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A multiple-hole input coupler for a 372 GHz gyro-travelling wave amplifier

Liang Zhang, Jason Garner, Wenlong He, Craig R. Donaldson and Adrian W. Cross
Department of Physics, SUPA, University of Strathclyde
Glasgow, Scotland, UK, G4 0NG
liang.zhang@strath.ac.uk

***Abstract*—The design of a multiple-hole coupler that operates at a center frequency of 372 GHz for use in a gyrotron traveling-wave amplifier (gyro-TWA) is presented. In simulations, the coupler achieved 35% bandwidth from 289GHz to–410 GHz with transmission losses of -0.5 dB predicted.**

Keywords—input coupler; gyrotron traveling-wave amplifier; multiple-hole coupling;

I. INTRODUCTION

Gyrotron travelling wave amplifiers (gyro-TWAs) can be used in applications such as electron paramagnetic resonance and dynamic nuclear polarization in a nuclear magnetic resonance system. Currently, a gyro-TWA that operates at a center frequency of 372 GHz is being studied for these applications. The gyro-TWA was simulated to have 5% bandwidth and ~200 W output power when driven by 30 kV, 0.5 A electron beam.

The experimental configuration of the higher-frequency gyro-TWA is similar to a W-band gyrotron TWA that has been designed built and tested [1], as shown in Fig. 1. It includes the cusp electron gun (1) [2], the superconducting magnet (2 and 3), the helically corrugated interaction region [3], and the output launcher (6) [4, 5]. The input microwave signal is coupled into the system through a microwave window (4) then transported to the interaction region via a coupler. For the microwave components operating near the terahertz region, the dimension and the Ohmic loss caused by the reduction in the skin depth are two major problems. The efficient coupling of the microwave radiation is important to the overall performance of the device, not only to reduce the cost of the high frequency source, but also minimize the possibility of oscillation in the system.

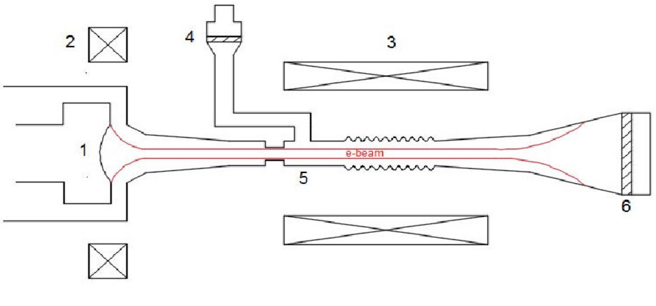

Fig. 1. The schematic of the 372 GHz gyro-TWA.

A side-wall coupler [6] has been developed for a W-band gyro-TWA, and the simulated and measured results show that a good transmission coefficient can be achieved by using a rectangular-to-circular T-junction and a broadband reflector [7]. The W-band design can be scaled to higher frequencies, but the tolerance studies show that the bandwidth is sensitive to the dimensions of the rectangular hole. In this paper, an input coupler based on multiple-hole coupling configuration is presented. The multiple-hole coupler has the advantage of not requiring a cutoff waveguide or a reflector, as well as possessing a wider bandwidth [8].

II. THE MULTIPLE-HOLE COUPLER

Different with the 3-port T-junction coupler, a multiple-hole coupler is a 4-port component. Its configuration is shown in Fig. 2. The input microwave signal is fed at port 1 via a rectangular waveguide, and the electromagnetic wave was coupled into the circular waveguide through a series of common wall apertures. With proper design, a waveguide directional coupler will allow high coupling between port 1 and 2, and with good isolation at port 3 and 4. For the input coupler in the 372 GHz gyro-TWA, the transmission between port 1 and 2 needs to be as high as possible for the operating TE_{11}, mode and the coupling to the other ports should be as small as possible.

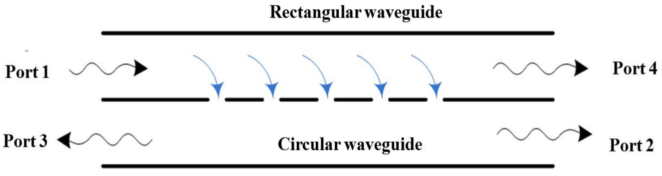

Fig. 2. Power flow of the 4-port directional coupler.

The field profile through an individual coupling hole can be described by the small aperture coupling theory between transmission lines. The coupling C and directivity D for a small apreture with uniform displacement can be written as

$$C = \frac{\sum_{i=1}^{i=N} a_i cos\left(\frac{2i-1}{2N-1}\right) L(\beta_1 - \beta_2)/2}{\sum_{i=1}^{i=N} a_i} \qquad (1)$$

$$D = \frac{\sum_{i=1}^{i=N} a_i cos\left(\frac{2i-1}{2N-1}\right) L(\beta_1 + \beta_2)/2}{\sum_{i=1}^{i=N} a_i} \qquad (2)$$

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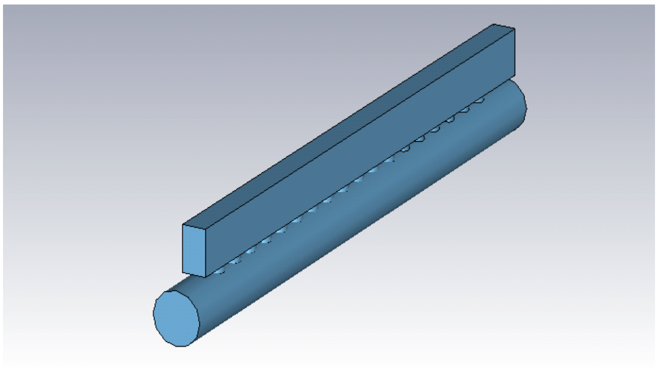
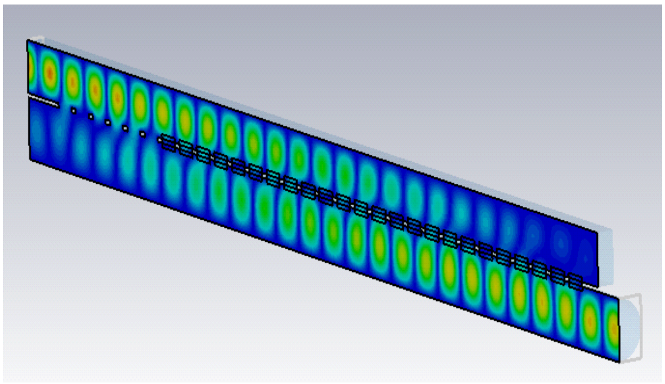
where L is the coupling section length, and $2N$ is the aperture number. β_1, β_2 are the phase constants of the coupling modes. In this design, the two coupling modes are the TE_{10} mode in rectangular waveguide and TE_{11} mode in circular waveguide. By using these equations, the initial dimensions of the multiple-hole coupler can be calculated. It shows that the bigger N is, the higher coupling can be achieved. However, it also means the whole structure becomes longer and it is not preferred in higher frequency due to Ohmic loss. Fig. 3(a) and (b) shows the geometry of the multiple-hole coupler with $N = 15$ and the simulated electric field pattern obtained from 3D FDTD code CST Microwave Studio.

Further simulation and optimization shows that even a 12-hole coupler can achieve good results, as shown in Fig. 3(c). as well as being is more feasible for the manufacture. The coupling coefficient can be -0.5 dB with 35% bandwidth, from 289 GHz to 410 GHz, which covers the bandwidth of the gyro-TWA.



(a)



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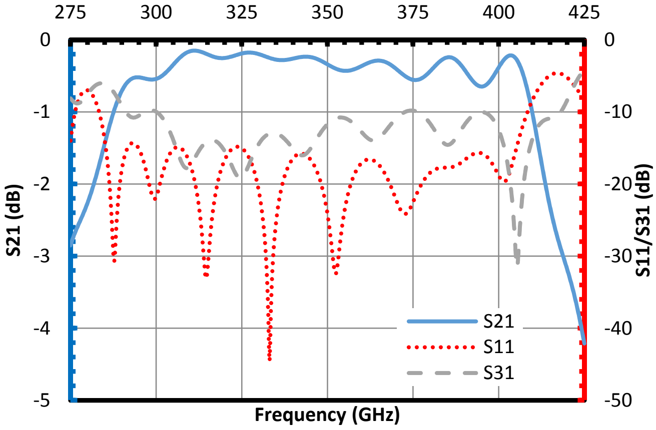

(c)

Fig. 3. The performance of the multiple-hole coupler. (a) structure, (b) electric field pattern, and (c) the simulated scattering parameters.

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