Output coupler for a THz gyro-amplifier

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***Abstract*— This paper presents the design and simulation results of an output coupler for a gyro-amplifier operating at THz frequencies. The combination of a smoothly profiled horn and multilayer microwave window allow for the almost total conversion of the TE_{11} mode to the Gaussian-like HE_{11} mode while forming a vacuum tight seal with very low reflections. This assembly operates over the 360-384 GHz frequency range.**

Keywords*— *gyrotron traveling wave amplifier, output coupler, multilayer window, Gaussian horn

I. Introduction

High power, and broadband, amplifiers are in demand, especially at ever-increasing frequencies where there are is a lack of capable devices. The gyrotron traveling wave amplifier (gyro-TWA), a fast-wave device, has great potential to meet that demand. In comparison to the TWT-like amplifiers (part of the slow-wave family) the gyro-TWA benefits from having an enlarged interaction region and hence does not rely on a slow-wave structure and they do not suffer the same power handling limitations. Further enhancement to the gyro-TWA's naturally wide bandwidth can be made through changing its interaction region to a helically corrugated interaction region (HCIR) [1]. A gyro-TWA operating in the W-band frequency range, and based on a HCIR in conjunction with a cusp electron gun [2,3], was measured to have 3.4 kW output power over 91-96.5 GHz [4]. Further experiments have been conducted to demonstrate its frequency agility in amplifying a 1 GHz frequency-swept input signal [5]. Based on this design, a gyro-TWA operating centrally at 372 GHz with 5% bandwidth is being developed. Similarly the beam-wave interaction will be driven by a cusp electron gun with a HCIR [6]. Further components will be required including input coupler [7] with a pillbox window [8], polarizer [9], and an output coupler, which will be the topic of this paper. The output coupler will contain a mode converting horn [10,11] and a vacuum window [12,13]. This paper will consider these as separate components initially as well as together in a finished assembly.

A corrugated horn can, and usually is used to, achieve the conversion into a very high purity Gaussian mode. However, the gyro-TWA will be operational only in a UHV environment, due to the use of a thermionic cathode corrugated horns have caused issues in achieving the desired vacuum. When designed to operate at high frequencies the corrugated horns are usually made through electroforming, rather than direct machining, and have a large surface area, due to the numerous corrugations, which leads to long out-gassing times. An attractive alternative is to use a smoothly profiled horn [14].

This horn is shown in Fig. 1, it consists of two sections a smoothly profiled taper (shown within the L_1 region of Fig 1), and a linear taper (L_2 in the fig). The smoothly profiled section is a series of steps that convert the TE_{11} mode to the TE_{1n} and TM_{1n} modes and if properly designed will give the desired mode mixture. If that mode mixture is of the required amplitude with desired phase the mode will be similar to the fundamental Gaussian. Usually this would be 85% TE_{11} and 15% TM_{11}, with appropriate phase.

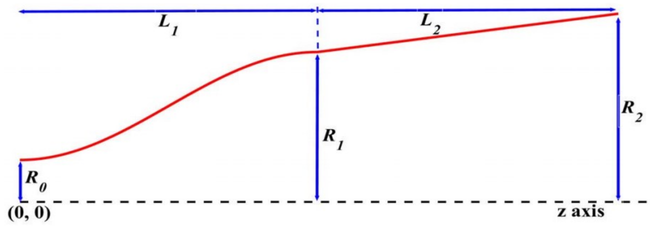

Fig. 1 A schematic of the smoothly profiled horn configuration.

The microwave window has many design choices such as pillbox, Brewster and multilayer window. The multilayer type was chosen for output coupler, particularly based on the authors experience with realizing such a window. It is based on combining multiple dielectric discs, which are separated by some distance, to create a sandwitch of varying dielectric layers. When using more layers the bandwidth can be increased, but the complexity and reliance on tight tolerances will also increase as the frequency of operation is increased. It was found that in this study a suitable configuration would be 5 layers consisting of 3 dielectric discs.

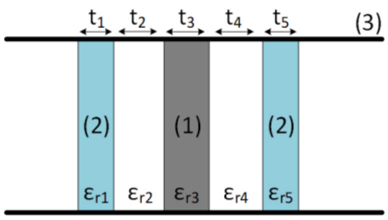

Fig. 2 A schematic of the multilayer window configuration.

II. Simulation and Measurement results

Conveniently for both of these components they can be speedily analyzed and optimized using a mode matching method. Through this a single solution can take some seconds, compared to the full 3D analysis using CST Microwave Studio which will take minutes to hours.

The smoothly profiled horn was analyzed as a large number of small waveguide steps of increasing diameter. A global multiple-objective optimization method was employed. The value of R_0 was set by the output from the waveguides in the interaction circuit, at 0.7 mm radius. The value of R_2 was set by the designed multilayer window of 3.2 mm radius. Thus, the profile in-between was numerically optimized to achieve a less than 30 dB reflection, as shown in Fig. 3.

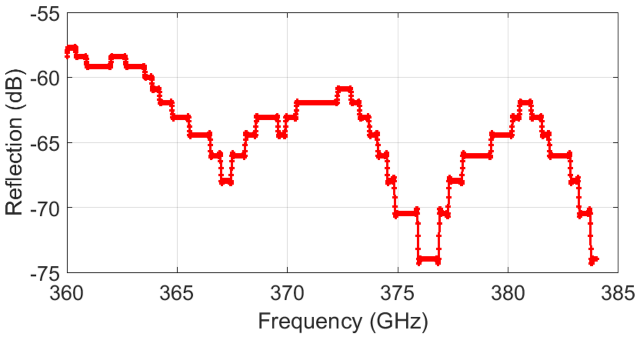

Fig. 3 Calculated optimized reflection through the smoothly profiled horn.

The multilayer window consists of a central alumina disc, with relative dielectric constant (R_c) of 9.4, flanked by two quartz discs (R_c = 3.75) separated with a vacuum/air gap. All the dielectric layers were the same diameter. Thus, the free parameters in the optimization were only the thickness of those layers. Some compromise has to be made however, as the central disc will experience a pressure differential and thus it needs to be mechanically strong and robust. Therefore, this disc cannot become too thin. The optimized window shows that better than -30 dB reflection can be achieved over a 7% bandwidth as shown in Fig. 4.

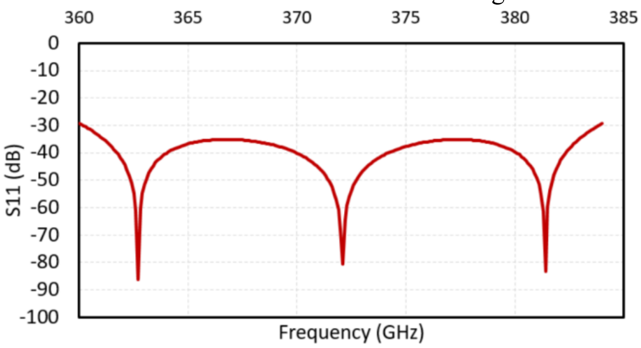

Fig. 4 Calculated optimized reflection through the smoothly profiled horn.

III. Conclusion

An output coupler for a THz gyro-TWA has been designed, simulated and optimized. It consists of a smoothly profiled horn and multilayer window. Each of these can achieve a better than -30 dB reflection over the desired passband. Work is on-going to construct and measure these ~370GHz components using a vector network analyser.

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