for a reference frequency.

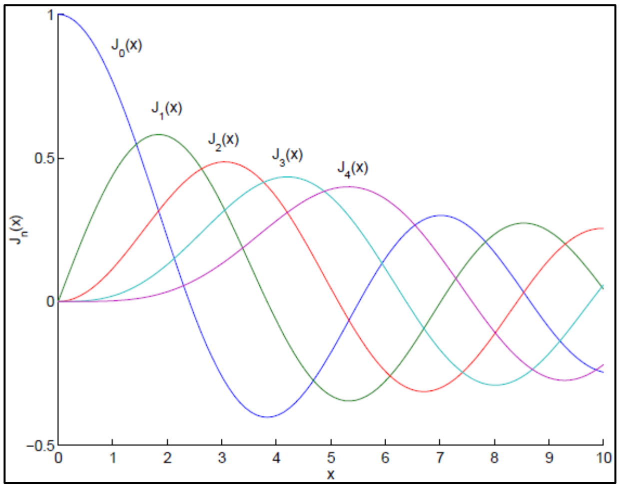

Fig. 2. Bessel Function Chart of First Class.

TABLE. I. ROOTS FOR TE MODES

n	n=1	n=2	n=3
m=0	3.832	7.016	10.174
m=1	1.841	5.331	8.536
m=2	3.054	6.706	9.970

TABLE. II. ROOTS FOR TM MODES

n	n=1	n=2	n=3
m=0	2.405	5.520	8.654
m=1	3.832	7.016	10.174
m=2	5.135	8.417	11.620

TABLE. III. LIST OF STANDARDS FOR CIRCULAR GUIDES IEC

Designación	Radio (mm)	Frecuencia de corte (GHz)		f (GHz)	Atenuación (dB/m)
		TE11	TM01		
C30	35.7	2.46	3.21	2.95	0.0184
C35	30.5	2.88	3.76	3.45	0.0233
C40	26.0	3.38	4.41	4.06	0.0297
C48	22.2	3.95	5.16	4.74	0.0375
C56	19.0	4.61	6.02	5.53	0.0473
C65	16.3	5.40	7.05	6.48	0.0599
C76	13.9	6.32	8.26	7.59	0.0759
C89	11.9	7.37	9.63	8.85	0.0956
C140	7.54	11.6	15.2	13.98	0.1893
C290	3.56	24.6	32.2	29.54	0.5834

III. RESULTS

Studies were conducted to determine the parameters of the waveguide antenna. Determining based on the measurements of the antenna and the equations.

A. *Theoretical Results*

To find the theoretical results we use the formulas mentioned above.

1) Based on the radius that is equal to r = 14mm, we can determine the cutting frequency f_c for the mode TE_{11},, being this f_c=6.3 GHz, as well as the f_c for the mode TM_{01}, it would f_c =8.2GHz. Obtaining the theoretical bandwidth of the difference of these, would be BW=1.9GHz. Finding these frequencies of the modes to work in the optimal frequency of 7.59 GHz, according to the IEC system, which provides these standards in Table I.

2) We find the wavelength of the dielectric$\lambda = 0.0395$, the wavelength of the group is $\lambda_g = 0.0708m$, with which we define the size of L. Obtaining also the phase of the mode $TE_{11}, \beta = 88.72\ rad/m.$

B. *Simulation Results*

The results of the simulation are obtained from the circular waveguide antenna obtained with the Ansoft HFSS program. Within the parameters that we will calculate first with the dimensions of our antenna will be the cutoff frequency f_c, that is obtained in Fig. 3. As it is observed there are two frequencies of cut for the two modes, in which the frequency 6.3 GHz for being the smaller one will be our frequency of cut below which the ones of more frequencies in our antenna.

Radiation diagrams are a graphic representation of the radiation properties of the antenna as a function of the different directions of space at a fixed distance. Express the electric field, in the far field area where the shape of the diagram is invariant as a function of distance. The following diagram shows the Cartesian and 3D polar radiation diagram in Fig. 4 and 5. Obtaining as a result both a directional radiation diagram, which means that we can cover more distant distances, but the effective beam amplitude decreases, what can not cover large areas.

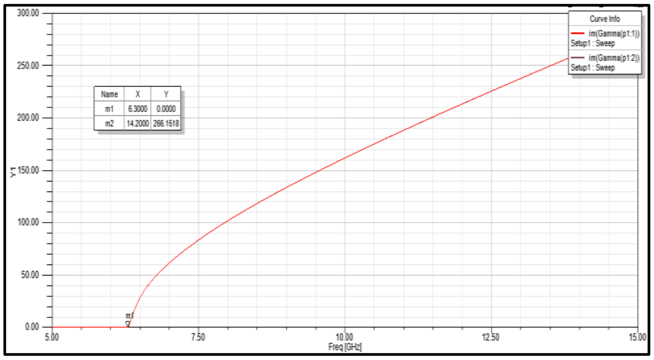

Fig. 3. Graph of the Diagram f_c in Ansoft HFSS.

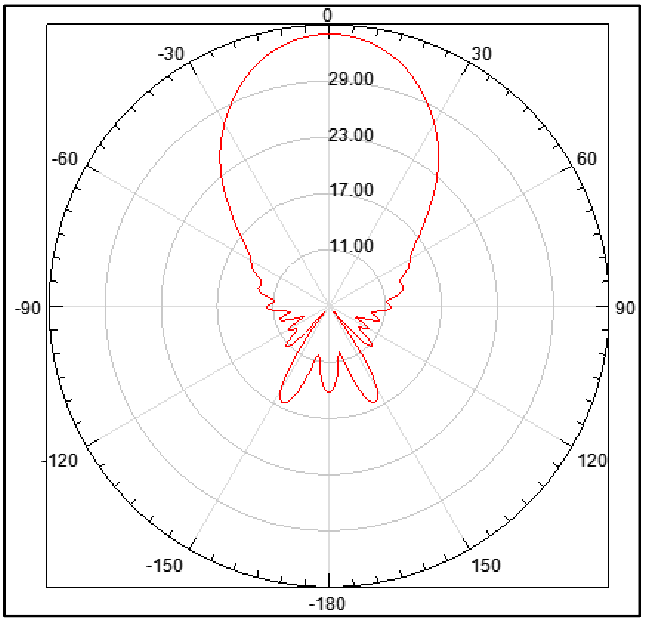

Fig. 4. Radiation Diagram in Cartesian Coordinates.

As it is observed the main lobe has an angle of 0º, while the rear lobe has an angle of 180º, finding the rear lobes between these two.

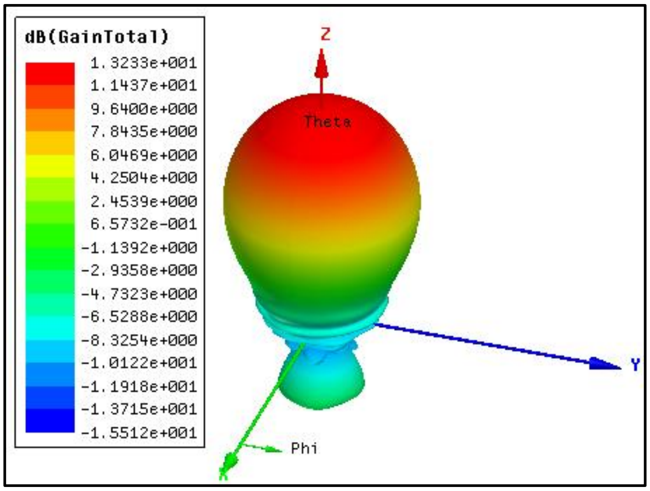

Fig. 5. 3D Radiation Diagram.

IV. DISCUSSION

It is concluded by the theoretical and simulated results obtained that the waveguide antenna is good for operating at microwave frequencies (300 MHz - 30GHz), cutting frequency f_c=6.3 GHz. Showing in the graph of Fig. 5, its radiation pattern is more directive, which reaches a greater distance, ideal for radio link communication. This polarization is due to the fact that the dominant pattern can be oriented in any direction of the z-axis of the guide, so that the two dominant modes can be transmitted at the same time, oriented their electric fields with a phase difference of 90 °. Compared to other antennas, the satellite dish has a high gain due to the shape of its radiation pattern that is more direct, unlike the waveguide antenna, which has a high average gain. Being among the advantages of waveguide antennas their circular or cross polarization, so that the reception of both vertical and horizontal polarization, is very convenient for satellite communication that requires using this type of polarization, in addition to being optimal for working in the microwave bands of C (4 to 8 GHz) and X (8 to 12 GHz).

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