Simulation of Rectangular TE_{10} to Circular TE_{11} Terahertz Mode Converters

J. R. Garner, L. Zhang, C. R. Donaldson, A. W. Cross, A. D. R. Phelps and W. He
Department of Physics, SUPA, University of Strathclyde Glasgow, Scotland, UK

***Abstract*— Two designs of fundamental mode rectangular to circular waveguide TE_{10} to TE_{11} mode converter are presented. The waveguide transitions are optimized for operation as an input coupler on a 372 GHz gyro-TWA for Dynamic Nuclear Polarization (DNP) enhancement of NMR imaging. A T-junction input coupler and a multiple hole directional coupler were optimized for operation between 360 – 384 GHz. The T-junction coupler and the multiple hole coupler exhibited bandwidths of 10% and 35% respectively with a high coupling factor of > -1 dB.**

I. INTRODUCTION

Gyro-devices are sources of coherent EM radiation based on the cyclotron resonance maser (CRM) instability [1] capable of delivering high power microwave signals at high frequencies. Applications of the gyro-devices include plasma heating, RADAR systems and spectroscopes. A gyrotron-travelling wave amplifier (gyro-TWA) operating at a centre frequency of 372 GHz is being developed for applications of Electron Paramagnetic Resonance (EPR) and Dynamic Nuclear Polarization (DNP) in a Nuclear Magnetic Resonance (NMR) system. High power, wide bandwidth gyro-amplifiers are ideal for pulsed EPR- and DNP-NMR applications. The high frequency research is a development from previous W-band investigations [2 – 4]. The application of a gyro-amplifier on a DNP-NMR imager can result in a factor of 100x increase in spectral resolution compared to conventional NMR spectroscopy.

Efficient coupling of electromagnetic radiation into the gyro-TWA interaction cavity is important to the overall performance of the gyro-TWA [5 – 6]. The target performance characteristics of the low-THz gyro-TWA are shown in Table I. At frequencies approaching the THz region, the coupling process encounters tremendous difficulties due to the sub-mm dimensions and the subsequent increase in waveguide losses caused by a reduction in the skin depth (~100 nm). In this paper the theoretical and numerical designs of two fundamental mode input couplers, a T-junction and a multiple hole coupler, are presented.

TABLE I: TARGET GYRO-TWA PERFORMANCE.

Frequency (GHz)	360 - 384
Output Power (W)	200
Gain (dB)	~ 40
Beam Voltage (kV)	30
Beam Current (A)	0.5

II. T-JUNCTION INPUT COUPLER WITH BRAGG REFLECTOR

The proposed mm-wave coupler design is based upon a 3-port rectangular-to-circular T-junction. A waveguide reflector is used to terminate signal propagation at one port. A step down waveguide reflector with R_C (cut-off radius) << R (cavity radius) has a high reflectivity; however, at high frequency, the reduced beam tunnel radius may result in

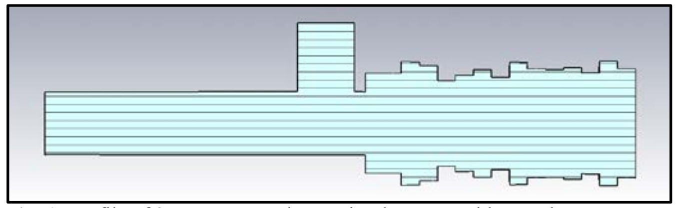

Fig. 1: Profile of 3-port rectangular-to-circular waveguide coupler.

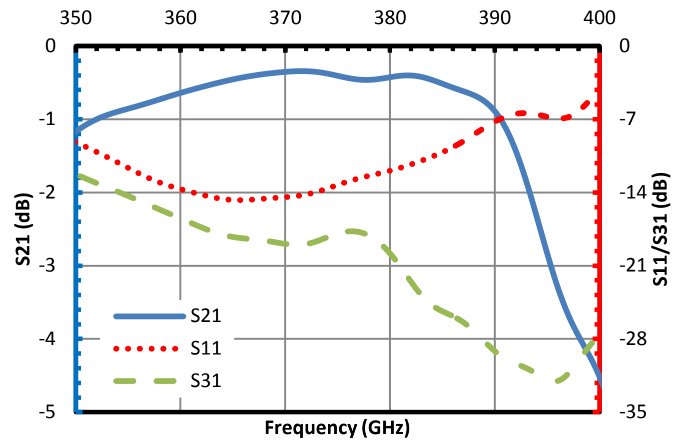

Fig. 2: S-parameters of a TE_{10} – TE_{11} T-junction coupler with Bragg reflector.

electron interference. A Bragg reflector is an oversized waveguide structure with radial periodicity which can be used as a method of providing frequency selective feedback. A schematic of the 3-port coupler with attached corrugated waveguide reflector is shown in Fig. 1.

The numerical scattering parameters of an optimized TE_{10} – TE_{11} T-junction low-THz coupler with Bragg reflector is shown in Fig. 2. Transmission loss of > 1 dB was achieved over a ~ 10% bandwidth (352 – 390 GHz) which includes the operational frequency range (360 – 384 GHz) of a low-THz gyro-TWA.

III. MULTIPLE HOLE COUPLER

A low-THz multiple-hole input coupler was also evaluated through numerical simulations. A power flow diagram of the coupler is shown in Fig. 3. The multiple-aperture coupler is a four port device consisting of two transmission lines coupled through a series of common wall apertures. A linear profile of circular apertures is employed in the design to enhance manufacturability. The coupled transmission lines can be designed for arbitrary power division with common coupling factors of (3, 6, 10, 20) dB; however, a 0 dB mode coupler is required at the input of the 372 GHz gyro-TWA to allow for high efficiency interaction.

Fig. 4 shows that an operational frequency range of 121 GHz (~ 35% bandwidth) is achieved with a 12-aperture coupler. Investigation into an increased hole number show that a high coupling factor may be achieved when a perfect electrical conductor is used. In practice, however, the increased length with result in increased waveguide wall

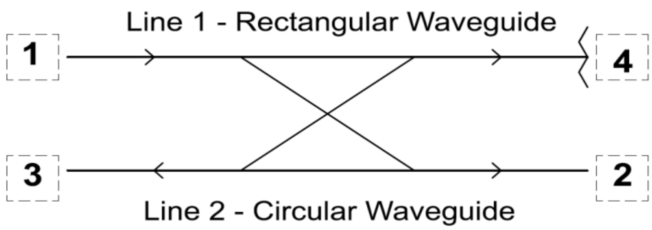

Fig. 3: Power flow of 4-port directional coupler with Port 1 – Input, Port 2 – Coupled, Port 3 – Isolated and Port 4 – Through.

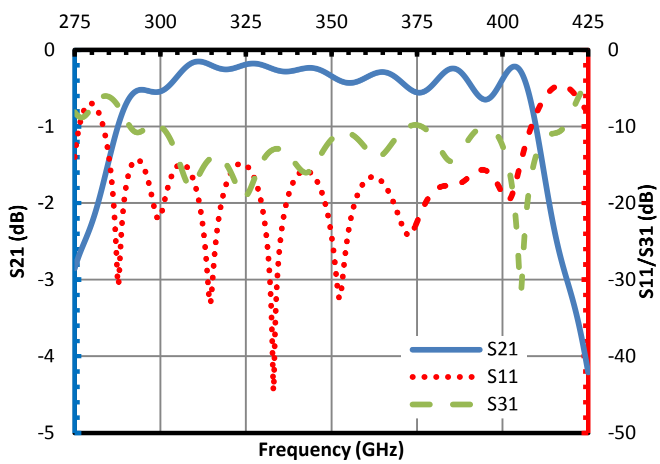

Fig. 4: Transmission and reflection of 372 GHz 12-hole input coupler.

losses. Therefore, the 12-aperture coupler design will provide the optimum performance. The use of a matched multiple hole waveguide transition eliminates the requirement for a waveguide reflector; therefore the manufacturing complexity is reduced compared to the T-junction coupler.

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