

High Order Mode Beam Waveguide for Technological Medium Power Millimeter Wave Applications

Carlos del Río, Ramón Gonzalo, Miguel Marín, Mario Sorolla, Arnold Möbius¹ and Manfred Thumm^{1,2}

E.T.S.I.I. y Telecomunicación
Universidad Pública de Navarra
Campus Arrosadía s/n. E-31006 Pamplona, Spain
Fax: +34 48 169169 e.m.: carlos@upna.es

⁽¹⁾Forschungszentrum Karlsruhe
Institute for Technical Physics
D-76021 Karlsruhe, Germany

⁽²⁾and Universität Karlsruhe
Institut für Höchstfrequenztechnik und Elektronik

Abstract

The use of medium power millimeter wave CW gyrotrons (10-30 kW and 30-100 GHz) has several potential applications in advanced materials processing. Since a stochastic field distribution in the applicator is desirable no pencil beam is necessary. Then the possibility to couple the circular symmetric gyrotron output to a higher order free space mode can be considered. Beam waveguides based on iterative reflection of such high order beams on properly designed mirrors opens the possibility to increase the efficiency and to reduce costs of present compact transmission lines in gyrotron technological systems.

1. Introduction

The advantages of quasi-optical transmission lines compared to conventional ones are well known [1]. In this paper, we want to introduce the possibility to use higher order mode beams to drive the power through a compact quasi-optical transmission line.

The main idea, is to transform as soon as possible the gyrotron output waveguide mode into a gaussian structure, because these structures are able to travel through a quasi-optical line as we show in this paper. This idea can be very useful for systems without important restrictions over the beam shape because a stochastic field distribution in the final cavity is desired.

The main advantage to use these modes is the simplicity of the whole transmission system.

As it is shown in "Optimum horn antennas for high order free space mode beam waveguides" [2], it is possible to obtain by using an optimized horn antenna these gaussian modes from the gyrotron output waveguide mode.

2. Gaussian modes

The gaussian modes presented here, form a set of solutions of the paraxial Helmholtz equation. This means, that any field distribution in a half-space without sources can be represented as a combination of them.

In these solutions, each transversal electric field component can be expressed as in [3] and [4]:

$$E_a^{b,\varphi_0} = A_a^{b,\varphi_0} \cdot \Psi_a^{b,\varphi_0} \cdot e^{-jkz} \quad (1)$$

A_a^{b,φ_0} being a complex amplitude factor and Ψ_a^{b,φ_0} the structural function, defined in equation (2), where ξ is a function of z , defined,

$$\xi = \frac{\lambda z}{\pi \bar{\omega}_0^2} = \frac{z}{z_0} \quad (3)$$

$L_a^{(b)}$ being the Laguerre polynomials, $\bar{\omega}_0$ the minimum waist of the beam for the fundamental mode, λ the wavelength in the corresponding media and z_0 the Rayleigh distance. In these formulas the beams are centered at $z = 0$.

In the structural function, we have used three different indices:

- φ_0 a real number, allowing the possibility to rotate the whole structure,
- a and b have the same meaning of the indices of the circular waveguide modes, corresponding to the radial and azimuthal variations.

Unless in the normalization factor, the radius variable r , and the distance variable z , always appear in the same form,

$$\frac{r}{\bar{\omega}(z)} = \frac{r}{\bar{\omega}_0 \sqrt{1 + \left(\frac{2z}{k\bar{\omega}_0^2}\right)^2}} \quad (4)$$

$$\Psi_a^{b,\varphi_0}(r, \varphi, z) = \frac{1}{\sqrt{1 + \xi^2}} \left(\frac{\sqrt{2}r}{\bar{\omega}_0 \sqrt{1 + \xi^2}} \right)^b \cos(b\varphi - \varphi_0) L_a^{(b)} \left(\frac{2r^2}{\bar{\omega}_0^2 (1 + \xi^2)} \right) e^{j(b+2a+1)\text{tg}^{-1}(\xi)} \cdot e^{-\frac{r^2}{\bar{\omega}_0^2 (1 - j\xi)}} \quad (2)$$

and for large values of the distance, we can simplify this expression in a linear relation. This is the main property of

these gaussian modes, because with a particular value of $\bar{\omega}_0$, we can design the diffraction slope of the gaussian structure.

The gaussian exponential is modulated by different polynomials to obtain different gaussian modes; if we increase the order of the modes, we have the power distributed in a large area, as we can see in figure 1.

The phase fronts for these modes are defined by the expression:

$$r^2 = \frac{2R(z)}{k} \left[2\pi q + (b + 2a + 1) \text{tg}^{-1}(\xi) - kz \right] \quad (5)$$

where q is the value of the phase in a particular surface.

Basically, these surfaces are ellipsoidal, and only one factor is depending on the mode. This factor is not relevant to distinguish the surfaces for neighbour modes.

3. Designing a quasi-optical transmission line

To design a quasi-optical transmission line for higher order gaussian modes, we have to take into account:

- *reflector dimensions*. As we have seen before, an increase in the mode order, is directly related to an increase of the power distribution area. This means, that to maintain the level of diffraction losses, we have to scale the reflector according to the new power distribution area.
- *reflector shape*. This point is the most important, because all the quasi-optical transmission lines for the fundamental mode, are designed under the assumption of spherical phase-fronts. For the higher order modes, the power is spread in a large area, and the assumption of spherical phase-fronts is only valid in a small center region where we have practically no power inside. If we want to define properly the shape for the mirrors, we have to take into account the exact formulas for the constant phase surfaces (5).

If we have pure modes propagating through the line, we can define the reflector shapes analytically, knowing the

characteristics of the input mode and the desired position and ω_0 value of the reflected beam.

If we want to work with a mixture of gaussian modes, we have to use recursive numerical methods, looking for the fields over the mirror and looking for the scattered fields to modify the mirror surface in relation with the difference between the scattered and desired fields.

4. Conclusions

In this paper we have presented the possibility to use higher order modes in quasi-optical transmission lines. This usage can be very useful in advanced material processing systems, which have not hard restrictions on the beam properties, because of the stochastic field distribution desired at the end cavity system.

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5. References

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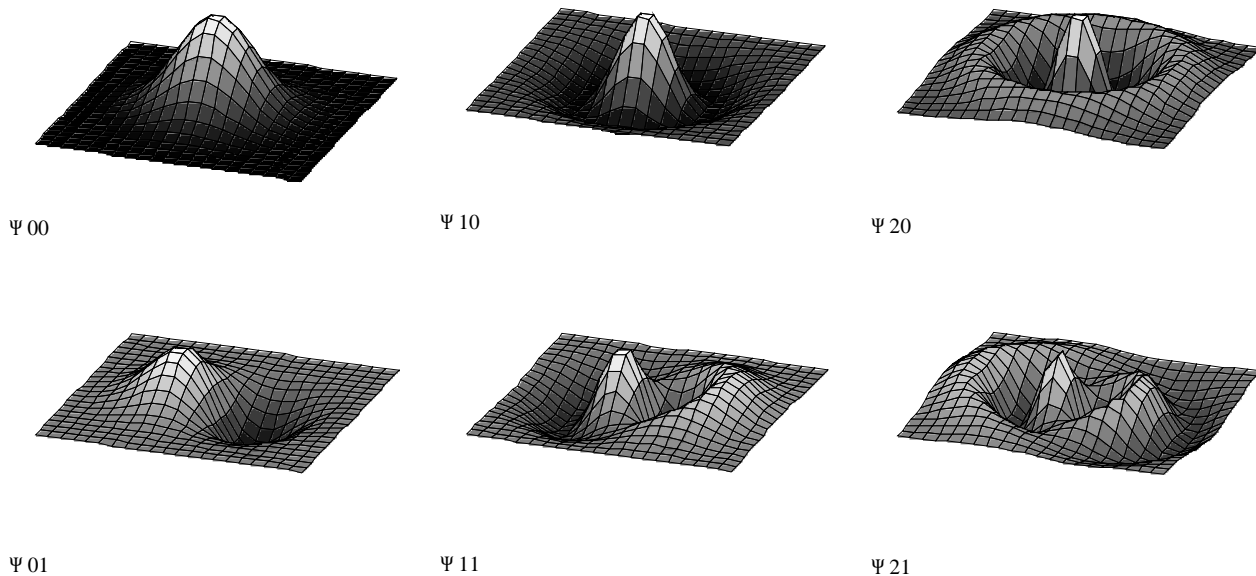


Figure 1: Shapes of the lower gaussian modes defined with function (2), the notation is Ψ_{ab} , a being the radial index and b the azimuthal one.