FDTD method: Analysis of an one-dimensional array of H-plane sectoral horn antennas with dielectric lens

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Abstract — **The FDTD method is used in the analysis of the radiation characteristics of an one-dimensional array antenna. Here, the array elements are two-dimensional H-plane sectoral horns with parabolic dielectric lenses. In this case, the dielectric materials used were chosen so that they have low dielectric constant in order to avoid considerable reflections on the air-dielectric interfaces. The numerical results obtained show that the distance between the array elements and the lens characteristics, in spite of its low dielectric constant, change the phase distribution and power at the aperture of the array. For a suited choice of these parameters, radiation patterns are obtained with low level of side lobes.**

Index Terms — **FDTD Method, Horn Antennas, Dielectric Lenses, array.**

I. Introduction

The finite difference time domain (FDTD) method was introduced by Yee in 1966 [1] , and represents an efficient and simple form of solving Maxwell's equations when written in time domain – differential form. In Yee's proposal, the magnetic and electric field components are intercalated in time and space in such a way that there is reciprocity among them. Users of this method have progressively increased in the last years because of its low cost implementation, probably on account of new generation appearing of computers and the developing of new numerical techniques which made it possible to use the FDTD method to model open structures [2-8]. The FDTD method has been used in characterizing horn antennas [9-11]. In [9] and [10], the FDTD method is used to determine the field distribution (phase and amplitude) in the horn opening as well as the radiation pattern for both bidimensional and tridimentional cases, respectively, and in [11] the method (stepped-edge) is introduced and applied in calculating the radiation pattern of various aperture antennas. The use of dielectric lenses to correct the phase and /or power distribution in the horn antenna opening is very common and, in [12], experimental results for triangular lenses have been presented, considering low refraction index lenses.

The main objective of this paper is to analyze the radiation characteristics of an one-dimensional array antenna, where the array elements are two-dimensional H-plane sectorial horns with parabolic dielectrics lenses and is assumed no coupling between the array elements. This structure is then present as a proposal of phase correction and power distribution at the aperture of the array.

II. Theory

The transversal section of the bidimensional model for the H-plane sectoral horn to be analyzed in this paper is shown in Fig. 1. For the antenna design, $R_2 = 8\lambda$ and $A = 4\lambda$ were considered. Only the TM mode is considered in our analysis, so that the problem is reduced to the following (H_x, H_y) magnetic components and (E_z) electric component, which are expressed (obtained from Maxwell's equations) as:

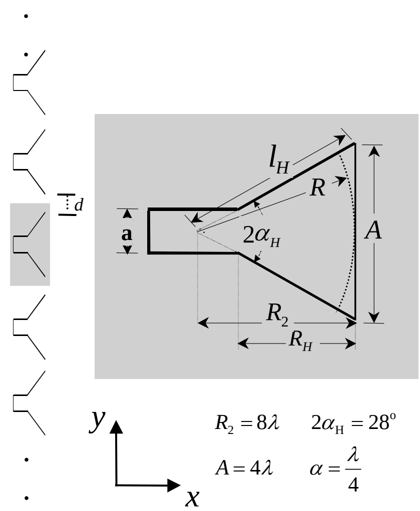

Figure 1. Two-dimensional H-plane sectorial horn with an one-dimensional array inset.

$$\frac{\partial H_x}{\partial t} = -\frac{1}{\mu}\frac{\partial E_z}{\partial y}$$
$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\frac{\partial E_z}{\partial x} \qquad (1)$$
$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial y} - \frac{\partial H_y}{\partial x}\right)$$

The above written equations are solved numerically through the FDTD method [1]. To define the FDTD grid (sets the number of cells in each dimension and the cell size), a bidimensional uniform grid with cells dimensioned in space and time as, respectively, λ/20 per λ/20 and $\Delta t \leq \Delta x / 2c$ obeying the stability criterion suggested by Courant et al. [13] in the central frequency (f_c). The sine modulated Gaussian pulse was used as the excitation function, and expressed as,

$$f(t) = 1.484\exp[(t-3\tau_o)/\tau_o]^2 \sin[2\pi f_c t]$$

where,

$\tau_o = [\pi(f_h - f_c)]^{-1}$, f_h = 15 GHz , f_c = 10 GHz , $\Delta t = \lambda / 40c$, c = 2.99792458 × 10^8 m/s, with t= n. Δt ,

this source being placed at λ/4 from the guide rear side.

In other to truncate the FDTD grid (Fig.2), the uniaxial anisotropic PML technique developed by S.D. Gedney [14] was chosen, for it is more efficient than the PML developed by Berenger [8] concerning the computational aspect. Every detail related to the positioning of each element considered in our analysis is shown in Fig.2. Here, the distances are expressed in cell numbers, where i and j represent the number of cells in the x and y directions, respectively. The near field to far field transformation surface (S) is defined by the planes Ia1=37; Ia2=273; Jb1=37; and Jb2=211. The excitation source is placed in i = IL = 47. The parameter A=80(4λ) represents the horn opening. The waveguide is Ic2 – Ic1=2λ long and Ic2 – Ic1=λ/2 high. The parameter i = IA = 221 indicates the horn opening position. A 20-cell region was used, around the analysis region, as PML.

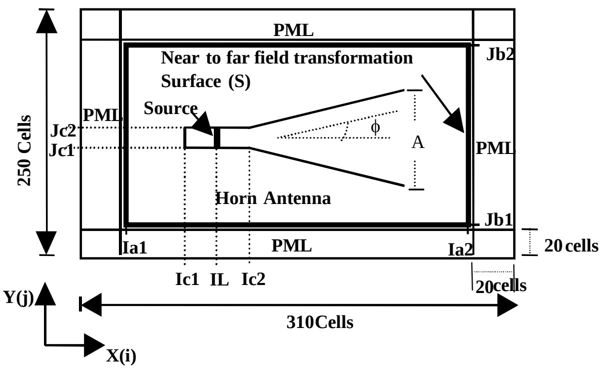

Figure 2- FDTD grid zone

II.1 - Transformation – Near Field to Far Field

To obtain the far field, a dummy surface S (the surface formed by the thickest line of Fig.2) is defined so as to surround the antenna in the field region called scattered field region. Above S, the tangential components of the scattered electric (E^s) and magnetic (H^s) fields are first obtained using the FDTD method. Using the Fourier transformation, these tangential components are obtained in frequency domain. Following this, an equivalent problem is established for the region outside the S one, where the superficial current densities, electric (Js) and magnetic (Ms), are the new excitation sources to find the far scattered fields [9,10].

III. Numerical Results

The horn antenna, as shown in Fig.2, was first analyzed without any kind of lens, and stability was observed after 800 iterations in time. Figure 3 shows the phase variation in the horn opening. An 85° phase change is observed from the center of the aperture to the edge. The electric field amplitude in the horn opening is shown in Fig.4. Fig.5 shows the electric field magnitude all along the near field to far field transformation surface. Such magnitude is calculated after 800 iterations, and a greater field intensity was observed in the opening front part. The far field diagram for 10 GHz , obtained through the near field to far field transformation, is shown in Fig.6 with the following characteristics: half power beam width, HPBW = 17.54° and level of the first side lobe equal to –28 dB. This diagram is in good conformity with the one presented by [9] (analytical solution) for a phase error parameter $t = A^2/8\lambda R_1 = 1/4$.

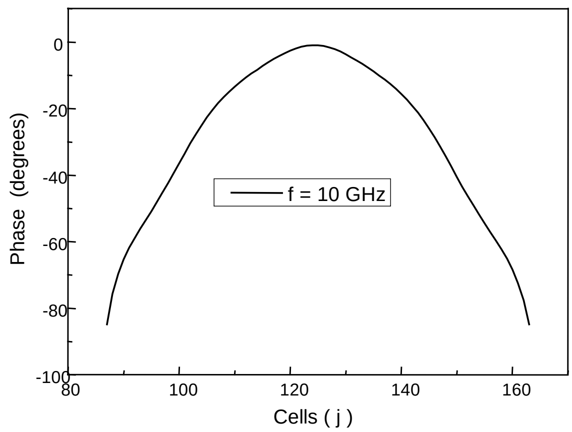

Figure 3 - Normalized phase in the opening of the H-phase sector horn antenna.

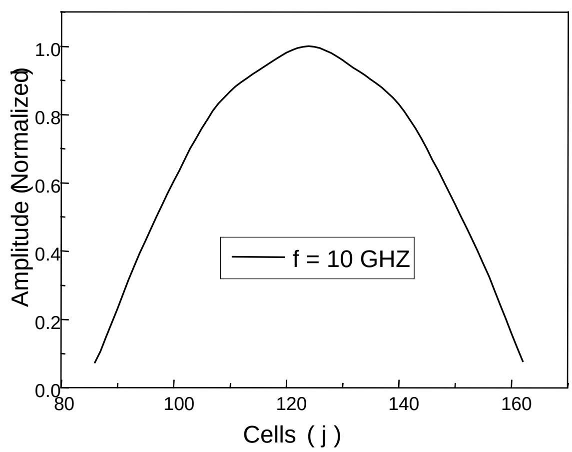

Figure 4- Normalized amplitude in the opening of the H-plane sector horn antenna.

In order to correct the phase change that occurs at the horn opening, a dielectric lens with parabolic geometry is used. To observe the effect of this lens at the horn radiation diagram, as well as the phase distribution at its aperture, the position of the lens vertex was varied of $\lambda/2$ in $\lambda/2$ in relation to aperture of the horn, using 1.3 dielectric constant lens as suggested in [15]. For the radiation diagram (Fig.7), the main characteristics observed was the half power beam width increasing in relation to the one shown in figure 6 (without lens), and the directivity decreasing when the position of the lens vertex is moved towards the horn mouth (from i = 150 to i = 180).

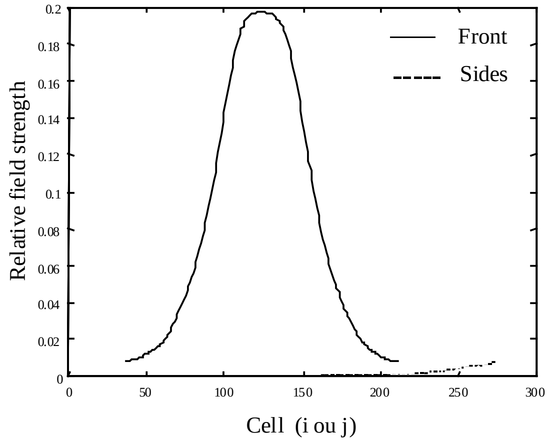

Figure 5- Electric field amplitude in the near field to far field transformation surface after 800 iterations.

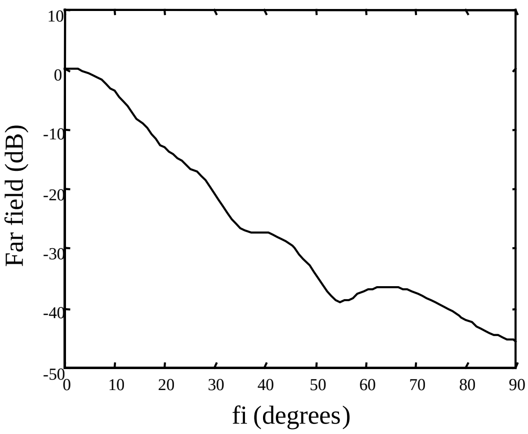

Figure 6- H-plane sector horn rectangular diagram (14^0 opening)

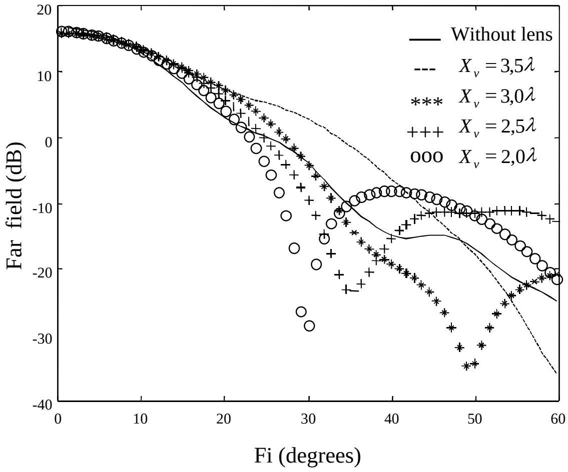

Figure 7- Influence of the parabolic lens vertex position variation in the H-plane sector horn far field.

Figure 8 provides an excellent visual of the phase distribution of the electric field, from the horn opening center to one of the horn edges. An irregularity near the horn edges is not critical in the design because of the low power density in these areas of the aperture.

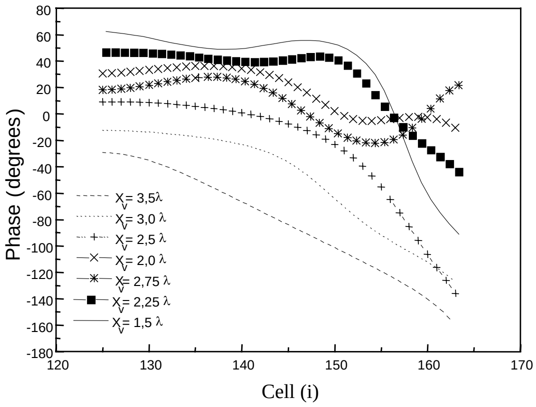

Figure 8- Influence of the parabolic dielectric lens in the phase of a H-plane sector horn, for a 1.3 dielectric constant.

III.1 - Horn Array Antennas

The geometry of an one-dimensional H-plane sectoral horn array antenna is shown in Fig.1, where its analysis is done by using periodicity condition, in this way only one horn needs to be analyzed. For Figs.9 and 11 no coupling between the elements is considered and d, in Fig.1, is done equals zero. Fig. 9 shows the far field of the array without the use of dielectric lenses. It is observed that there is increase of the side lobes when compared to the radiation pattern shown in Fig.6. With the purpose of reducing the level of the side lobes, dielectric lenses were used inside of the horns.

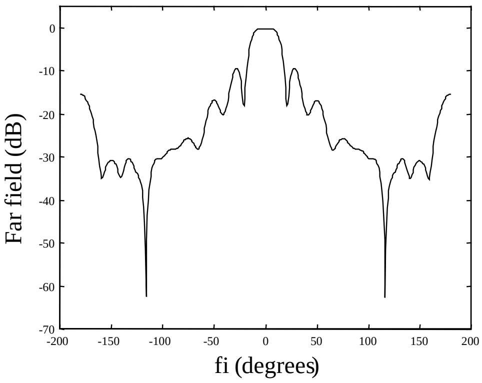

Figure 9 – Rectangular pattern of the H-plane sectoral horn antenna array without lens.

The characteristics of the lens are given in Fig.10 and in Fig. 11 the radiation pattern of the array with dielectric parabolic lens is shown, where it is possible to observe the decrease of the side lobes when compared to the pattern in Fig.9.

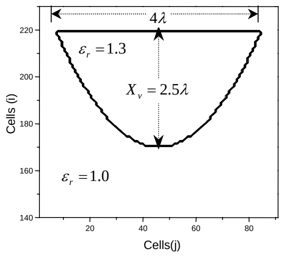

Figure 10 – The geometric characteristics of the dielectric lens.

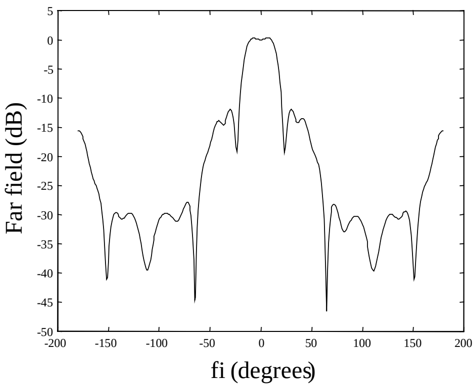

Figure 11 –Rectangular pattern of the H-plane sectoral horn antenna array with dielectric lens.

IV. Conclusions

The FDTD method was used in the analysis of the radiation characteristic of an H-plane sectoral horn antenna and one-dimensional array with and without dielectric lenses. The array elements are H-plane sectoral horns and is assumed no coupling between the array elements. It was observed that the dielectric lenses change the phase distribution and power at the antenna aperture. For a suited choice of the problem parameters it is possible to obtain radiation patterns with low level of side-lobes.

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VI. References

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