PARAMETRIC ANALYSIS OF OPEN-ENDED DIELECTRIC-SLAB-LOADED RECTANGULAR WAVEGUIDE

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Abstract

The radiation characteristics of an antenna composed by a rectangular guide loaded with dielectric slab are analyzed and presented in this paper. A parametric study involving the dielectric loading level and the behavior of the cross-polarization is also included. The obtained results shows a plane performance for the maximum cross-polarization on a wide frequency band for the hybrid mode LSE10, dominant in the structure.

Keywords: hybrid structures, waveguides, antennas, cross polarization.

I - INTRODUCTION

The great rise in satellite communications pushes the need for more efficient antennas with low levels of cross-polarization. Good cross-polarization characteristics offer the possibility of channel duplication with the reuse of the frequency band. In this work the far-field radiation characteristics will be investigated for the partially filled dielectric rectangular waveguide. The study will focus on the parametric cross-polar analysis for the rectangular waveguide WR 112 [1] loaded with PTFE (polytetrafluoroethylene, $\varepsilon_r = 2.32$) for the dominant mode LSE10.

In section II and III, the theory associated with the problem will be presented. The behavior of radiated fields, as a function of the dielectric loading in the guide will be examined using cross-polarization as a reference parameter. Taking the best loading configuration obtained for the hybrid structure, the maximum cross-polarization values will be investigated as function of frequency.

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II - THEORY

The structure of the partially filled dielectric rectangular waveguide is shown in Fig. 1, where the dielectric is considered homogeneous and losses. The hybrid modes that appear in the structure are combinations of transverse electric and transverse magnetic modes. These modes are said longitudinal section magnetic (LSM) and longitudinal section electric (LSE) and can be obtained from the Hertz vector potentials Π_e and Π_h [2]-[4]. In particular, the TEm0 modes are equivalent to the LSEm0 modes.

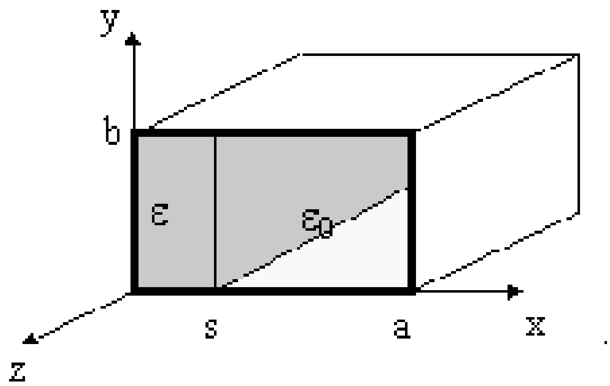

Fig. 1. Rectangular waveguide partially filled with dielectric.

In order to obtain the propagation constant (β_z) for the hybrid modes LSE and LSM, a system of transcendental functions must be numerically solved. The open-ended rectangular waveguide is commonly used as feeder for reflector antennas, probes for near-field scans, and as antenna array elements.

Using Maxwell's equations and the gauge condition [2]-[4], the electromagnetic field equations for the hybrid modes LSE can be obtained by the following expression:

$$\vec{E}_{LSE} = -j\omega\mu\nabla\times\vec{\Pi}_h \tag{1}$$

$$\vec{H}_{LSE} = \nabla\times\nabla\times\vec{\Pi}_h \tag{2}$$

The magnetic Hertz vector potential (Π_h) should satisfy the wave equation,

$$\nabla^2\vec{\Pi}_h + \varepsilon r(x)\beta^2\vec{\Pi}_h = 0 \tag{3}$$

where $\varepsilon r(x)$ is the relative electric permittivity of the dielectric.

$$\varepsilon r(x) = \begin{cases} \varepsilon r, & 0 \le x \le s \\ 1, & s \le x \le a \end{cases} \tag{4}$$

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The boundary conditions impose that the electric tangential fields are null on the waveguide walls and that the tangential electric and magnetic fields are continuous in the dielectric interface. With these conditions we have (for the LSE modes):

$$\beta_{xd}\cot(\beta_{xd}s)+\beta_{x0}\cot(\beta_{x0}(a-s))=0 \tag{5}$$

where β_{xd} and β_{x0} are respectively the phase constants in the dielectric and in the air in the x-direction. Due to geometry of the problem, the phase constants in the y-direction are $\beta_{y0}=\beta_d=\beta_y=\dfrac{n\pi}{b}$, with n = 0, 1, 2... . Therefore,

$$\beta_{xd}=\sqrt{\omega^2\mu\varepsilon_0\varepsilon_r-\left(\frac{n\pi}{b}\right)^2-\beta_z{}^2} \qquad \beta_{x0}=\sqrt{\omega^2\mu\varepsilon_0-\left(\frac{n\pi}{b}\right)^2-\beta_z{}^2} \tag{6}$$

From (6) and (5) we form the transcendental equation to extract the phase constant β_z. The Hertz vector potentials that satisfy (3) and the boundary conditions are given by:

$$\vec{\Pi}_h^d=B_{mn}^d\,\text{sen}(\beta_{xd}x).\cos(\beta_y y).e^{-j\beta_z z} \tag{7}$$

$$\vec{\Pi}_h^0=B_{mn}^0\,\text{sen}(\beta_{x0}(a-x)).\cos(\beta_y y).e^{-j\beta_z z} \tag{8}$$

where B_{mn}^d and B_{mn}^0 are constants and the indexes *d* and *0* indicate the dielectric and air regions, respectively, in which the solutions are valid. The equations for the LSM modes are obtained following the same procedure shown previously for the LSE modes.

The electromagnetic far field radiated from the hybrid guide is obtained considering the aperture shown in Fig. 2. The technique is well known in the literature [5]-[10] and will only be briefly presented here. To simplify the analysis, it's considered that the field distribution in the opening is known and from only the dominant LSE10 mode. The tangential fields at the aperture are:

$$\vec{E}_t=\begin{cases}-B\omega\mu\beta_z\,\text{sen}(\beta_{xd}x)\hat{a}y & \text{para } 0\le x\le s,\,0\le y\le b\\ -\omega\mu\beta_z\,\text{sen}[\beta_{x0}(a-x)]\hat{a}y & \text{para } s\le x\le a,\,0\le y\le b\end{cases} \tag{9}$$

$$\vec{H}_t=\begin{cases}B\beta_z{}^2\,\text{sen}(\beta_{xd}x)\hat{a}x & \text{para } 0\le x\le s,\,0\le y\le b\\ \beta_z{}^2\,\text{sen}[\beta_{x0}(a-x)]\hat{a}x & \text{para } s\le x\le a,\,0\le y\le b\end{cases} \tag{10}$$

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where the constant *B* is given by the relationship $\frac{B_{mn}^{d}}{B_{mn}^{0}}$, that is:

$$B = \frac{\text{sen}[\beta_{x0}(a-x)]}{\text{sen}(\beta_{xd}\,x)} \tag{11}$$

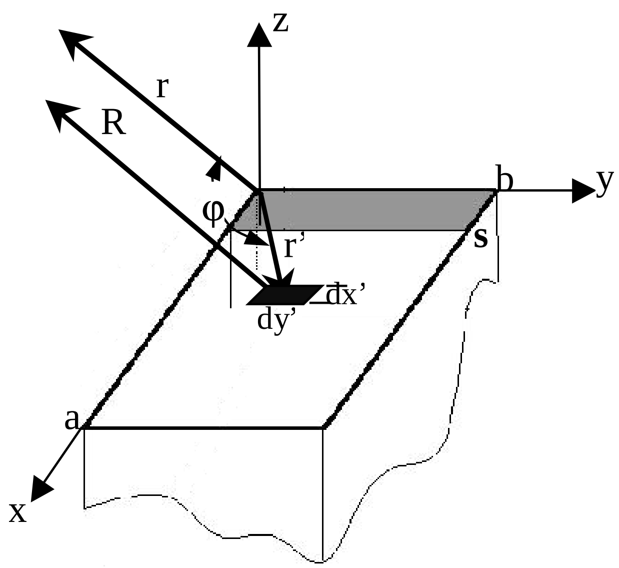

Fig. 2. Open-ended partially filled waveguide radiating in free space.

The far-fields are obtained applying the Fourier Transform in the aperture tangential fields as described in [2]-[4].

III - RESULTS

A rectangular waveguide was considered with dimensions a = 2.850 cm and b = 1.262 cm (waveguide WR112). The dispersion curves obtained for this guide are shown in Fig. (3). Ludwig's third definition [11] was used in the cross-polarization study. It was considered the plane ϕ=45º in the cross-polar analysis. Fig. (4) shows the maximum cross-polar variation as a function of dielectric loading, s. We can observe in Fig. (4) that the smallest values of cross-polarization occur near s = 0.45a. In this case, the value of the maximum cross-polarization corresponds approximately to –10 dB. Fig. (5) shows the radiation pattern considering s = 0.45a and f = 7 GHz. Modifications in the diagram due to the dielectric loading can be monitored in order to obtain high efficient configurations in terms of low side-lobes (LSL), front-to-back relation and cross-polar levels.

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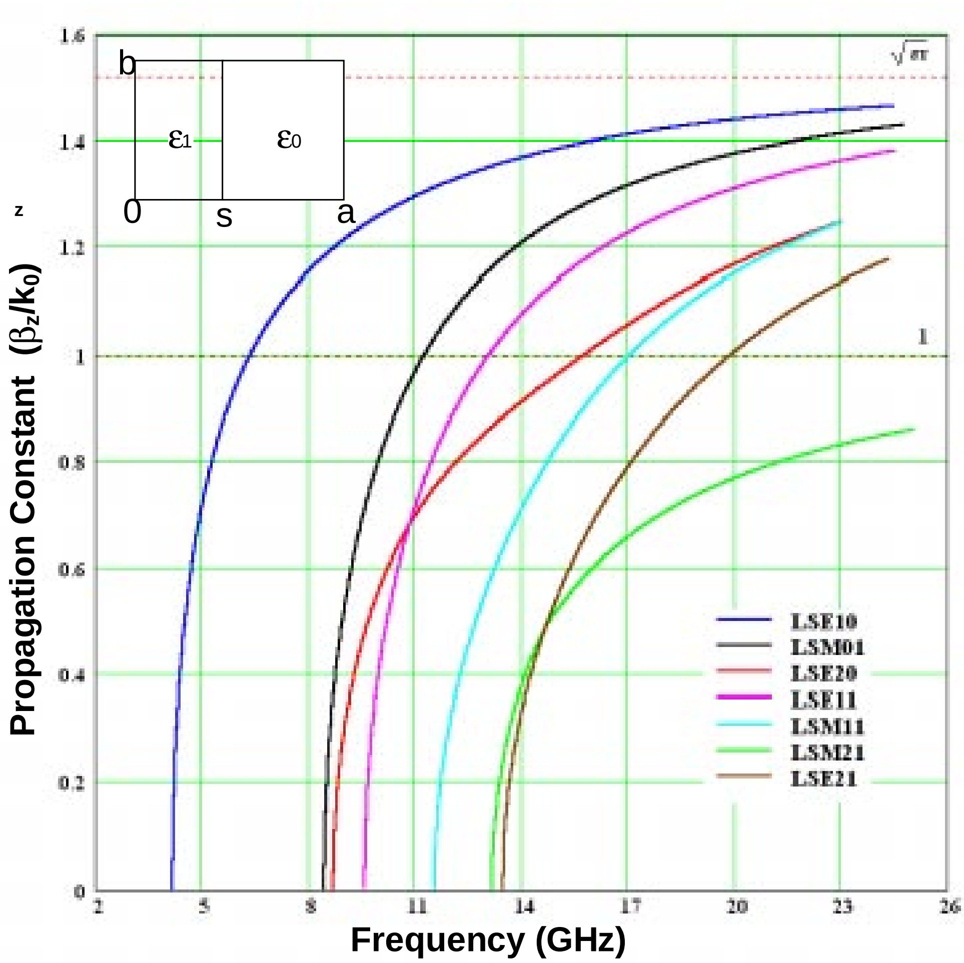

Fig. 3. Dispersion curves for the waveguide WR112 partially filled with dielectric layer with ε_r = 2.32. s = 0.45a.

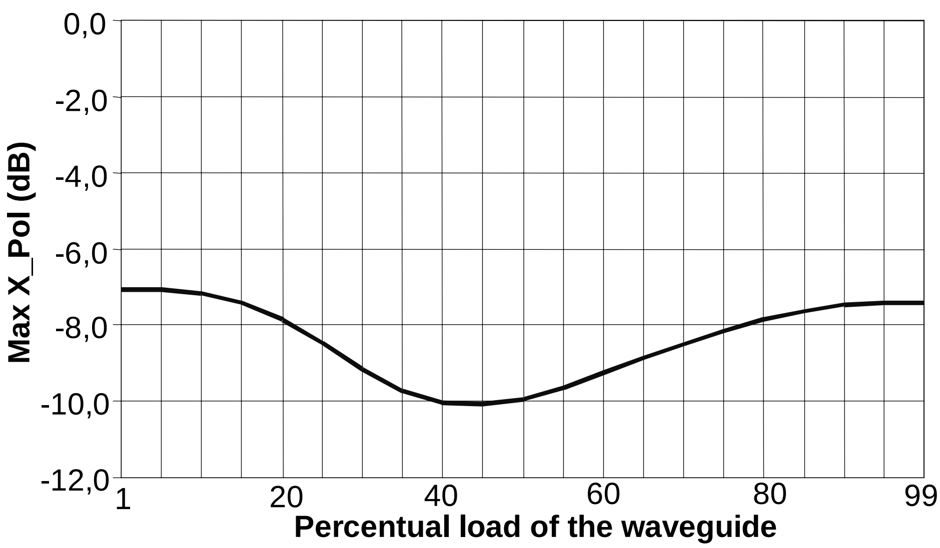

Fig. 4. Maximum cross-polarization as a function of the dielectric loading, s.
Rectangular waveguide WR112 (a = 2.850 cm and b = 1.262 cm). ε_r = 2.32.

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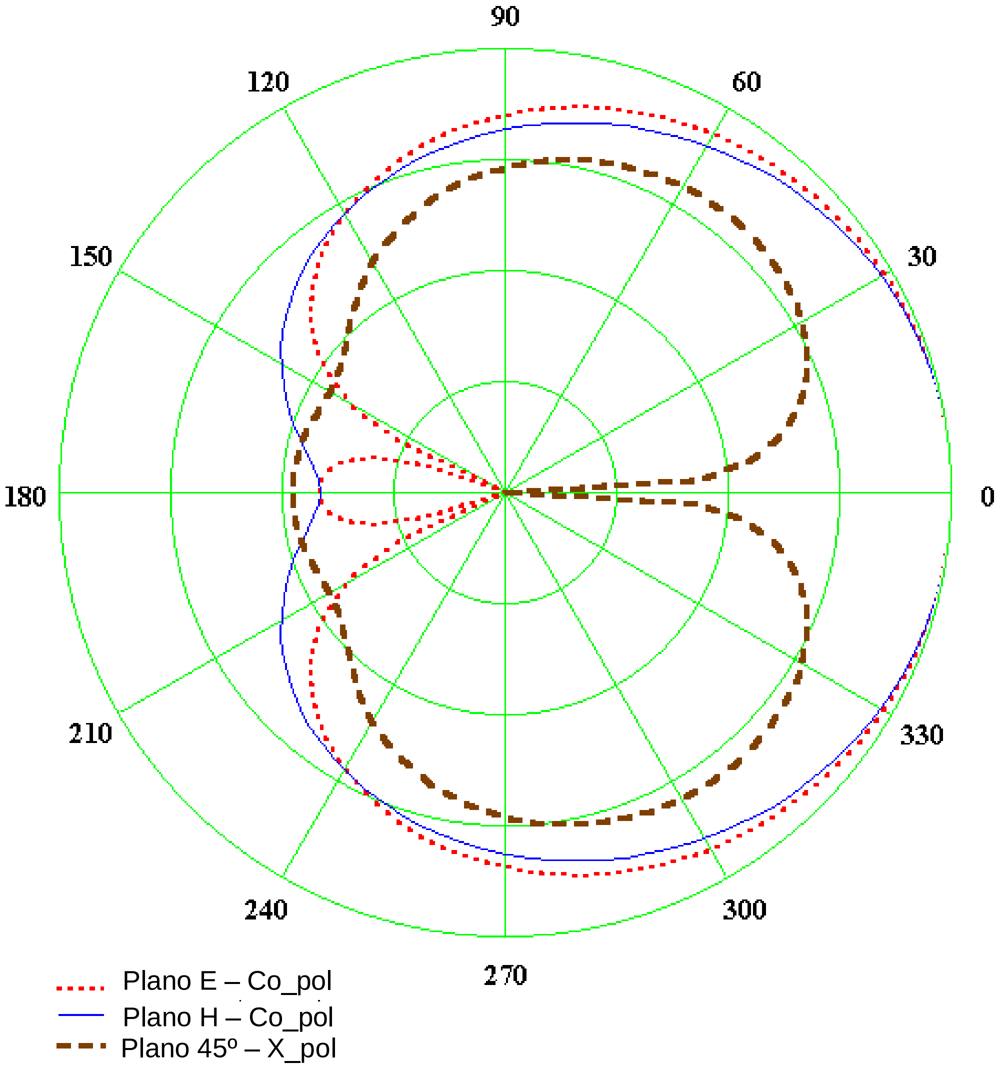

Fig. 5. Radiation diagram for the waveguide WR112 partially filled with dielectric layer with ε_r = 2.32. s = 0.45a, frequency of operation of f = 7 GHz.

Fig. (6) shows the behavior of the maximum cross-polar level as a function of frequency, in the LSE10 mono-mode operation, for s = 0.45a. The curve is very flat indicating the low frequency sensitiveness near the central frequency of f_0 = 6 GHz (practically constant with -10dB in the 3.5 GHz total Band).

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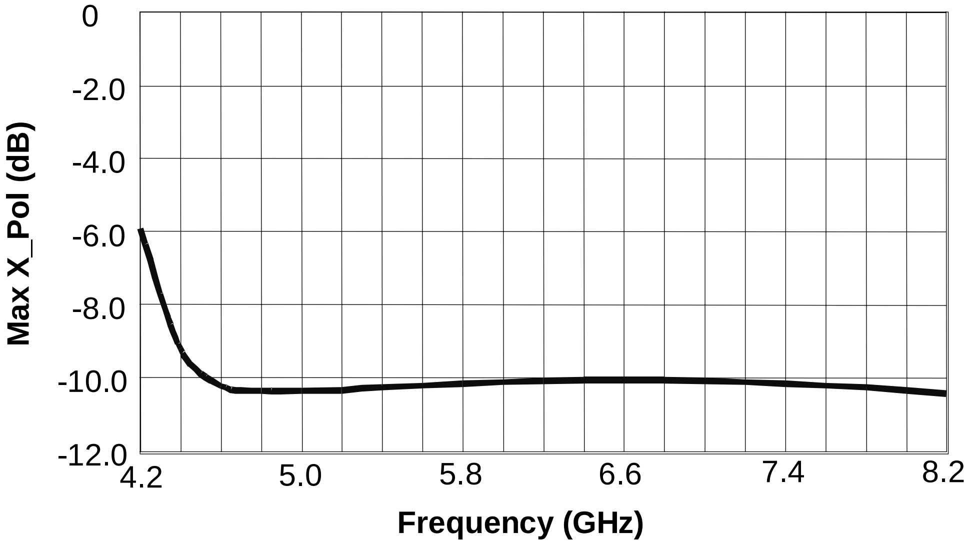

Fig. 6. Maximum cross-polar level as a function of frequency in the waveguide WR112, partially filled with dielectric, ε_r = 2.32. s = 0.45a. Radiation plane ϕ=45°.

IV - CONCLUSIONS

The radiation characteristics of an antenna composed by a rectangular guide loaded with dielectric slab were analyzed and presented in this paper. A parametric study involving the dielectric loading level and the behavior of the cross-polarization is also included. When considering a loading of s=0.45a and LSE10 mono-mode operation, simulations show maximum cross-polar levels of –10 dB. The authors believe that lower levels can be obtained by considering dielectrics with relative electric permittivity greater than 2.32. However, it is expected that materials with high ε_r introduce reflection losses in the system. The presence of the dielectric moved the band of operation in the main mode, as expected, from 5-9 Ghz in the dominant TE10 mode of the empty guide, to 4-8 Ghz considering the same guide with dielectric loading (s = 0.45a). Although the curve of the maximum cross-polar as a function of frequency presented a flat curve, the obtained levels are relatively high. Researches are being carried to reduce these levels.

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