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NOVEL INJECTION LOCKED COAXIAL MAGNETRONS*

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Abstract

To meet phase stability requirements, a high peak power coaxial magnetron-based RF system with >70% efficiency would usually be injection-locked to an RF source using a circulator to send the locking signal into the magnetron through the antenna. This added requirement of a high-power circulator pushes the inherently low coaxial magnetron's cost-per-watt to a high overall RF Power Source system cost-per-watt. For this project, the injected phase locking signal for the magnetron will use a novel input port that does not require a high-power circulator. The new input port uses the cathode stalk assembly to turn the filament-cathode into an antenna that couples to the resonant circuit of the magnetron. The coupling system between the cathode stalk, which runs at high voltage, and the RF input includes isolation for high voltage.

INTRODUCTION

We are designing and building a 10 GHz coaxial magnetron [1] to generate a few KW in CW mode. The program aims to make a highly efficient magnetron tube. The COMSOL[2] program was used to study the tube's electromagnetism. Figure 1 shows the coaxial magnetron with cavity waveguide transformer and output waveguide and the clear formation of TE011 mode at 10 GHz in the coaxial cavity.

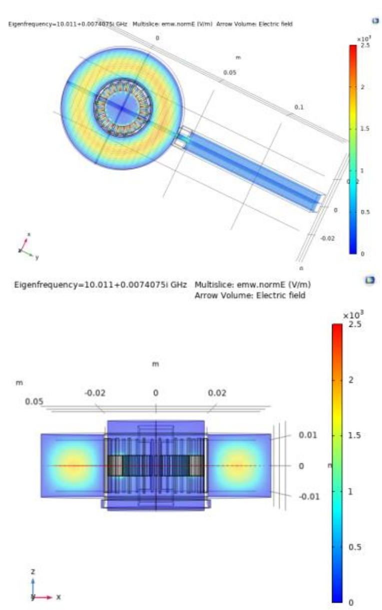

Figure 1. 10GHz, Coaxial Magnetron

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We have varied the number of vanes to find the best geometry for a CW tube at 10GHz. Figure 2 shows the internals of a 24-vane tube and E field at 10 GHz resonance.

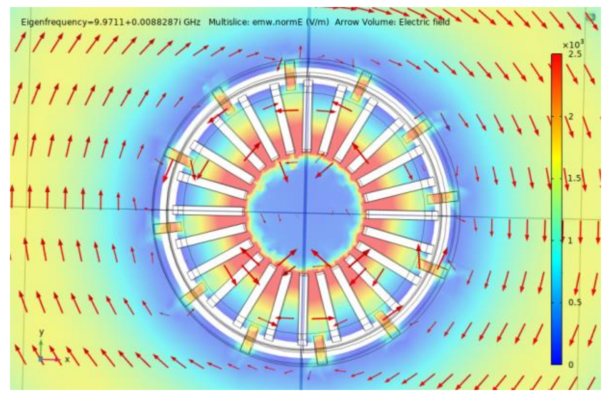

Figure 2. The circulating E-field is TE011 mode.

The thermal studies (shown in Fig. 3) done in COMSOL led us to conclude that the CW operation structure with 20 vanes will allow us to have a tube that can generate a few kW of RF power.

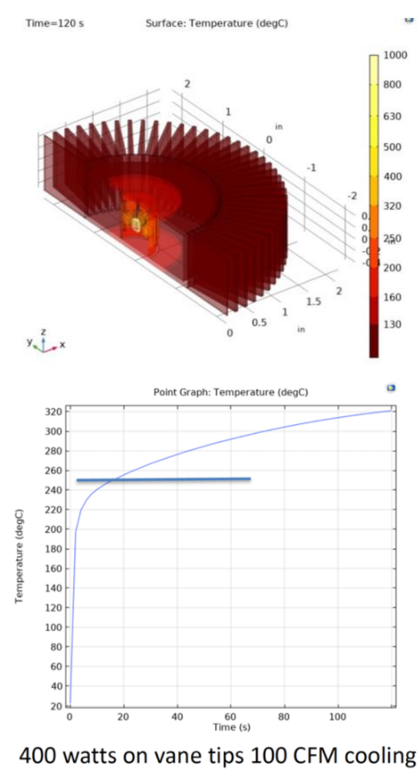

Figure 3. COMSOL thermal calculations

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To study tube efficiency, we created a fully parametrized model of the coaxial magnetron as input for the NEPTUNE simulation code [3]. Figure 4 shows the parametrized geometry of the structure with as many as 40 vanes.

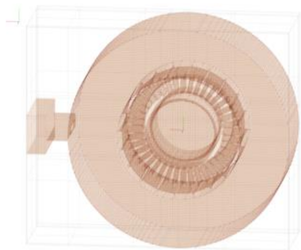

Figure 4. NEPTUNE model of 40-vane coaxial magnetron.

As was mentioned before, the initial values of parameters were ones from the COMSOL model.

Adjusting the width and length of coupling slots resulted in most of the efficiency gain. The RF signal is generated in the structure from noise. NEPTUNE allows the user to see the formation of the spokes. Figure 5 shows a strong RF field leaking out from coupling slots and ten spokes formed above the base distribution of electrons (blue) around the cathode.

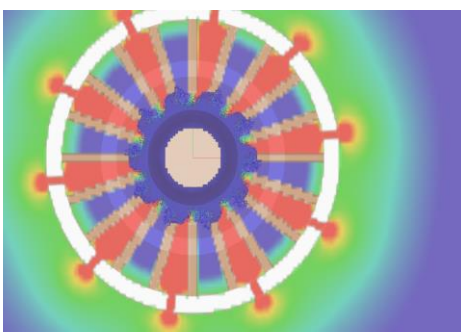

Figure 5. NEPTUNE simulation shows the cathode's centre surrounded by emitting electrons, and the spokes emerge from the electron continuum. Strong RF in coupling cells and almost no field in other cells indicate that pi mode is generated.

The following Fig. 6 shows anode voltage and RF signal as a function of time. Plots on the left are Fourier transforms of corresponding voltages.

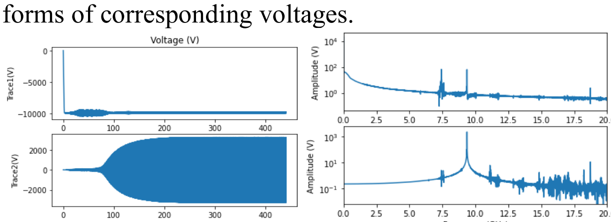

Figure 6: RF signal as a function of time (right). Also, plots with Fourier transforms of corresponding voltages (left).

The anode voltage is slowly increase from zero to full voltage in about 10 ns. As can be seen from the plots, it takes about 80 ns for the RF signal to emerge from the noise. The simulations are run up to 1 µs. The result is acceptable, as an RF signal around 10GHz is formed and stable for more than 200 ns.

The studies so far show that our design is ~40% efficient. In the process of trying to increase efficiency, we found that NEPTUNE produces a stable solution as long as the transformer coupling slot is small. This indicates that in simulations, we have only an under-coupled system, which may explain the relatively low efficiency. We expect the NEPTUNE model to improve with an injection locking feature, described below.

The results of measurement and simulations are shown in Fig. 7.

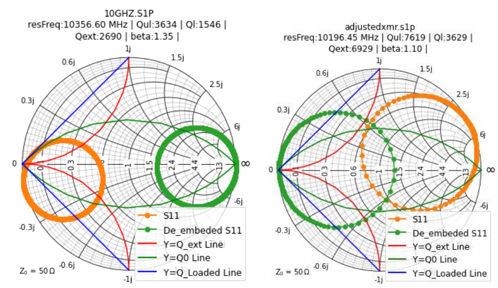

Figure 7. The measurement and simulation show relatively weak coupling, which causes efficiency to be only 40% in the NEPTUNE.

As the next step we built an anode for the coaxial magnetron and the coaxial cavity, transformer, and waveguide. (Figures 8, 9 below).

Figure 8. 10GHz, 20 vanes, coaxial magnetron used for cold test.

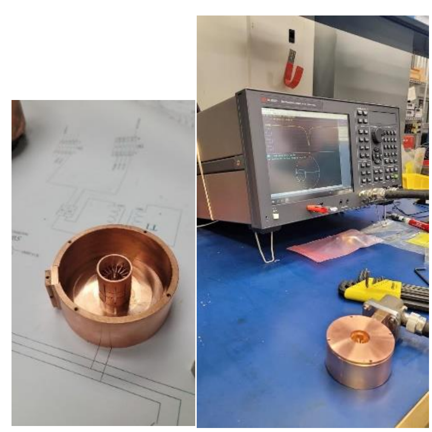

Figure 9. Coaxial magnetron and cold test setup.

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PHASE LOCKING

We are considering several different methods for phase-locked coaxial magnetrons:

- Conventional approach using output waveguide to inject locking signal [4].
- Using the filament helix as an antenna into the resonant structure of the magnetron.
- Introducing an additional port to the coaxial cavity

We see several reasons to consider the last option as the most adequate. The coaxial cavity is part of the system with the highest Qo. The signal injected in this cavity will be very stable, so the coupling of this port can be small, and power can be injected or extracted through this port. Adding new port will simultaneously lower the Q's and bring Qext down. The injection locking signal will be small and can be generated using one of the existing SS boards as shown in Fig. 10. Figure 11 shows a cartoon of the concept.

Figure 10. Solid State 500W amplifier with circulator and load.

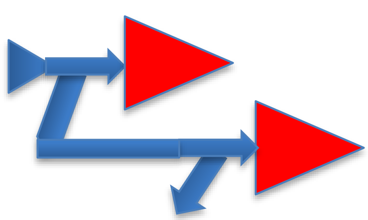

Figure 11. The concept of phase looking two plus magnetrons (red) using a single (blue) solid-state RF amplifier.

CONCLUSION

Studies so far show that a CW 10 GHz tube generating a few kW can be made. Phase locking using an additional port attached to the coaxial cavity looks possible, and it will be simulated, designed, and tested in the following couple of months.

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