Design and simulation of a 0.37 THz gyro-TWA

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Abstract— This paper reports the work being carried out to realize a gyrotron-traveling wave amplifier operating at 372 GHz based on a helically corrugated interaction region (HCIR). The high magnetic field will be provided through a cryo-free superconducting magnet. There are many components in the waveguide circuit, which must achieve very low reflection targets. The design and simulation results of the gyro-TWA, the cusp electron beam source, the sub-millimetre wave components, as well as measurement of the HCIR will be presented in this paper.

I. INTRODUCTION

THE demand for THz amplifiers is ever increasing and the gyrotron-traveling wave amplifier (gyro-TWA) is a natural and ideal choice to meet those needs. Unlike conventional TWT-like amplifiers, gyro-TWA's [1,2] operate with a fast-wave interaction and so do not require a slow-wave structure. It further benefits from an enlarged interaction region. These properties greatly assist the design of the gyro-TWA's operating at very high frequencies. It allows the output power to be comparatively large, as well as reducing the effect of manufacturing techniques and tolerances, therefore making it possible to construct components that can operate at sub-millimetre wavelengths. At the University of Strathclyde a gyro-TWA operating at 0.37 THz is being designed which has a calculated output power in the 100's W range. The beam-wave interaction will be driven by an electron beam produced by a cusp gun [3] and traveling through a helically corrugated interaction region (HCIR) with a magnetic field of 7.3 T. A cryogenic-free superconducting magnet (SCM), as shown in Fig. 1, will provide the required field. The HCIR enables a favorable dispersion characteristic allowing for even more broadband amplification, higher power capabilities, reduced effect of electron beam velocity spread and a second harmonic interaction [4]. Further waveguide components will be required such as a circular polarizer (5) [5], input (3) [6] and output couplers (8) [7] and microwave windows (3,9) [8], see Fig. 2. This paper will present the design of the gyro-TWA, its components with particular focus on the design and measurement of the HCIR.

II. HELICALLY CORRUGATED INTERACTION REGION

The HCIR offers unmatched capabilities in achieving broadband, high power amplification. Two modes, in this case the first spatial harmonic of the TE_{11} mode and the TE_{21} mode, couple together to form an eigenwave that is near ideal for an amplifier. It has reduced values of k_z which minimizes the effect of Doppler broadening of the electron beam line. As well, at low frequencies the eigenwave will mostly follow the TE_{11} mode, while at higher frequencies it will be determined by the TE_{21} mode, at the transition between modes it is a combination of them both. If the geometrical parameters of the HCIR are set properly then a straight dispersion line in this region can be achieved, which can be well-matched by the electron beam line over a very wide bandwidth.

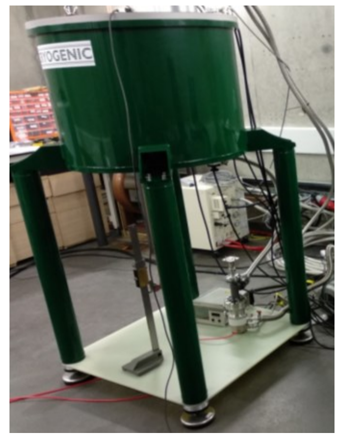

Fig. 1 Superconducting magnet

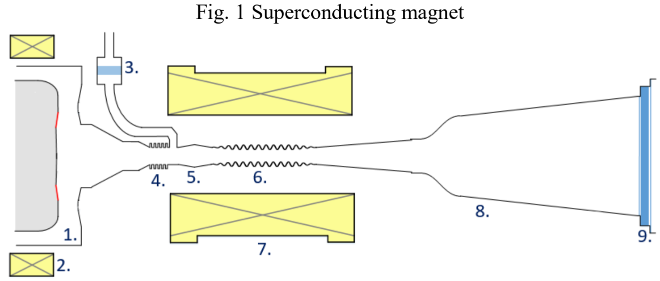

Fig. 2 Schematic of the gyro-TWA

The HCIR was designed for this gyro-TWA through analytical calculation and then its beam-wave interaction properties confirmed through the 3D PIC code MAGIC. The optimal 3-fold HCIR is found to have a corrugation amplitude of 42 μm with a nominal diameter of 0.760 mm and corrugation period of 0.882 mm. Of course such a guide cannot be directly machined from solid copper so the electroforming method was chosen as a viable solution. This requires an aluminium mandrel and the scale of the corrugations, small nominal diameter and relatively long length of the guide made the manufacturing of such a mandrel to be a technically challenging task which was eventually overcome. Electrochemical deposition of copper on the aluminium mandrel with the aluminium mandrel later removed resulted in the 3-fold HCIR, as shown in Fig. 3.

A vector network analyser (VNA) was used to measure the transmission and reflection from the HCIR [2]. The VNA-measured dispersion agreed well with the numerically calculated values, as shown in Fig. 3, which showed that the grown copper waveguide was accurately made.

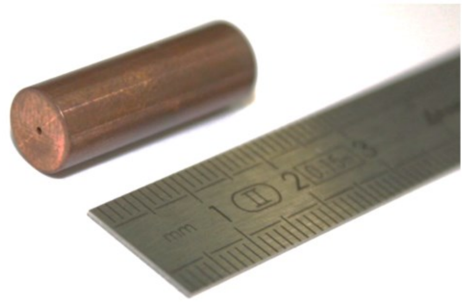

Fig. 3 The electroformed helically corrugated interaction region.

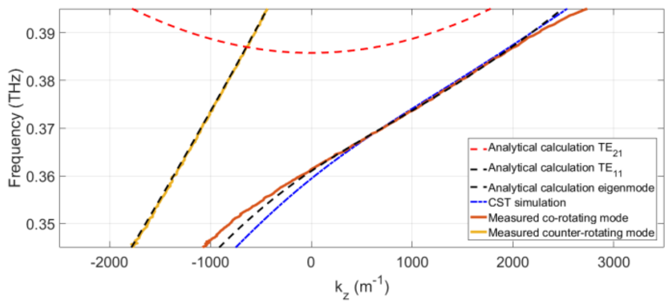

Fig. 4 The calculated, numerically simulated and measured dispersion characteristic of the 3-fold HCIR.

III. CUSP ELECTRON GUN

An axis-encircling electron beam is ideal for harmonic operation of gyro-devices, such as in the HCIR, as the mode selectivity nature of such a beam requires that the harmonic number is equal to the azimuthal index of a waveguide mode for effective beam wave coupling [9], which leads to a reduced possibility of parasitic oscillations. The principle of the cusp gun is based on the conservation of canonical momentum. When the electron beam passes through a magnetic field reversal an axis-encircling annular electron beam is produced [10]. The electrons gain transverse velocity mainly due to $V_z \times B_r$ force in the cusp region. It is possible to show that the alpha value of the beam in the downstream uniform B field region is governed by Eq. (1):

$$\alpha = \frac{v_\perp}{v_z} = \sqrt{\frac{-r_0^2\eta^2 B_c B_0}{\gamma^2 v^2 c^2 + r_c^2\eta^2 B_c B_0}} \quad (1)$$

Here v is the electron velocity, subscripts '⊥', 'z' denote transverse and z components, γ is the relativistic factor, c is the speed of light, η is the charge-to-mass ratio of an electron, r is the radius of the electron beam, B is the magnetic field, '0' and 'c' the values in the final and cathode region respectively.

A 'smooth' cusp formed by two coils without any magnetic shaping poles will be used to generate the required axis-encircling electron beam because in this case the Larmor step is much larger due to the small amplitude of the cusp and small transverse velocity component. This allows a field reversal over a longer distance. In Fig. 4. a typical electron beam trajectory from discrete emission points form the cathode from a cusp electron gun is shown, which clearly demonstrates the axis-encircling nature of the electron beam generated.

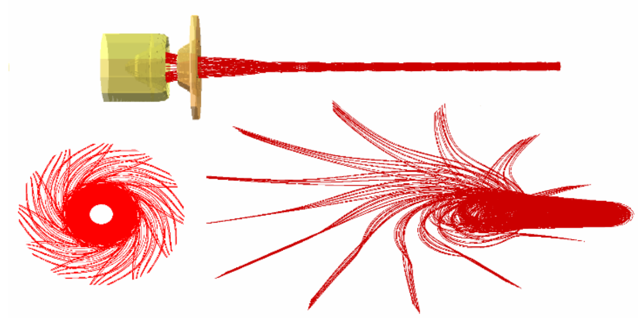

Fig. 4. Typical electron beam trajectory from a cusp electron gun.

IV. ACKNOWLEDGMENTS

The authors would like to thank Technology Facilities Council (STFC) (research Grant No. ST/P001890/1) for supporting this work.

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