Smoothly profiled quasi-optical output launcher for a W-band gyro-TWA

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***Abstract*—A W-band quasi-optical horn with smoothly profiled circular inner surface was optimized and measured for a gyrotron traveling wave amplifier. It was designed to achieve low reflection, high fundamental Gaussian mode content and high directivity in the desired frequency range of 90 to 100 GHz. In the measurement, the reflection of the TE_{11} mode was lower than -37 dB and the directivity was ~27 dB with side lobes better than -30 dB.**

Keywords—horn, smoothly profiled horn, gyrotron traveling wave amplifier, Gaussian mode

I. INTRODUCTION

Gyro-devices [1-2] are capable of producing high power coherent microwave radiation at mm-wave and sub-mm-wave frequencies. They can be used in applications such as radar, plasma diagnostics, high-field electron paramagnetic resonance (EPR) spectroscopy, and so on. At Strathclyde University, a W-band gyrotron traveling wave oscillator (gyro-BWO) has been developed to provide a continuously tunable microwave radiation over the frequency range of 88 to 102.5 GHz with a maximum output power of 12 kW [3]. An amplifier based on the same cusp electron gun and magnet system, but with upgraded input coupler [4-6] and output launcher [7-8] was also experimental studied. It was able to amplify 0.5 watt signal to ~3 kW output in the frequency range of 91 to 96.5 GHz matching the frequency tenability of the input drive millimeter wave signal.

For application such as radar and EPR, the microwave radiation with high fundamental Gaussian mode content is preferred. Therefore a mode converter to convert the output TE_{11} mode from the helically corrugated interaction region into a quasi-Gaussian mode is required. Two corrugated horns had been designed and measured for the W-band gyro-TWA and excellent performance was achieved. However, it was found that the corrugated horns were not ideal for the ultra-high vacuum environment. The corrugated horns [9] had large surface area because of the corrugations. Meanwhile the electrochemically grown copper surface took a much longer time to reach vacuum (10^{-7}mbarr) due to out-gassing as compared with directly machined copper. It was therefore decided to employ a smoothly profiled horn [10] to replace the corrugated horn, whilst not compromising the microwave performance. In this paper, the design and measured results are presented.

II. DESIGN OF THE SMOOTHLY PROFILED HORN

The smoothly profiled horn can be represented as a discrete series of circular waveguide steps and therefore can be efficiently simulated by the mode-matching method, as shown in Fig. 1. In a circular waveguide step, the mode conversions among the TE_{1n} and TM_{1n} modes occur, generating a mixture of these modes at the output port. A quasi-optical field pattern can be achieved if the modes have desired amplitudes and phases.

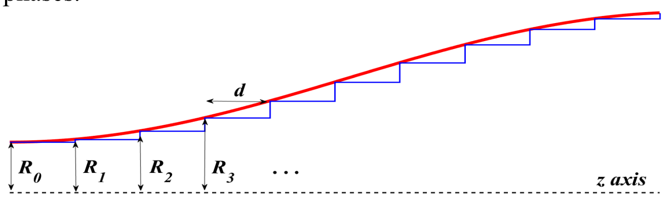

Fig. 1. the parameter define of the profiled horn.

The overall scattering matrix of the whole horn structure can be obtained by cascading all the scattering matrix of the waveguide steps and the straight waveguide sections, the transmission and reflection of the modes can therefore be obtained. With the given mode contents at the input port, the mode contents at the output aperture can be calculated. The electric field E_{ap} at the output aperture of the horn can also be obtained which can be expressed as the sum of the TE and TM modes in the circular waveguide.

Various key parameters can be used to evaluate the performance of the horn, such as the gain or directivity, the far field pattern in the E- and H-plane and the cross polarization. The normalized far field radiation pattern of the field at a circular aperture can be evaluated from the aperture field using the field integration method. In our study, the reflection of the TE_{11} mode and the coupling coefficient of E_{ap} to the fundamental Gaussian mode E_{LG} are two important parameters.

The horn profile [11, 12] used in this study were based on the $\sin^p$ function. The whole profile is divided into two parts. The first part is defined by

$$\mathrm{R(z)} = R_0 + \frac{(R_1 - R_0)z}{L_1} sin^{p_1+(p_2-p_1)\frac{z}{L}}\left(\frac{\pi}{2}\cdot\frac{z}{L_1}\right),$$
$$0 < z < L_1$$

where R_0, R_1 and L_1 are defined in Fig. 2. It is then followed by a conical circular waveguide taper from radius R_1 to R_2 with a length of L_2. The use of the linear taper section allowed a short nonlinear section which could be directly machined with less difficulty and cost. The final optimized geometry was with the parameters $R_0 = 2.8\, mm$, $R_2 = 12.56\, mm$, $p_1 = 3.445$, $p_2 = 1.546$, $R_1 = 8.41$ mm, $L_1 = 50.5$ mm and $L_2 = 158.0$ mm. The coupling coefficient to the E_{LG} mode is better than 97% and the reflection is less than -56 dB.

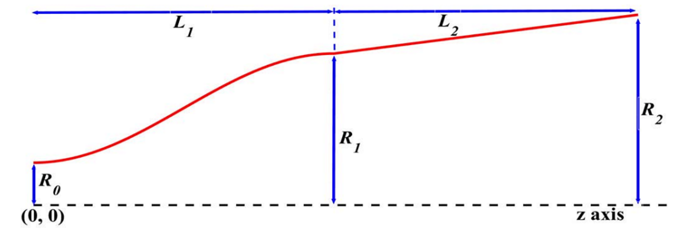

Fig. 2. parameter definition of the proposed horn.

III. Measurement results

The designed horn was divided into two parts and directly machined separately. They were then brazed together to form one piece with two stainless steel vacuum flanges one at each end also attached during brazing. The whole assembly was measured using an Anritsu ME7808BW-band vector network analyzer. The reflection was measured to be lower than -37 dB over the desired frequency range of 90 to 100 GHz. The far field measurement of the horn is shown in Fig. 3. The directivity in the measurement was found to be 27 dB with the side lobes lower than -30 dB. The cross-polar level was -25 dB in accordance with simulations.

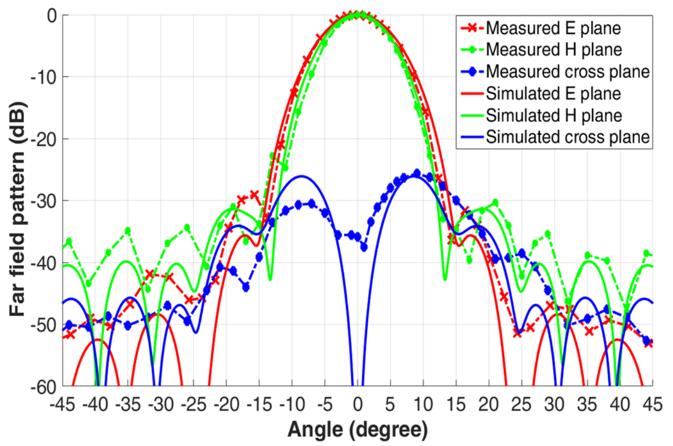

Fig. 3. The simulated and measured far field patterns of the smooth-walled horn connected with a multilayer microwave window at 95 GHz.

IV. Conclusion

This paper presents the design and experimental measurement of a smoothly profiled horn for a W-band gyro-TWA. It achieved a low input reflection of less than -37 dB and coupling to a fundamental Gaussian mode of over 97%.

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