Optimum Horn Antennas for High Order Mode Beam Waveguides

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Abstract

Higher order free space modes can be considered as serious candidates for power millimeter wave transmission in advanced material processing by using medium power CW gyrotrons. These modes can be propagated in a beam waveguide with properly designed mirrors. Here, we present some optimal ways to excite these higher order free space modes from circular symmetric cylindrical waveguide modes by using optimal non linear horn launchers. An original synthesis procedure is proposed which has been successfully tested by computational simulation.

1. Introduction

Nowadays, for some applications in advanced materials processing, we don't need the classical pencil like beam, because, the main idea in these applications is to obtain a uniform distribution of the fields inside the final experimental cavity, and for this purpose, a stirrer device, is placed inside the cavity. In these systems, the critical point is to transfer the power as efficiently as possible to the final cavity and to avoid reflections.

In this paper, optimal ways to excite higher order free space modes from waveguide modes by using optimal non linear horn launchers are presented. The possibility to use these higher order modes to drive the power through a simpler and cheaper compact quasi-optical transmission line is presented at this conference in the paper entitled "Higher order mode beam waveguide for technological medium power millimeter wave applications" [1].

2. Gaussian modes and waveguide modes

As it is shown in [1], there are solutions of the paraxial Helmholtz equation where the field distribution has high correlation with some waveguide modes. The most clear example is the fundamental gaussian beam, Ψ_0^0 [1], because the matching to the circular corrugated waveguide HE_{11} mode is really very high.

Nevertheless, this is not the only possibility. We can say that there are combinations of solutions of the paraxial Helmholtz equation which produce very similar field distributions as combinations of waveguide modes. The only limitation to this matching procedure is the paraxiality of the Helmholtz solutions [1] y [2].

3. Horn antennas for high order gaussian beams

Now we will focus on the particular case to get higher order gaussian modes from circular smooth circular waveguide TE_{0m} mode mixtures.

Due to the fact, that the input modes have circular symmetry, the gaussian mode that we wish to obtain as a combinations of these waveguide modes has to be also circular symmetric. These modes can be defined as Ψ_m^1 by the expression:

$$\Psi_m^1(r,\varphi,z) \equiv \Psi_m^{1,0}(r,\varphi,z)\vec{x} + \Psi_m^{1,0}(r,\varphi,z)\vec{y} \qquad (1)$$

$\vec{x}$ and $\vec{y}$ being unitary vectors in two perpendicular directions and both perpendicular to the propagation axis.

In figure 1, we have represented the shape of the power density over a perpendicular plane to the propagation axis for the three lower order modes defined in equation (1).

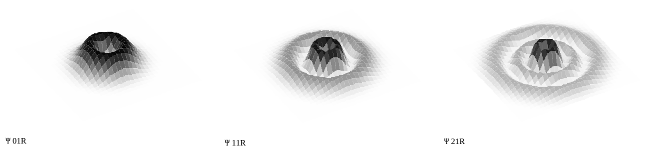

Figure 1: Power density in a perpendicular plane to the propagation axis; the notation is ΨabR, *a* being the radial index and *b* the azimuthal one (R is used to remind the circular symmetry)

The problem is to excite efficiently these gaussian structures from waveguide mode mixtures. The component will have horn antenna behavior, in order to match as good as possible the waveguide and the free space.

A. First solution

The first idea to design this component is to open the waveguide in the same way as the gaussian mode does from the beam waist position. Then, the expression for the taper profile should be:

$$r(z) = r_0\sqrt{1+\left(\frac{\lambda z}{\pi\varpi_0^2}\right)^2} \qquad (2)$$

r_0 being the initial radius for the taper, λ the wavelength, and ϖ_0 the beam waist of the fundamental gaussian mode associated to the higher gaussian mode.

In figure 2, we show the far field radiation pattern for different waveguide mode mixtures which have been obtained cutting this horn at different lengths (z_0 and $2z_0$) (z_0 is the Rayleigh distance) with a TE_{01} circular smooth waveguide mode as input, compared with the far field pattern of the desired gaussian mode.

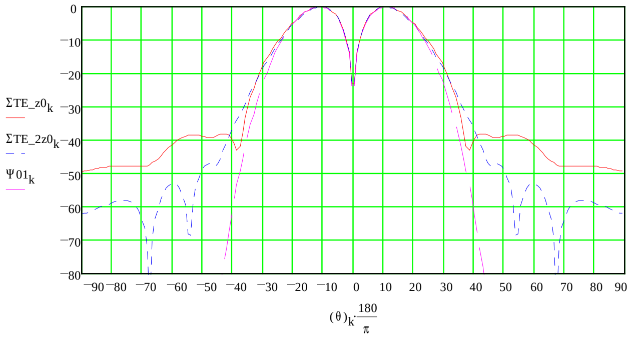

Figure 2: Far field pattern of the waveguide mixtures for different taper lengths (TE_z0 and TE_2z0) and the far field pattern of the desired gaussian mode (Ψ01), taking r_0 = 19.75 mm. and ϖ_0 = 11.85 mm.

The output radius for the two horns are 27.93 mm. and 44.162 mm. Nevertheless the far field pattern for these two different output radii are practically the same, and one is twice the other. This is possible, because in each case the mixture of waveguide modes at the aperture is automatically produced by the taper, in order to maintain the far field radiation pattern practically constant. Probably, this is the best demonstration to show that we get a gaussian structure, because the far field pattern of these structures remains constant along the propagation axis, due to the linear relation between the radius and the distance in the gaussian formulas, as it is shown in [1].

Ideally, we can cut the horn elsewhere, and the resultant mixture of waveguide modes produces the same far field pattern. In practice, for short tapers this is not true, due to the fact that the input mixture (in this case the TE_{01} mode) has not a gaussian structure. Nevertheless, if we calculate the correlation between the TE_{01} and the gaussian structure, we obtain that the TE_{01} mode has a high correlation coefficient with the gaussian beam, about 97.6 % for a value of $\varpi_0 = 0.565 \cdot a$, a being the waveguide radius. Along the taper, this value increase until practically 99.5% during a broad interval of distances ($2z_0$) and if we make the taper longer, this value starts to go slowly down.

In practice, due to the fact that the input mode is not gaussian, there is a transition zone, where the mixture becomes gaussian. This is the explanation to obtain a different value for ϖ_0 than those used in the formula. There is a fixed relations, as we can see in table I.

Desired ϖ_0	Obtained ϖ_0
0.49	0.595
0.50	0.595
0.51	0.6
0.52	0.605
0.53	0.605

Table I: Relation between the ϖ_0 value used in the formula (2), and the ϖ_0 obtained.

The optimum conversion efficiency is for the gaussian structure with $\varpi_0 = 0.6a$.

B. Parabolic horns

The main disadvantage of “natural” horns is that the field distribution grows inside the taper at the same time as the taper, this means, that the scaling of the fields shape inside the waveguide keeps constant along the taper. In our case, to do the numerical calculations we have supposed no influence in the results the waveguide structure. It is clear, that this problem not should be very important, because the far field pattern of a TE_{01} waveguide mode without taking care about the waveguide is practically the measured one.

This problem, will be solved using parabolic profile for the horns. The working way is practically the same, and we can understand this behavior thinking to change along the taper the scaling of the fields inside. This horns can be defined by:

$$r(z) = r_0 \left(1 + \left(\frac{z}{\alpha k r_0^2} \right)^2 \right) \qquad (3)$$

where α is the slope parameter chosen in order to maximize the conversion to a gaussian structure [3].

Also using this tapers, the maximum is when we are coupling to a Ψ_{01} gaussian mode with $\varpi_0 = 0.6a$ parameter value.

With this horns, the efficiencies are a little bit higher than the “natural” ones.

4. Conclusions

In this paper, two different families of horns have been presented which automatically change the mixture of waveguide modes at the output to generate a gaussian field distribution.

These tapers are very useful to solve the problem to match waveguides to quasi-optical transmission lines propagating higher order gaussian modes.

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5. References

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