# A ~10kW W-Band Gyro-BWO using a Helically Corrugated Waveguide

Craig R. Donaldson, Wenlong He, Alan D.R. Phelps, Fengping Li, Adrian W. Cross, Kevin Ronald, Alan R. Young and Colin G. Whyte
SUPA, Department of Physics, University of Strathclyde, Glasgow, G4 0NG, Scotland, UK

***Abstract*—Presented in this paper are the results of a 10kW W-Band Gyro-BWO based on a helically corrugated interaction region and novel cusp electron gun. Microwave measurements of the helically corrugated interaction region are shown to give a low loss of ~1dB over the frequency region of interest (84-104 GHz). The measured dispersion was found in good agreement with the analytically calculated and numerically simulated dispersions. The design and simulation results of the cusp electron gun of the Gyro-BWO device are given in this paper.**

## I. Introduction And Background

A Gyro-BWO is a promising, coherent, frequency-tunable source up to sub-millimeter frequencies. Previously [1] it has been demonstrated that a wide tuning range at high efficiency and high powers can be realized using a smooth bore waveguide. An interaction region with helical corrugations of the inner surface will further widen the frequency tuning range while maintaining the efficiency of the interaction. Simulation results of the W-band Gyro-BWO currently being built at the University of Strathclyde would have a 3dB frequency bandwidth of ~84-104GHz at 17% interaction efficiency and 10kW CW power.

An interaction region with a helically corrugated inner surface couples two partial waves, one near cut-off and one far from cut-off wave, when the Bragg conditions are met. This results in an eigenwave of ideal dispersion for the beam-wave interaction giving rise to wide turning range in a Gyro-BWO [2] and a broad bandwidth for a Gyro-TWT at the same time increasing efficiency [3,4]. The interaction between the second harmonic of the electron cyclotron mode and the eigenwave generates or amplifies microwaves through the CRM instability. By using an interaction region with a helically corrugated inner surface the frequency tuning range of the Gyro-BWO can be further improved and at the same time can lead to an increase in the efficiency of the interaction.

A novel cusp electron gun uses a non-adiabatic reversal of magnetic field to form an annular large orbit electron beam due to the conservation of canonical angular momentum [5]. The type of electron beam is ideal to interact with a harmonic mode in the CRM instability.

## II. Cathode Design

A 1.5A, 40kV cusp electron gun has been designed to drive the Gyro-BWO. The electron beam generated by this cusp gun has been simulated using the 3D PiC code MAGIC and optimized to drive the beam-wave interaction. An electron beam of 40kV, 1.5A at pitch factor 1.65 is generated with an axial velocity spread, $\Delta V_z/V_z$, of 8% and pitch alpha spread, $\Delta\alpha/\alpha$, of 11%. The electron beam can transit through the tube over the required magnetic field tuning range of 1.6-2.1T with only slight change in beam quality.

## III. Cathode Construction

Manufacturing a W-Band thermionic cathode is complicated due to the small size of the structure and tight engineering tolerances. The design has to be as simple as possible while special care has to be taken to reduce the possibility of vacuum breakdown inside the gun. Furthermore thermal shields are necessary to reduce thermal expansion and stress on the gun structure.

The cusp gun designed for the Gyro-BWO has an emitting ring of radius 6.4mm and operates with a current density of 8.8A/cm$^2$. A 3D CAD drawing of the electron gun can be seen in figure 1. The reverse coil is placed just behind the cathode head and outside of the vacuum enclosure. By adjusting its axial position the position of the cusp and the amplitude of the magnetic field at the cathode surface can be easily adjusted.

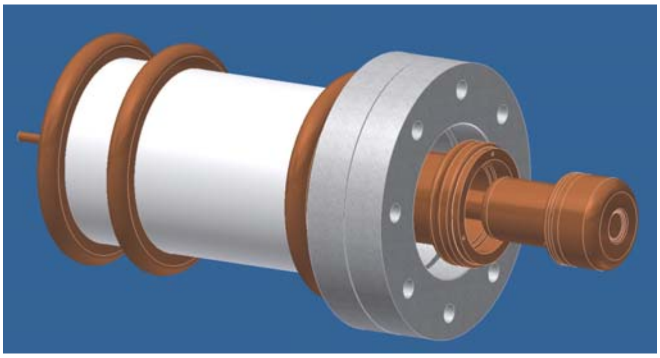

**Fig. 1**. 3D visualization of cathode for cusp electron gun.

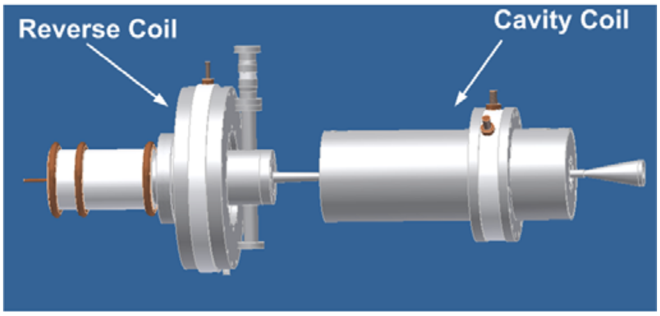


**Fig. 2**. A schematic setup of the Gyro-BWO showing positions of the reverse and cavity coil.

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## IV. SOLENOID CONSTRUCTION

The Gyro-BWO interaction requires a solenoid with tuning magnetic field from 1.6T to 2.1T in the designed operating frequency range. When operating in the CW regime, cooling is a major issue due to the significant amounts of electric power needed to drive the current through the solenoid. The power required for this solenoid is predicted to be 64kW. This coil has 14 layers and 104 turns in each layer with 2 shim coils at each end to maximize the length of flat magnetic field region at a given electrical power.

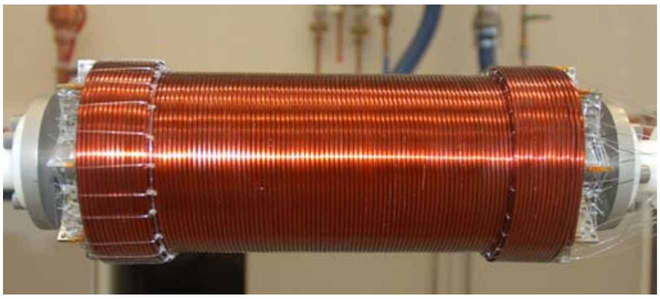

***Fig. 3***. A photograph showing 2.1T DC solenoid.

## V. RESULTS

A helically corrugated interaction region has been designed and optimized through linear perturbation theory and MAGIC simulation of the beam-wave interaction. Over the magnetic field range 1.6T-2.1T the simulations showed a maximum output power of 10kW. A helically corrugated waveguide was manufactured and microwave measurements were taken using a W-Band vector network analyzer. Dispersions obtained using linear theory and MAGIC simulations were compared with the measured results and are shown in Fig. 4. The loss was found to be ~1dB over the frequency range of interest.

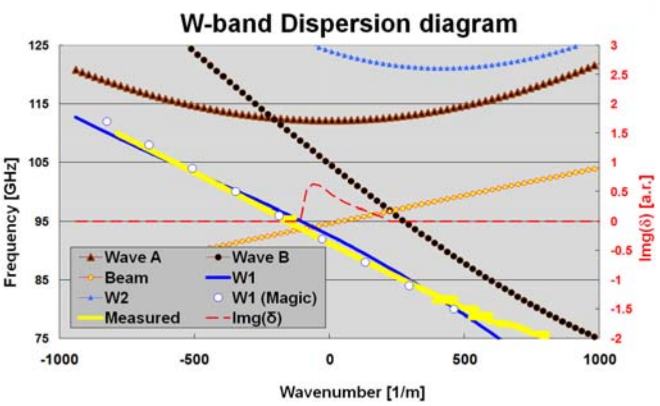


**Fig. 4**. Dispersion diagram of the helical waveguide and electron cyclotron mode of the Gyro-BWO showing an interaction at 94GHz.

The waveguide dispersion was obtained by measuring the phase transition of the wave when it travels through the waveguide. The measured dispersion was in excellent agreement to both the analytical calculations and numerical simulations.

## VI. CONCLUSIONS

In this paper the design of a W-Band Gyro-BWO is presented. The helically corrugated interaction region has been constructed. The measured wave dispersion property was in very good agreement with theoretical and numerical predictions. The measured transmission loss over the operating frequency band was ~1dB. The cusp gun has been simulated and the electron beam is of high quality to drive the interaction. The 2.1T solenoid has been constructed and is in the process of being tested. The Gyro-BWO is predicted to output at a centre interaction frequency of 94GHz with a 3dB bandwidth of ~84-104 GHz and maximum output power of ~10kW.

## VII. ACKNOWLEDGEMENTS

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