TE_{11} TO TM_{11} COMPACT MODE CONVERTER FOR CIRCULAR WAVEGUIDE

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ABSTRACT

A compact, low cost, circular waveguide TE_{11} to TM_{11} mode converter has been designed and built using a scattering optimization method. A far field radiation pattern measurement indicates 98.1% of the output power to be in TM_{11}, which is very close to the theoretical efficiency of 98.84% for the mode converter.

INTRODUCTION

Plasma fusion research has provided some interesting challenges in the microwave arena, particularly in the development of mode converters for conversion of higher order gyrotron modes into lower order modes for plasma heating [1, 2, 3]. Many designs have been implemented which provide very high conversion efficiencies, however, their lengths are large as compared to the radial dimension of the waveguide [1, 2, 3, 4, 5, 6, 7]. These designs rely on a ripple wall structure, wherein a periodic perturbation of the waveguide radial dimension is used to achieve conversion between circularly symmetric modes. Haq *et al.* [8, 9] recently introduced a scattering optimization method for the design of both efficient as well as compact mode converters. This method relies on a strong disturbance of the field, thus achieving conversion in a shorter length. Numerical simulations were performed for a parallel plate waveguide geometry indicating high efficiencies of conversion and compact lengths.

High power microwave applications of mode converters typically involve circular waveguide implementations. To demonstrate the practical feasibility of the scattering optimization method for circular waveguides, a TE_{11} to TM_{11} mode converter has been designed, fabricated and tested. The test results indicate a 98.1% pure TM_{11} mode at the converter output, which is in close conformity with the theoretical results.

DESIGN AND FABRICATION

The mode converter was designed using easily available components to keep the fabrication cost low. A design frequency of 9.94GHz was selected for ease of measurement in the X-Band. The input waveguide radius is 0.468", so as to be sure that it is single moded and only the TE_{11} mode propagates. The output waveguide has a radius of 0.812" and it can propagate both the TE_{11} and TM_{11} modes. The profile of the scattering optimization mode converter consists of a staircase model, as shown in Figure 1. The width of each step in the staircase, ΔL, is the same and was chosen to be 0.25". The scattering optimization design procedure, as provided in [8], was then implemented. In this procedure, the surface profile of the mode converter is represented by the heights of the steps in the staircase model. This profile is then optimized to maximize the power in the required output mode. A mode matching solution involving 30 evanescent modes was used to formulate scattering matrices for the discontinuities at the step edges, which were then combined with the transmission matrices for straight sections to develop the generalized scattering matrix for the com-

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plete staircase structure. The power in the TM_{11} mode was optimized as a function of step heights, using a sectional, heirarchical optimization procedure. The final design is shown in Figure 1. It consists of 10 steps in the staircase, with a total length of 2.5" and a center frequency conversion efficiency of 98.84%. The mode converter was fabricated using standard copper/brass tubing and 0.25" thick aluminium sheet. Figure 2 shows a photograph of the fabricated mode converter. A coaxial SMA launcher was used to excite the TE_{11} mode in the input waveguide. The length of the guide was so selected that any evanescent modes excited at the input would be negligibly small at the input plane of the mode converter.

TESTING

A far field radiation pattern measurement method [10] was implemented to characterize the mode converter. For TE_{11} and TM_{11} modes with the same circular symmetry, the E_θ component of the far field can be written as [11],

$$E_{\theta(TE_{11})} = f(\theta)\frac{J_1(kasin\theta)}{sin\theta}cos\phi e^{-jkr}$$
$$E_{\theta(TM_{11})} = g(\theta)\frac{J_1(kasin\theta)}{1-(\frac{k_{11}}{ksin\theta})^2}cos\phi e^{-jkr}$$

The functions f and g are given in [11]. It can be seen that at $\phi = 0°$, $E_{\theta(TM_{11})}$ has a null at $\theta = 0°$ and $E_{\theta(TE_{11})}$ has a null at an angle θ_M, where $J_1(kasin\theta_M) = 0$. Thus, in the $\phi = 0°$ plane, if the power in E_θ at $\theta = 0°$ and $\theta = \theta_M$ is measured, the relative content of the TM_{11} and TE_{11} modes in the output waveguide can be established. There is, however, one major limitation of this method. It assumes that all the modes in the waveguide are perfectly coupled into free space and there are no reflections or cross-coupling at the open end of the waveguide. This assumption is valid for modes that are far above cutoff, but not in the present case. To resolve this issue, a dual mode horn antenna was fabricated to produce a smooth transition into free space [12]. The horn exit plane radius is 2.72", which is wide enough for a smooth coupling of TM_{11} and TE_{11} modes to free space. The measured far field pattern of the horn indicated 98.1% power to be in TM_{11} mode. The bandwidth around the center frequency for which the efficiency decreased by 1% was found to be 40 MHz. The measured power and the bandwidth are in close agreement with the theoretical values.

CONCLUSION

The scattering optimization method, which was formerly introduced in the realm of parallel plate waveguides [8, 9], has been successfully implemented to build a circular waveguide TE_{11} to TM_{11} mode converter, giving a 98.1% pure TM_{11} mode. The mode converter was built using readily available components with minimum effort and cost. This demonstration, therefore, establishes the viability of the scattering optimization method for the design of compact mode converters for high power gyrotron outputs.

Apart from conversion of a single mode at the input to a single mode at the output, this method can be used to convert a set of modes into a single mode, provided the complex mode coefficients for each input mode are known. The method therefore can also be used to design efficient mode filters for gyrotron outputs. Some interesting applications in optics relate to the design of aperiodic gratings in confined structures. Another application of the method is the development of compact mode synthesisers for laboratory demonstrations, which would allow conversion of a dominant waveguide mode into a higher order mode of concern.

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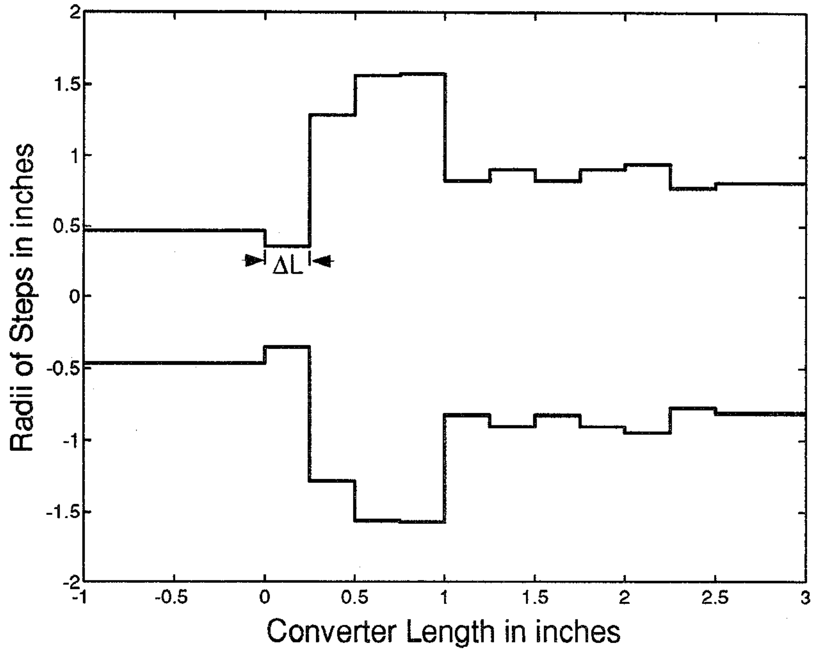

Figure 1 : Cross-section view of the TE_{11} to TM_{11} Circular Waveguide Mode Converter.