650 GHz Traveling Wave Tube Amplifier

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***Abstract*—Calabazas Creek Research, Inc. (CCR) and the University of Wisconsin, Madison (UW) are developing a 650 GHz traveling wave tube amplifier (TWTA). Simulations predict 360 mW peak output power with a 2-10% duty cycle. This paper summarizes the design and fabrication of the TWT. Testing is expected in November, 2008.**

I. Introduction And Background

Calabazas Creek Research, Inc. (CCR) and the University of Wisconsin (UW) are developing an innovative, THz, traveling-wave tube amplifier (TWTA) compatible with three-dimensional (3D) micro-fabrication techniques. The development focuses on novel, planar, interaction circuits; long life, high current density, electron guns; and compact power supplies providing high-efficiency, compact, lightweight, and affordable devices. The batch nature of micro-fabrication provides repeatability of components for increased yields and reliability, and reduced cost.

The proposed applications for this THz device are terrestrial stand-off imaging and detection. In addition, upper atmosphere imaging and detection via satellite and look down detection at the upper altitudes (above troposphere) are being considered. Table 1 lists the THz source operating parameters.

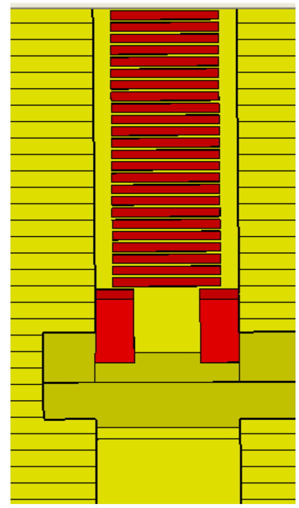
TABLE 1. OPERATING PARAMETERS FOR 650 GHZ TWTA.

Voltage (kV)	12
Current (mA)	8
Output power (mW)	360
Center frequency (GHz)	650

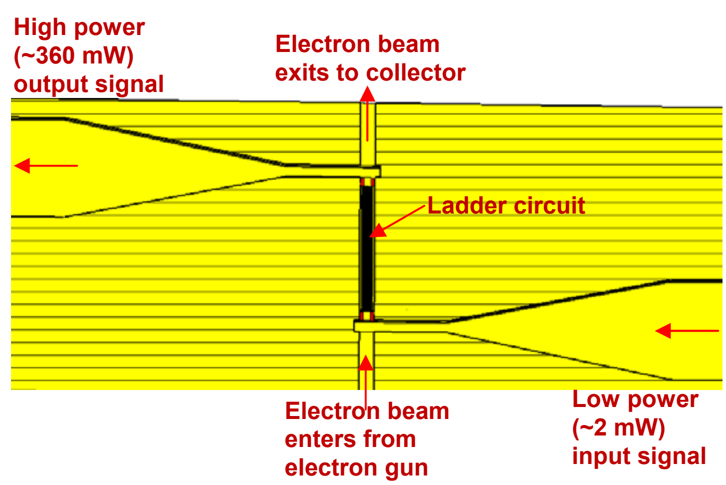
II. Interaction Circuit And Coupling

We investigated several interaction circuits. Simulation results using Microwave Studio [1] showed the planar ladder circuit to be superior in terms of compatibility with micro-fabrication and maximum RF efficiency. As shown in Fig. 1a, this circuit includes an etched substrate with selective metallization along the ladder rungs. The substrate is a layered structure of fused silica and silicon, which undergoes three etching steps of different depths to form the circuit, waveguides, and RF choke. A top copper piece cut using electro-discharge machining (EDM) completes the circuit by providing a beam tunnel and half of the input/output waveguides (not shown). Fig. 1a shows the top cut through view of the microstrip transition from the ladder circuit to fundamental rectangular waveguide.

The input and output signals are coupled in and out of the TWT quasi-optically using asymmetrically tapered, pyramidal horn antennas with 23 dBi directivity. Fig. 1b shows a top view of the circuit, linear transitions from rectangular waveguides to horn antennas, and relative positions of the electron gun and collector.



(a)



(b)

Fig. 1. (a) Top view of ladder circuit showing microstrip transition to rectangular waveguide. Red indicates dielectric and gold indicates metal. (b) Top view of ladder circuit and pyramidal horn antennas at input and output (Drawing not to scale).

III. Electron Gun

A 70 x 160 microns sheet electron beam travels above the planar ladder circuit with lower edge 5 microns above the circuit. One of the principal goals is to keep the current density at the cathode as low as possible. The required current density in the circuit is 70 A/cm^2. While this is about half that typical of backward wave oscillators at this frequency, it is still very high by microwave tube standards, and we explored means for compressing the beam to reduce the cathode loading further.

The beam perveance of 0.006 microperves is very low, and the emittance of the beam is limited by thermal effects. Fortunately, emittance does not directly affect the interaction with the RF structure, so the primary limitation is the size of the beam and ripple in a magnetic focusing structure. This is an important limitation where the clearance between the beam and the structure must be as small as 5 microns.

The program explored several approaches to beam compression, including the use of a thin magnetic lens to form an elliptical beam from a round, conventionally generated, beam. While this was successful, the only practical way the beam could be introduced into a magnetic field to guide the propagation was with Brillouin focusing. This resulted in very poor beam transmission because the beam waist at the entrance to the field was poorly defined due to the high emittance.

The other approaches used geometries that were compatible with immersed flow. The first used an elliptically shaped focus electrode and anode to generate an elliptical beam from a circular cathode. This produced the desired beam; however, manufacturing with the required very tight tolerances would be extremely difficult. Producing a magnetic field appropriate for confined flow would also be extremely challenging.

A simpler approach is to use a rectangular cathode and compress in only one direction. A preliminary design with a 3:1 compression was achieved. However, it was found that errors in placement of the cathode of a few microns would cause unacceptably high beam ripple.

The final approach started with a rectangular cathode with modest (18%) compression in only one dimension. This reduced the cathode current density to 59 A/cm^2. The magnetic field in the circuit region is 0.9 Tesla.

The approach is relatively simple mechanically, and formation of the magnetic field using a SmCo permanent magnet is straightforward. Fig. 2 shows the magnet, gun and circuit.

The 3D trajectory code Omnitrak calculated the beam trajectories. Fig. 3 shows the beam in the YZ plane, while Fig. 4 shows the cross section of the beam near the end of the circuit, 20 mm downstream of the cathode. The beam is 70 micron x 160 micron, as required.

Details on the design and fabrication of the circuit, electron gun, focusing magnet, collector, and vacuum envelope will be presented at the conference.

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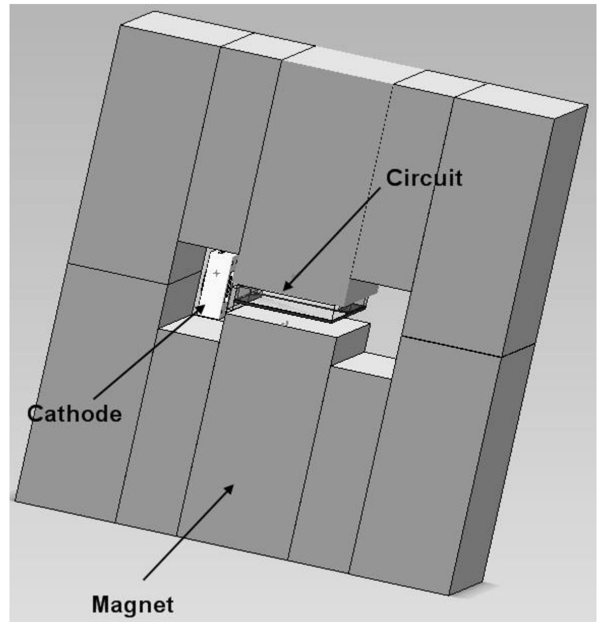

Fig. 2. THz TWT elements, including the magnet, gun, and circuit. The magnet is approximately 40 x 80 x 80 mm.

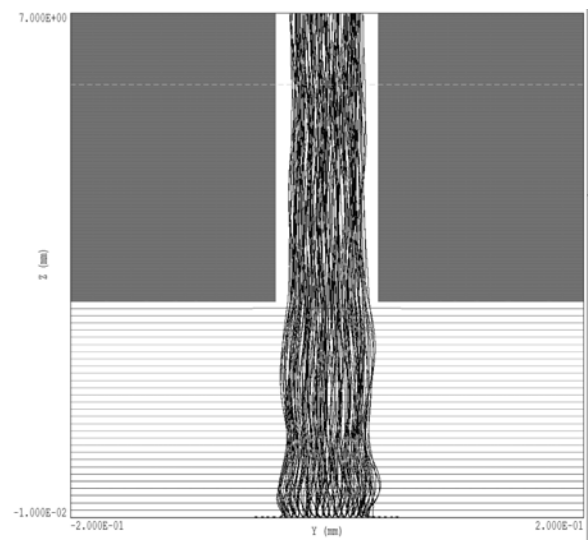

Fig. 3. Beam trajectories in the YZ plane.

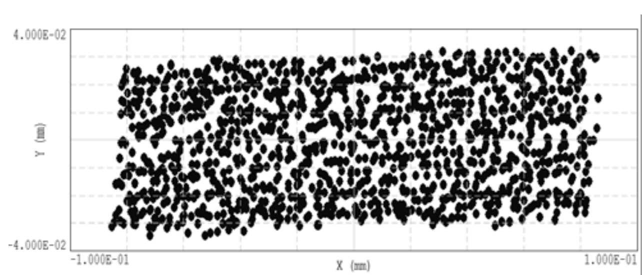

Fig. 4. Beam cross section at the end of the circuit, 20 mm downstream of the cathode.

REFERENCES

[1] www.cst.com