ANALYSIS OF AN EFFICIENT $TE_{0,n}$-TO-$TE_{0,n+p}$-MODE CONVERTER IN CIRCULAR WAVEGUIDES

A. Jöstingmeier[1], C. Rieckmann[1], and A. S. Omar[2]

[1] Technische Universität Braunschweig
Institut für Hochfrequenztechnik
Postfach 33 29, D-3300 Braunschweig, FRG

[2] Technische Universität Hamburg-Harburg
Arbeitsbereich Hochfrequenztechnik
Postfach 90 10 52, D-2100 Hamburg 90, FRG

ABSTRACT

Mode converters which have recently been proposed for high power gyrotron applications are analyzed. For the computation of the local modes at each cross section of the converter, a generalized spectral domain technique is applied, while in the axial direction a waveguide taper analysis is made which is based on a generalized scattering matrix method.

STATEMENT OF THE PROBLEM

In high output power gyrotrons, the interaction between the electron beam and the electromagnetic field takes place in a highly overmoded cavity. Therefore mode competition becomes a severe problem especially in the design of gyrotrons operating at higher harmonics of the cyclotron frequency. Recently it has been suggested to overcome this problem by using a new cavity structure which contains a $TE_{0,n}$-to-$TE_{0,n+p}$ mode converter ([1], [2]), see Fig. 1.

The mode converter consists of a slotted-circular waveguide with gradually changing cross section. The angle of the slot varies slowly from 0 to $2\pi/N$ (N equals the number of slots) along the axis of the converter whereas the depth of each slot is constant. If the radii a and b fulfill the design criterion

$$\frac{\mu_{0,n}}{a} = \frac{\mu_{0,n+p}}{b} \quad \text{with} \quad J_0'(\mu_{0,n}) = J_0'(\mu_{0,n+p}) = 0$$

an incident $TE_{0,n}$ mode at the left port of the converter is efficiently converted to a $TE_{0,n+p}$ mode at the right port. Except from a small self-reflection, no other unwanted mode conversion takes place.

But due to the discontinuities in front of and behind the converter which are part of the cavity, see Fig. 1, modes with undesired radial indices are excited. Because these modes do not fulfill the design criterion they are characterized by a strong mode conversion. Hence it is necessary to take these modes also into account. Such an analysis is presented in this contribution. In a first step, the local slotted-circular waveguide modes are computed based on the generalized spectral domain (GSD) method [3]. Then a waveguide taper analysis is carried out by applying the generalized scattering matrix (GSM) method [4].

In [1], a field matching technique has been used to compute the local modes corresponding to a slotted-circular waveguide in which it has been assumed that the azimuthal component of the electric field is constant across a slot.

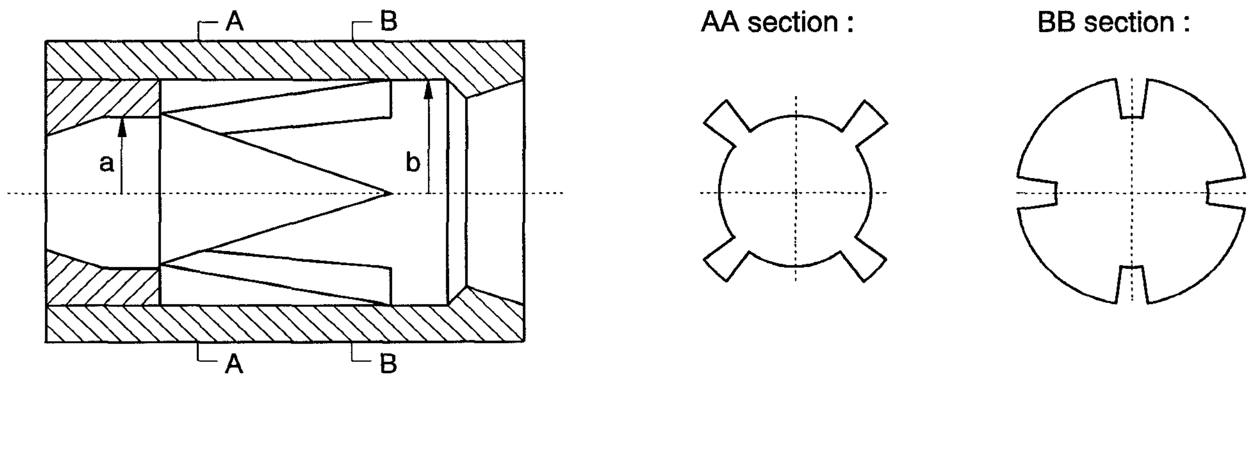

Figure 1: Gyrotron cavity with $TE_{0,n}$-to-$TE_{0,n+p}$-mode converter.

But this assumption violates the edge condition at the 90° edges of the metal ridges. Even if the method presented in [1] is extended by expanding the slot fields with respect to complete sets, it remains numerically inefficient. Due to the field singularities at the edges, this method leads to oversized matrices because the size of the characteristic matrix is proportional to the number of field expansion functions.

COMPUTATION OF THE LOCAL MODES

In this contribution, the computation of the local modes is carried out by the GSD method. The analysis of the slot-coupled circular waveguide is based on short-circuiting the coupling slots and replacing the non-vanishing slot tangential electric field by two surface magnetic currents at the two sides of the short-circuit. The electromagnetic field in the individual waveguides is then expanded with respect to the corresponding eigenmodes. However, the size of the characteristic system of equations is related now to the number of basis functions which are used to expand the surface currents. If the edge condition is taken into account only a small number of such basis functions is necessary which leads to a numerically efficient method. The performance of the GSD method can be improved further if the infinite sums over eigenmodes which have to be evaluated for each element of the characteristic matrix are replaced by the closed-form expressions given in [5] and [6].

Figs. 2 and 3 give some numerical results. Fig. 2 shows the electric field lines of the mode for which the converter has been designed ($TE_{0,1}$-to-$TE_{0,3}$-mode conversion). This mode is identical to the $TE_{0,3}$ mode corresponding to the circular waveguide at the right port of the converter. In Fig. 3 a so-called slot-mode is presented. A slot-mode is tightly bound to the slots which means that the inner circular waveguide region is nearly without field.

ANALYSIS OF THE WAVEGUIDE TAPER

The waveguide taper analysis makes use of a subdivision of the converter into waveguide steps (steps in the slot angle) and uniform waveguide sections. The generalized scattering matrix of a single step is calculated by a mode matching method. Then the scattering matrices of the individual waveguide junctions are cascaded to obtain the resulting matrix of the converter. In order to achieve good accuracy with this approximation the steps have to be sufficiently small. Therefore all propagating modes and a number of evanescent modes have to be taken into account.

In Figs. 4 and 5 some scattering matrix elements are presented. The converter has been designed for a $TE_{0,1}$-to-$TE_{0,2}$-mode conversion. The frequency has been chosen so that all higher-order modes are below cut-off. However, at the right port of the converter two modes are propagating. Fig. 4 gives the return loss corresponding to the $TE_{0,2}$-mode as a function of the axial coordinate ($z = 0$ and $z = L$ correspond to the right port and left port, respectively.) Because this mode is efficiently converted to the $TE_{0,1}$ mode, the return loss is small. On the other hand, the $TE_{0,1}$ mode at the right port of the converter does not fulfill the design criterion. This mode is converted to a slot-mode. Fig. 5 shows the corresponding return loss. Since the slots are short-circuited at $z = L$, the reflection of a mode which is converted to a slot-mode gets large at the end of the converter.

CONCLUSIONS

The analysis of an efficient $TE_{0,n}$-to-$TE_{0,n+p}$ mode converter in circular waveguides which makes use of the generalized spectral domain technique and a waveguide taper analysis has been presented. The numerical results underline the good accuracy and the high numerical efficiency of the method.

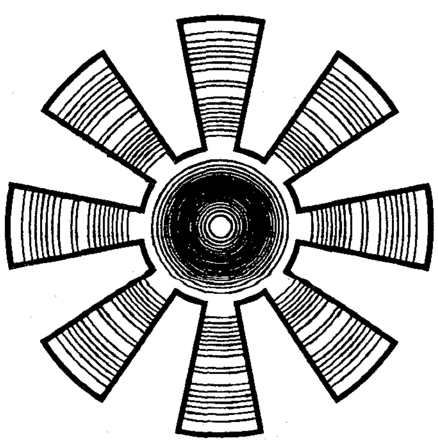

Figure 2: Electric field lines corresponding to the design mode of a $TE_{0,1}$-to-$TE_{0,3}$-mode converter.

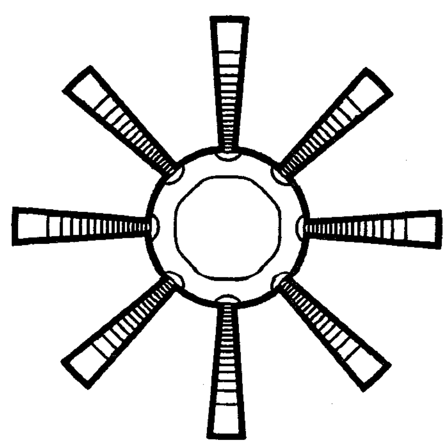

Figure 3: Electric field lines corresponding to a slot mode.

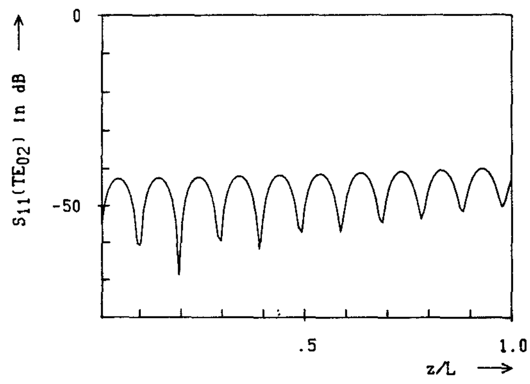

Figure 4: Return loss corresponding to the design mode of a $TE_{0,1}$-to-$TE_{0,2}$-mode converter.

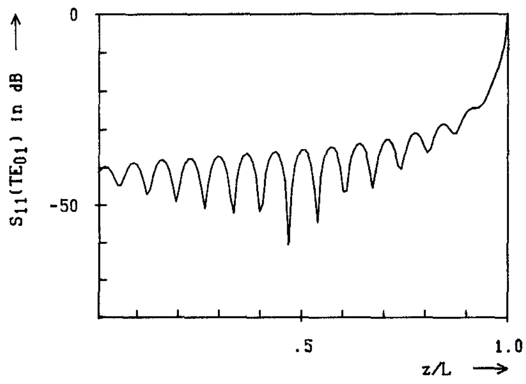

Figure 5: Return loss corresponding to a slot-mode.

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REFERENCES

[1] *H. Guo et al., "Special complex open-cavity and low-magnetic-field high-power gyrotron," IEEE Trans. Plasma Sci., vol. PS-18, pp. 326–333, 1990.*

[2] *S. Spira-Hakkarainen, K. Kreischer, and R. J. Temkin, "Slotted-resonator gyrotron experiments," IEEE Trans. Electron Devices, vol. ED-38, pp. 1544–1552, 1991.*

[3] *A. S. Omar and K. Schünemann, "Application of the generalized spectral-domain technique to the analysis of rectangular waveguides with rectangular and circular metal inserts," IEEE Trans. Microwave Theory Tech., vol. MTT-39, pp. 944–952, 1991.*

[4] *T. Itoh "Generalized scattering matrix technique," in Numerical Techniques for Microwave and Millimeter-Wave Passive Structures, Wiley, New York, 1989, pp. 622–636.*

[5] *J. A. Cochran, "Unusual identities for special functions from waveguide propagation analyses," IEEE Trans. Microwave Theory Tech., vol. MTT-36, pp. 611–614, 1988.*

[6] *A. Jöstingmeier, C. Rieckmann, and A. S. Omar, "Closed-form expressions for a number of Fourier-Bessel series encountered in the GSD method," IEEE Microwave Guided Wave Lett., vol. 2, pp. 391–393, 1992.*