Generation of the HE_{11} mode in Rectangular Waveguide using Gaussian Techniques.

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Abstract

A new and efficient design of a rectangular corrugated waveguide mode converter, from TE_{10} mode in a smooth rectangular monomode waveguide to HE_{11} mode in a corrugated rectangular waveguide, is proposed. The main idea is the application of Gaussian design techniques, described in the given references, previously applied in circular waveguides. By using these techniques compact and very efficient components are obtained.

The obtained far field pattern is rather good as illuminator of square or rectangular parabolic reflectors, with very low sidelobes and crosspolarisation levels, avoiding the use of a rectangular to circular waveguide converter.

Simulations by using the HP's Finite Element code HFSS shown very promising results.

Introduction

The HE_{11} fundamental circular corrugated mode has been the ideal solution for a wide variety of applications where a high axial symmetry beam, low sidelobe levels and low crosspolar level were required.

Nevertheless, a complex corrugated structure is needed, which transforms the fundamental smooth circular waveguide mode, TE_{11}, to the fundamental circular corrugated waveguide HE_{11} mode. Usually, because nearly all of the implemented feeding systems are made in rectangular geometry, a rectangular to circular mode converter must be used.

Thus, starting from a rectangular geometry if a mode with the same radiation characteristics as the circular corrugated waveguide HE_{11} mode could be generated, the rectangular to circular adapter could be eliminated. Furthermore, due to the inherent characteristics of rectangular geometry, it would be possible to obtain lower crosspolarization levels than its counterpart in circular geometry.

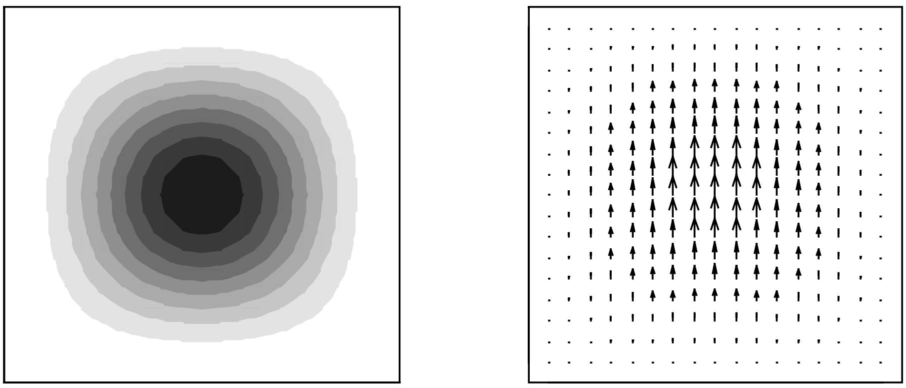

Fig. 1. - Representation of the transversal power density and field lines of the HE_{11} square corrugated waveguide mode.

With these previous considerations, the study of the equivalent aperture distribution for rectangular geometry was initiated. The transversal power density distribution and the field lines of the square corrugated waveguide HE_{11} mode is shown in fig. 1. The power density is very similar to the commonly used corrugated circular waveguide HE_{11} mode, but with some little square shaping effect. Additionally, the rectangular version of HE_{11} mode is supposed to present better crosspolarization characteristics inherent to the rectangular geometry.

This kind of aperture distribution is supposed to exhibit rather good features in radiation, with a little squared axial distribution, nevertheless it would be compensated with appropriate shaping reflectors.

Rectangular corrugated waveguide HE_{11} mode.

The HE_{11} transversal field distribution in a rectangular corrugated waveguide with $\lambda/4$ corrugation depth is defined in equation 1, this equation is obtained from an original development from simple physical considerations.

Using field correlation techniques, the necessary TE_{mn} and TM_{mn} smooth rectangular waveguide mode mixture to get the HE_{11} can be calculated [1]. The resulting mode mixture is unique, and does not depend on the design frequency or the transversal dimensions, as in circular geometry [3].

$$E_x = 0$$

$$E_y = \frac{\sqrt{8 \cdot Z_0}}{\sqrt{a \cdot b}} \cdot \sin\left(\frac{\pi}{a} \cdot x\right) \cdot \sin\left(\frac{\pi}{b} \cdot y\right) \qquad (1)$$

The mode mixture for an square aperture with a corrugation depth of $\lambda/4$ is presented in table 1.

TE_{mn} modes	**TM_{mn} modes**
TE_{10} : 81.057 %, 0 degrees	TM_{12} : 14.41 %, 180 degrees
TE_{12} : 3.603 %, 180 degrees	TM_{14} : 0.678 %, 180 degrees
TE_{14} : 0.042 %, 180 degrees	TM_{16} : 0.129 %, 180 degrees

Table 1. - Rectangular waveguide mode mixture to generate the HE_{11} mode in a square aperture.

To obtain a high efficiency device, nearly 99 %, at least three rectangular waveguide modes at the aperture must be used. Then, a profiled taper to obtain this mode mixture with appropriate phase must be designed.

TE_{10} to HE_{11} converter design.

For the design of a mode converter of this type it has been used the same technique proposed in [2] for circular geometry. Corrugating only both horizontal planes the necessary modes will be excited, and the variation is chosen to be the same that in the case of circular geometry [2]. The width also changes following some similar Gaussian profile in order to achieve a square aperture geometry.

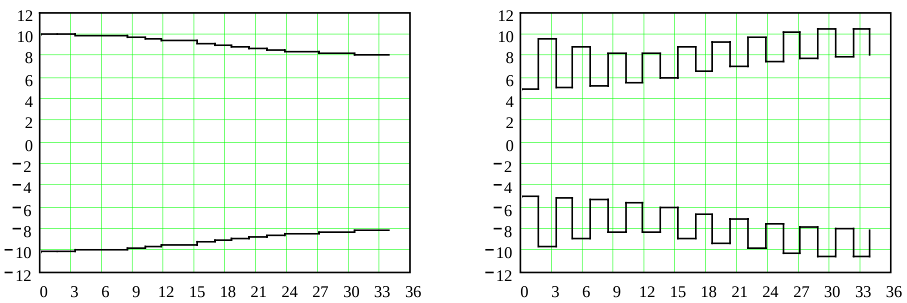

Fig. 2. – View in XZ plane (left) and YZ plane (right) of the proposed corrugated mode converter. All dimensions are given in millimeters.
Input and output aperture sizes: 20 x 10 mm. and 16.2 x 16.2 mm.
Converter and input impedance adapter lengths: 34 mm. ≈ 3.5·λ and 10 mm.
Period, tooth width and depth of the corrugations: 3.4 x 1.7 x 2.5 mm.

In figure 2, the profile of the proposed mode converter is designed at central frequency of 30 GHz.

Simulation results.

The HP's Finite Element code HFSS has been used to simulate this structure. The structure is fed with the TE_{10}, fundamental mode in smooth rectangular waveguide. The simulation process has been performed from 25 to 35 GHz obtaining the results given in figure 3:

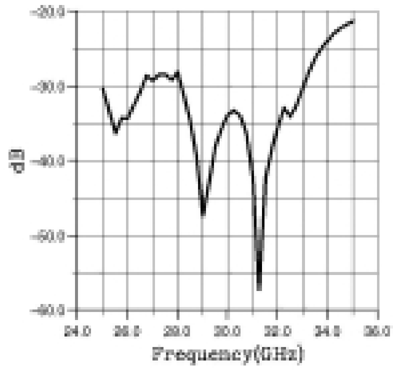

Fig. 3. - Reflection coefficient of the simulated structure.

The reflection features are lower than -28 dB from 25 to 33 GHz, (as figure 3 shows). The Far Field Radiation Patterns obtained for this short structure can be seen in figure 4, it should be noted that they show a rather symmetrically beam, wider in the 45 degrees plane.

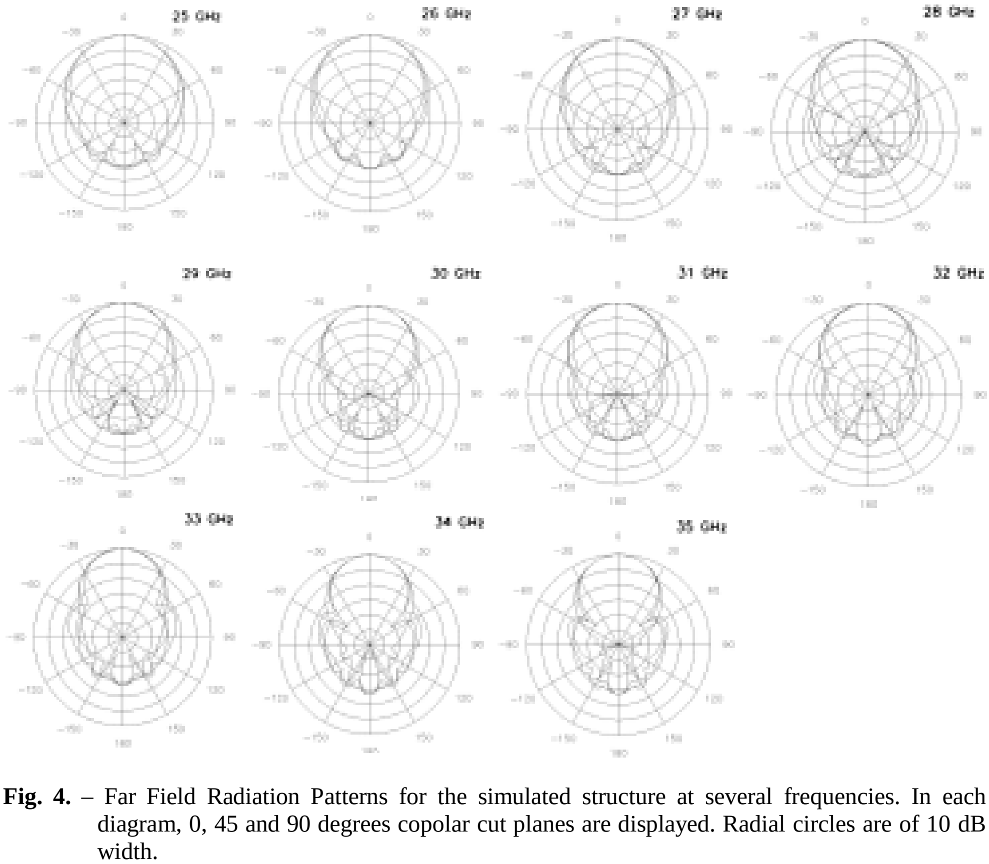

Fig. 4. – Far Field Radiation Patterns for the simulated structure at several frequencies. In each diagram, 0, 45 and 90 degrees copolar cut planes are displayed. Radial circles are of 10 dB width.

The TE_{mn} and TM_{mn} mode mixtures computed by means of HFSS in the considered frequency band are presented in figure 5. They are very similar to the proposed ones in table 1. Besides, it is also plotted in figure 5 the efficiency of the structure in the whole frequency band. This efficiency is always better than 95 %, but is practically near 98 % in the whole band.

As it is appreciated in figure 5, the efficiency falls can be attributed to the coupling to the mode TE_{30} with some relevant power in the aperture. When this mode adds in phase with the remaining mode mixture, the global efficiency decreases. Future designs will be optimized to avoid this spurious mode effect.

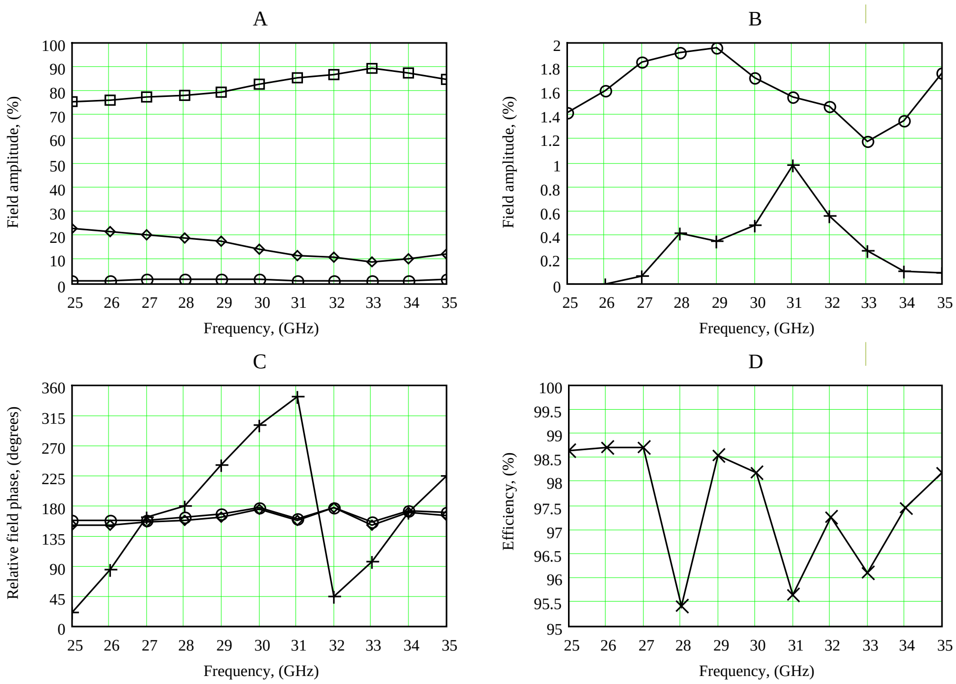

Fig. 5. The plots A, B and C, represent the field amplitude and relative phase in rectangular modes of the simulated structure. And in the D plot, the efficiency generating the HE_{11} square corrugated mode is presented.

- % TE_{10}
- % TM_{12}, and relative phase between TE_{10} and TM_{12}
- % TE_{12}, and relative phase between TE_{10} and TE_{12}
- % TE_{30}, and relative phase between TE_{10} and TE_{30}
- % Mode mixture efficiency at the aperture with HE_{11}

Conclusions.

A new design of short and very efficient TE_{10} to HE_{11} rectangular waveguide mode converter with square output aperture is presented.

Good agreement between theoretical mixtures and calculated mixtures at the output of the antenna have been obtained.

This structure can be applied to the illumination of reflectors with square geometry, avoiding the necessary transition between rectangular to circular geometry, with the advantages in crosspolar levels that rectangular geometry presents.

High efficiencies have been obtained, but this is the first step and improvements are expected in a close future.

References

[1] D. Wagner, W. Kasparek and M. Thumm, "Eigenmode Mixtures in Oversized Corrugated Rectangular Waveguides*." 10th Joint Russian-German Meeting on ECRH and Gyrotrons*, June 1998.

[2] R. Gonzalo, C. del Río, J. Teniente and M. Sorolla, "Generation of the HE_{11} Mode from Monomode Smooth Circular Waveguide", *Proc. 21st International Conference on Infrared and Millimeter Waves,* Bth8, Berlin, July 1996.

[3] R. Gonzalo, C. del Río, J. Teniente and M. Sorolla, "New approach to the design of Corrugated Horn antennas", 20 th ESTEC antenna Workshop on Millimetre Wave Antena Technology and Antenna Measurement, 18-20 June 1997, ESTEC Noordwijk, The Netherlands.