Demonstration of a W-band TWT with 10 GHz Bandwidth

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Abstract: *We present testing of a W-band traveling-wave tube (TWT) based on a serpentine waveguide circuit, powered by a 20 kV, 130 mA electron gun. We measure peak output power of 215 ± 2 W at 93 GHz with 20.1 ± 0.15 dB saturated gain, and >100 W from 88-98 GHz, pulsed at 0.1% duty. Operating at 20.8 kV, the TWT produces 285 ± 3 W at 91 GHz with 22.4 ± 0.15 dB gain.*

Keywords: traveling wave tubes; millimeter wave circuits; high power amplifiers; electron tubes

Introduction

Power amplifiers operating in the W-band (75-110 GHz) frequency range are important for applications such as high-data-rate communications and high-resolution radar. Output power at the ~10-100 W level is needed for long-range coverage with high signal-to-noise in varying weather conditions, due to high atmospheric losses in the millimeter-wave (mmW) range. Solid-state power amplifiers (SSPA) currently available as standard products in W-band produce up to 2.5 W continuous-wave (CW) output power over 4-6 GHz rated bandwidth, and prototypes have demonstrated up to 40 W over 25 GHz bandwidth [1]. By pairing a state-of-the-art SSPA, as the input driver, with a traveling-wave tube (TWT) as the power amplification stage, power levels well over 100 W with significant bandwidth are possible [2,3]. In this paper, we discuss the build and test of a W-band TWT prototype employing a high-current-density electron beam to achieve > 200 W pulsed output power and 10 GHz 3-dB bandwidth.

Design and Fabrication

The TWT is based on a serpentine waveguide (SWG) RF circuit [4,5]. The circuit consists of a bunching stage and a high-power output stage, isolated from each other by a sever. The sever is implemented using separate waveguide load terminations to absorb the forward RF power from the first stage and the reverse power in the second stage [6]. The circuit is fabricated by CNC micro-machining a waveguide channel in a solid block of oxygen-free high-conductivity copper in split-block halves. A top view of one half of the SWG split-block is shown in Fig. 1(a). The TWT is powered by a 20 kV, 130 mA round electron beam [7]. The beam is guided through the circuit by a 6.6 kG permanent magnet solenoid. A diagram of the device is shown in Fig. 1(b). The assembly weighs 22 kg and fits inside a cubic volume ~12 inches wide. Integrated water channels provide separate cooling circuits in the amplifier body and beam collector.

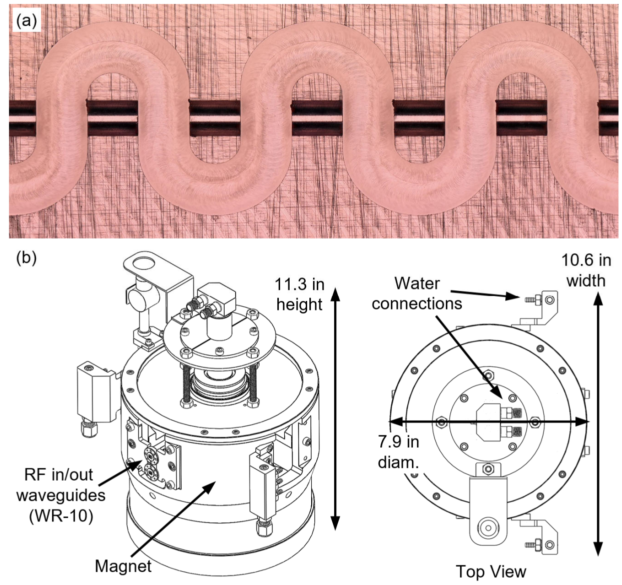

Figure 1. (a) Top view, half of serpentine waveguide circuit split-block; (b) Diagram of TWT.

TWT Test Results

The TWT was tested using a 20 kV modulator operating in 15 µs pulses at 0.1% duty (Colorado Power Electronics). The RF input drive source was a SSPA producing up to 2.5 W CW in the 88-96 GHz range (Quinstar model QPW), and the input power was measured using a WR-10 average power detector (Agilent W8486A). The RF output power from the TWT was measured using a calorimetric power meter (Virginia Diodes model PM4). The TWT was characterized at beam voltages 20.0 and 20.8 kV. Table 1 lists the measured performance parameters for these operating points. The single-stage collector was grounded or operated at a small depression up to -1000 V.

Table 1. TWT test performance parameters.

Beam voltage	**20.0 kV**	**20.8 kV**
Beam current	144 mA	139 mA
Collector voltage	0 V	800 V
Output power, saturated	215 W	285 W
Input power at saturation	2.1 W	1.6 W
Gain, saturated	20.1 dB	22.4 dB
Center frequency	93 GHz	91 GHz
Bandwidth, 3-dB	10 GHz	7 GHz
Efficiency	7.4%	9.8%
Duty cycle	0.1%	

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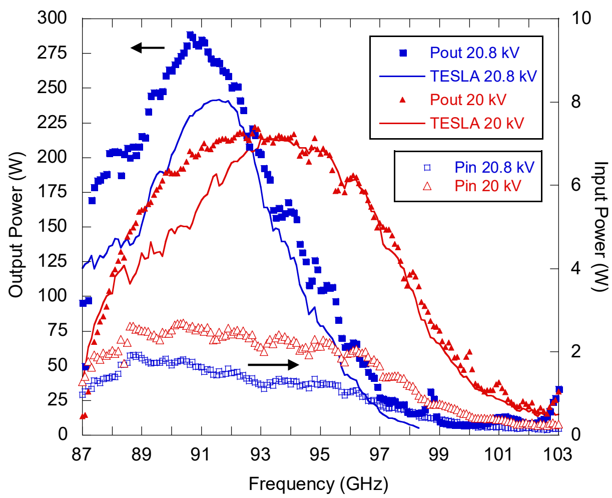

Figure 2. Output power (left axis) and input power (right axis) vs. frequency, at 20.0 kV and 20.8 kV. Solid lines show TESLA-Z simulations.

Fig. 2 shows the measured output power vs. frequency at 20.0 and 20.8 kV, and corresponding input power P_{in} on the right axis. At 20.0 kV, 215 ± 2 W peak power (pulsed) was measured at 93 GHz with 20.1 ± 0.15 dB saturated gain, and 100 W minimum from 88-98 GHz. At 20.8 kV, 285 ± 3 W peak power was measured at 91 GHz with 22.4 ± 0.15 dB saturated gain, and >150 W from 87.3-94.2 GHz. We observe that increasing the beam voltage changes the amplification interaction in the TWT circuit such that gain, power, and efficiency increase, bandwidth narrows, and center frequency decreases. The output power at frequencies above ~96 GHz was limited by available input power at both voltages. Fig. 3 shows power drive curves and gain, measured at frequencies 88, 92, 96 GHz (91 GHz) at 20.0 kV (20.8 kV). We observe that near the edges of the operating band, at 88 and 96 GHz, P_{in} was insufficient to saturate at 20 kV.

Data are compared to simulations with TESLA-Z, a 2D large-signal code used for modeling vacuum electron devices with high accuracy [8]. Excellent agreement is seen above 93 GHz (Fig. 2). In the experiment, the overall P_{in} level was set separately for each operating voltage but was not adjusted during the frequency sweep, leading to over-saturation in the highest-power part of the band. This may be a factor in the discrepancy between simulation and data below 93 GHz, as the spatial distribution of beam current in the over-saturated interaction may be significantly different than the simulated beam.

The duty cycle is limited in these tests by imperfect alignment of the electron beam in the circuit. In the reported results, ~9.5 mA of beam current (6.5%) is intercepted on the circuit wall at full RF power, leading to unacceptably high heating during high-duty operation. This may also contribute to the discrepancy between simulated and measured output power below 93 GHz (Fig.

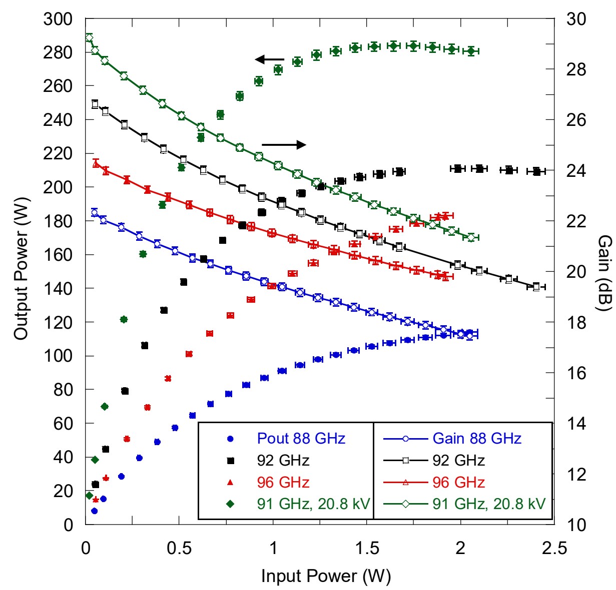

Figure 3. Power drive curves (left axis) and gain (right axis) measured at 20.0 kV; 20.8 kV where noted.

2). In further tests, we plan to improve alignment to reduce interception to < 2% to allow CW operation.

Acknowledgements

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