Design of a 693 GHz Folded-Waveguide Traveling-Wave Tube Amplifier

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Abstract: We present the design of a 693 GHz, 50 mW folded waveguide traveling-wave tube (FWTWT) amplifier with a round beam for application in plasma diagnostics in burning plasma experiments. The design of the circuit, electron beam transport system, and the vacuum windows are carried out with theoretical analysis followed by numerical simulations. Simulation results show a maximum power output of 140 mW and a maximum gain of 26 dB. Simulations predict a 3 dB circuit bandwidth of 40 GHz.

Keywords: Traveling-wave tube, beam transport magnet, folded waveguide TWT, vacuum window.

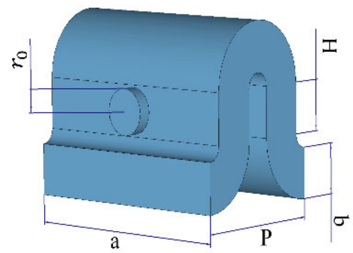

Fig. 1: Key dimensional parameters of the circuit.

Parameter	Value
a	252 μm
b	50 μm
P	80 μm
H	56 μm
r_0	26 μm

Table 1: Circuit dimensions.

I. Introduction

As fusion science research advances towards the demonstration of practical reactors for commercial adoption, there is a growing need to develop diagnostic systems for monitoring various plasma parameters in real time for control and shaping of the plasma density and profile. Recently, experiments have demonstrated the potential of microwave reflectometry for mapping the plasma density profile with a critical need for sources > 300 GHz for divertor reflectometry. Another emerging technique is a high-k scattering system for studying turbulence physics by providing a measurement of the k_θ-spectrum of both electron temperature gradient (ETG) and ion temperature gradient (ITG) modes. These diagnostics are vital for understanding and successful control of a burning plasma over time scales necessary in a commercial reactor. However, further development and maturity of the above techniques have been limited by the lack of 1-10 mW level sources in the 600-800 GHz regime. The commercial solid-state sources can generate less than 1 mW of power which is insufficient for either illuminating the plasma or for driving multiple mixers on the receivers as local oscillators.

We are developing a traveling wave tube (TWT) centered at 693 GHz with a bandwidth exceeding 20 GHz with a minimum of 50 mW across the band for driving an array of heterodyne receivers. The development of such a source will be essential for real time plasma monitoring in a commercial reactor. In the short term, such receivers will advance further development of the above techniques and methods at experiments such as the National Spherical Torus Experiment - Upgrade (NSTX-U) and MAST-U in the UK. The current system at NSTX can only use limited Schottky diode mixer elements due to limited power and must employ sub-harmonic mixers with limited conversion gain due to the unavailability of sufficient power in the 700-800 GHz range. Furthermore, there are several experimental setups in the world that require tens of mW of power in the 600 – 800 GHz range for plasma diagnostics. In this research, we focus on 693 GHz as this is the frequency employed in the NSTX-U and under consideration in a number of other devices.

II. Design and Results

A. Circuit

Fig. 1 shows the features of the slow wave structure (SWS). A serpentine folded-waveguide with a round beam tunnel is chosen as the circuit. The circuit dimensions are listed in Table 1. The SWS has been optimized for interaction with an 18.5 kV beam with a center frequency of 693 GHz. The circuit dispersion plot is shown in Fig. 2. The circuit was designed using analytical techniques outlined in [1], [2]. The beam wave

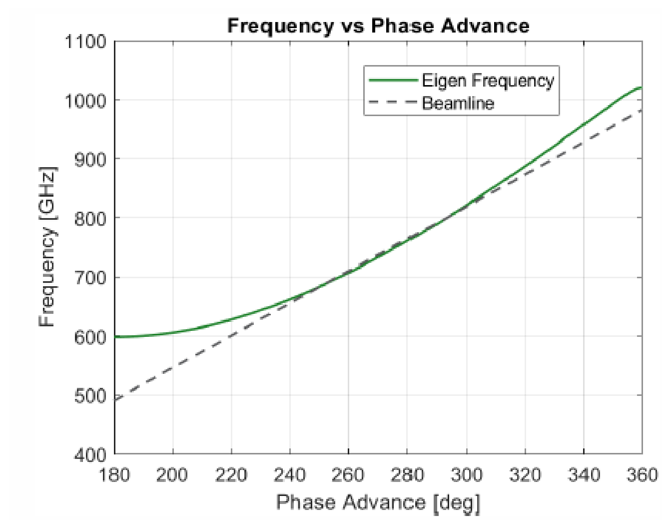

Fig. 2: Dispersion diagram of the circuit.

interaction was modeled using CST Particle Studio, a commercial Particle in Cell (PIC) solver. The predicted gain-

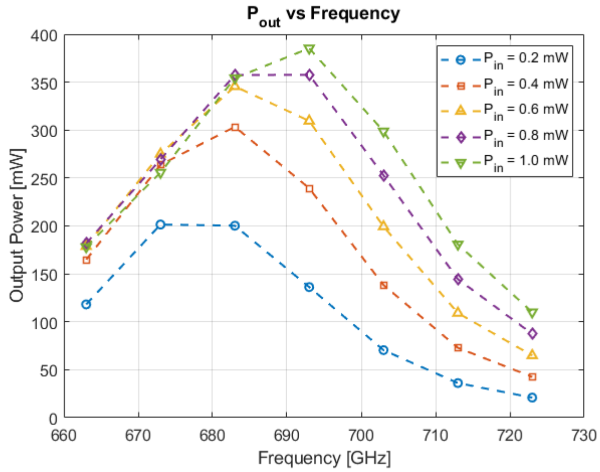

Fig. 3: Predicted power-bandwidth response of the TWT.

frequency response is plotted in Fig. 3. For the simulations, we used a beam current of 4 mA and an area filling factor of 56 %.

B. *Permanent Magnet for Beam Transport*

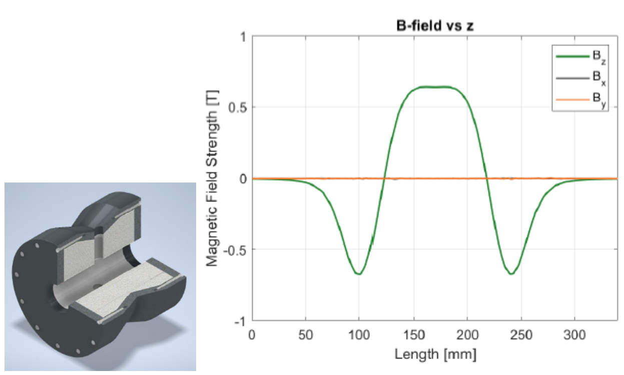

Fig. 4: Left: Solid model of the magnet system for the TWT and Right: On-axis field profile.

A permanent magnet system has been designed to meet the magnetic field requirement of 0.63 T. The design is based on the concept of magic spheres to create high magnetic fields as described in [3]. The magnet system uses high energy NdFeB magnets to generate a uniform axial magnetic field for a length of about 3 cm in the bore to confine the electron beam. The bore is 5 cm wide at the narrowest part of the magnet. The magnet system was modeled in ANSYS Maxwell. The solid model of the magnet and the on-axis field profile are shown in Fig. 4.

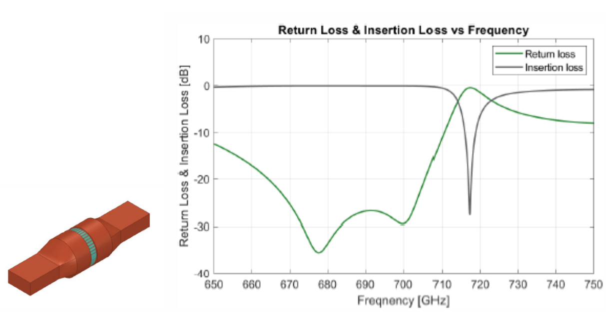

Fig. 5: Left: Solid model of the vacuum window, Right: Transmission properties of the window.

C. *Vacuum Window*

A pillbox vacuum window is designed using WR-1.5 waveguide and Diamond (CVD) as dielectric material. The effect of edge metallization on the dielectric was analyzed to ensure that no ghost resonant mode gets excited in the operating frequency band around the discontinuities. The designed window exhibits a return loss less 20 dB over a 40 GHz bandwidth. A simulation model of the window and its transmission characteristics are shown in Fig. 5.

III. CONCLUSIONS

A 693 GHz FWG TWT amplifier has been designed to generate > 50 mW of output power with a 3 dB bandwidth of 40 GHz. A 0.63 T permanent magnet system is designed to focus the electron beam. Input and output windows have been designed with a return loss below 20 dB over a 40 GHz bandwidth. PIC simulations using CST estimates a maximum gain of 26 dB and a maximum power of 140 mW at the output. The next phase of the work will focus on the design of the electron gun and the mechanical design of the TWT.

ACKNOWLEDGMENTS

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REFERENCES

[1] J. F. Gittins, *Power travelling-wave tubes*. American Elsevier Publishing Company, 1965.

[2] J. H. Booske *et al.*, "Accurate Parametric Modeling of Folded Waveguide Circuits for Millimeter-Wave Traveling Wave Tubes," *IEEE Trans. Electron Devices*, vol. 52, no. 5, pp. 685–694, May 2005.

[3] J. P. Clarke, E. Potenziani II, and H. A. Leupold, "Permanent-magnet annular, longitudinal field sources," *Journal of Applied Physics*, vol. 61, no. 8, pp. 3468–3470, Apr. 1987.