263 GHz Traveling Wave Tube (TWT) amplifier for Dynamic Nuclear Polarization (DNP) and Electron Paramagnetic Resonance (EPR) Spectroscopy

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Abstract— We present the circuit design of a 263 GHz Traveling Wave Tube (TWT) amplifier for use in Dynamic Nuclear Polarization (DNP) enhanced Nuclear Magnetic Resonance (NMR). The circuit design achieves a linear gain of 36 dB and output power > 50 W. This work describes the design of the interaction circuit for optimal interaction with a 20 kV, 125 mA elliptical beam using 3D electromagnetic Finite Element Method (FEM) and Particle-in-Cell (PIC) solvers.

I. INTRODUCTION

Terahertz gyrotron oscillators have been successfully used in DNP-NMR spectroscopy in the last decade. The availability of high power phase stable oscillators will enable the next generation of DNP-NMR experiments using pulsed methods [1]. We proposed to develop a 263 GHz TWT amplifier for use in DNP-NMR and Electron Paramagnetic Resonance (EPR) spectroscopy at high magnetic field (9.4 T). The main objective is to develop a 263 GHz TWT with a peak power > 50 W, with a gain > 35 dB and an instantaneous bandwidth > 5 GHz. The final goal is to have a versatile, compact, and cost-effective TWT amplifier for use by the DNP-NMR and EPR research communities. We have chosen a coupled cavity circuit driven by an elliptical beam (sheet beam) to provide the necessary output power and gain such that the device can be driven by a commercially available solid-state driver. The circuit was designed in two stages to suppress backward wave oscillations and achieve the desired gain. A model of the interaction structure with the electron beam is shown in Fig. 1.

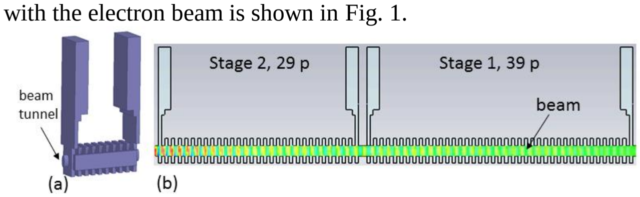

Fig. 1. (a) HFSS model of the circuit geometry showing 8 periods. (b) CST-PS model showing the interaction structure (two-stage circuit) with the electron beam. Stage 1 shows 39 periods and stage 2 shows 29 periods, respectively.

II. RESULTS

The cold (beam absent) dispersion of the circuit was optimized using Ansys HFSS code. The dispersion diagram of the operating mode and neighboring parasitic modes is shown in Fig. 2. The HFSS simulations were also used to extract the interaction impedance of the circuit which represents how much of the circuit field energy is available for synchronous interaction with the electron beam. For this circuit the interaction impedance was found to be 24.7 Ω. CST Particle Studio was used for particle-in-cell simulations to study the performance of the device over a range of frequencies 255 – 264 GHz, where 260 GHz was the operating frequency with the best performance and highest gain. The gain frequency response of the device is shown in Fig. 3. The peak circuit gain is 36.3 dB and maximum power output is 86.5 W. The next steps in this project include the design of the magnet system and the electron gun.

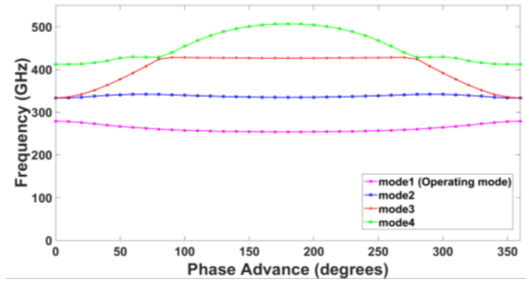

Fig. 2. HFSS simulations showing the dispersion diagram of the circuit. Phase advance (degrees) versus Frequency (GHz).

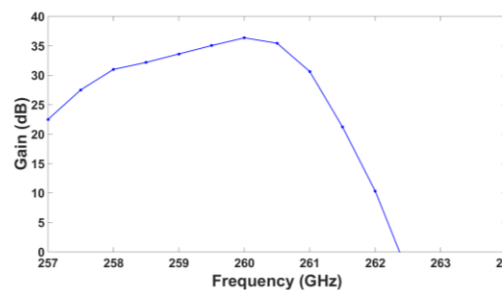

Fig. 3. CST simulations result data showing the gain-frequency response of the circuit. The device operates at 260 GHz with a maximum gain of 36.3 dB, peak power of 86.5 W and a bandwidth of ~ 3 GHz.

III. SUMMARY

A 260 GHz Traveling Wave Tube (TWT) amplifier was simulated in Ansys HFSS and CST-PS. This design operates at 18 kV, with a beam current of 100 mA, and a magnetic field of 1 T achieving a gain > 35 dB and a power output > 50 W. The next steps will include the design of the magnet and the electron gun. A cold test circuit will be fabricated and experimental results will be presented if available at the time of the conference.

ACKNOWLEDGEMENTS

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REFERENCES

[1]. Maly, T., et al., *Dynamic nuclear polarization at high magnetic fields.* J Chem Phys, 2008. **128**(5): p. 052211.