Corrugated mode converters with varying wall impedance

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ABSTRACT
Efficient transmission of high power microwaves and their launching can be achieved in corrugated waveguides by particular mixtures of hybrid modes. The optimum coupling of a free space Gaussian beam into a corrugated waveguide as well as forming of suitable launch patterns for diverse applications are investigated. There are many different schemes for mode conversion in corrugated waveguides to meet the specific requirements of different users. This paper reports on three different principles, a calculation method and a new type of mode converter based on varying the wall impedance, without inner diameter change.

INTRODUCTION

The successful application of high frequency microwaves up to 170 GHz (generated in gyrotrons up to 1 MW) for Electron Cyclotron Resonance Heating (ECRH) in fusion plasmas [1] required an ongoing design of various transmission systems in the last 30 years. This has resulted in development of components based on different principles for mode transmission and mode converting, as well as in use of two numerical calculation methods for describing of modes in corrugated waveguides: Scattering Matrix Code and Coupled Wave Equations. Scattering Matrix Code applications on mode converters, tapers, resonators are described in numerous publications [e.q. 2,3].

Calculations on hybrid mode mixtures in corrugated waveguides, their generation, propagation and optimization of mode converters producing particular mixtures with the coupled wave equation method are presented.

GENERATION OF HE_{11}+HE_{12} MODE MIXTURES

Long distance high-power mm-wave transmission from gyrotron to plasma-device with very low ohmic losses and high mode purity can be accomplished by quasi-optical transmission or by oversized, circumferentially corrugated circular waveguide [4]. Such waveguide is carrying the almost perfectly linearly polarized HE_{11} mode with an ohmic attenuation less than 0.01 dB/m.

A better coupling of the Gaussian beam into the waveguide can be realized by radiating particular mixtures of the hybrid modes HE_{11} and HE_{12}. The HE_{12} mode content can be generated in a mode converter directly from the input HE_{11} mode. Three principles are discussed:

A. Periodic change in waveguide diameter

Periodic axially symmetric perturbation of the waveguide walls causes a change of the second mode index. The coupled mode equations can be solved with coefficients describing the coupling between hybrid modes in corrugated waveguides [5]. Mode converters for two particular mixtures of HE_{11}+HE_{12}, (80+20)% and (90+10)% for a waveguide diameter of 27.79 mm at 70 GHz have been optimized [6].

B. Tapered waveguide diameter

For high power applications where a large overmoded waveguide diameter is needed, periodic mode converters become very long. Compact mode converting tapers at 140 GHz with optimized diameter, corrugation depth and taper shape were designed and produced. Horns generating a mode mixture of 80 % HE_{11} and 20 % HE_{12} were built in transmission lines systems with diameters of 87.0 mm and a taper length of 570 mm [6].

C. Varying wall impedance

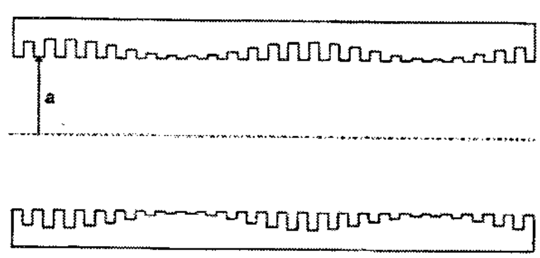

Fig.1. Corrugation shape in a mode converter with periodic change of the corrugation depth.

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This third principle allows the use of a mode converter in a straight waveguide with a continuous waveguide diameter. A scheme is shown in Fig. 1.

Theory

Mode conversion due to change of the diameter and wall impedance in circumferentially corrugated waveguides was investigated in [5]. From Maxwell's equations, the general integral formulas for coupling coefficients were derived, and explicit expressions for the coupling coefficients were obtained. In Fig.2, mode coupling between HE_{11} and other HE_{1n} or EH_{1n} modes as function of corrugation depth is shown for constant width w and period p of the corrugations.

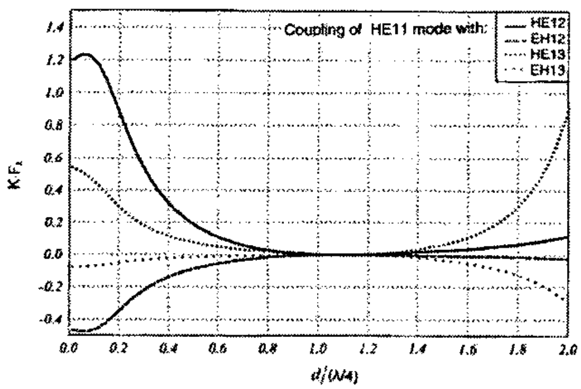

Fig. 2. Coupling coefficients due to varying wall impedance – as function of the normalized corrugation depth (f=70 GHz, a=13.9 mm).

Optimization results

The mode conversion of the input HE_{11} mode and the HE_{12} can be optimized by different periods of the perturbation, the number of beat-wavelengths and the corrugation depth. As plotted in Fig. 2, significant coupling occurs only at corrugation depths between 0.1 λ/4 and 0.6 λ/4. For a proof-of-principle, a 70 GHz, I.D.=27.8 mm mode converter was designed with a variation of the corrugation depth given by:

$$d(z) = d_0 - d_1 \sin[(2\pi/\lambda_w)z + \varphi_0] \quad (1)$$

The wanted mode mixture of 85% HE_{11} and 15% HE_{12} was achieved after 4 beat-wavelengths, each λ_w=0.12 m, with d_0=0.77mm and d_1=0.3mm, and a phase shift of φ_0=1.57. In Fig. 3, the power distribution of the two modes is plotted as function of the converter length. At z=480mm, the maximum spurious mode was 1.7% in the EH_{12} mode.

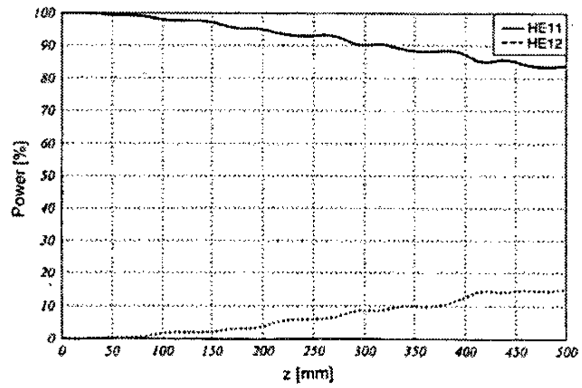

Fig. 3. The power distribution of HE_{11} and HE_{12} modes, as function of the mode converter length (70 GHz, I.D.=27.79 mm).

First measurement results and discussion

First far field measurements delivered a pattern with strong sidelobes and an asymmetric shape. Since the phase difference of HE_{11} and HE_{12} mode is very sensitive for the radiation pattern it probably deviates from the calculated value, and additional measurements are needed to clarify the problem. Some unexpected spurious modes, generated in the mode converter additional to the predicted HE_{12} mode also had influence on the pattern. Wavenumber-spectrometer measurements have shown a higher amount of additional spurious modes (EH_{12}, HE_{13}). Further calculations and measurements are underway to describe and verify the theory and design of the mode converter.

LITERATURE

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