Characterization of a W-band TWT Electron Gun

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Abstract: *We present experimental characterization of a 20 kV, 130 mA thermionic electron gun in a W-band TWT. The gun heater voltage, focus electrode voltage, and modulating anode voltage are swept to characterize the performance of the emitted cathode current and beam transport through the RF circuit. We observe variation of the cathode current from 107 to 155 mA and peak beam transmission of 95% at the collector. Experimental results are compared to 2D MICHELLE simulations.*

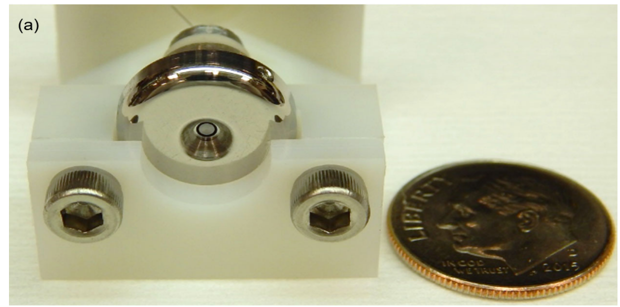
Keywords: Electron tubes; millimeter wave circuits; traveling wave tubes; vacuum electronics;

Introduction

Traveling-wave tubes (TWTs) are critical for applications requiring high power (~100 W) and broad bandwidth in the millimeter-wave (mmW) frequency range. A key component that enables high performance in these devices is the electron gun. The formation of the electron beam, in terms of focusing, transport, and current density, is essentially what determines the ultimate TWT power and bandwidth. Since thermionic cathodes have a practical limit to the emitted current density that they can produce at the surface, a high-current-density beam is created by focusing (compressing) the beam to a smaller cross-sectional size after it is generated at the cathode. While high beam compression ratio allows more current to be transported through a relatively small beam tunnel in the amplifier circuit, a high magnetic field is required to confine the beam at small size. This balance is a primary limiting factor in mmW TWT device design. In this paper we present experimental characterization of a gun designed to produce 130 mA nominal beam current at 20 kV cathode voltage, with a compression ratio ~50:1, for a W-band TWT amplifier operating in the 90-100 GHz range [1].

Electron Gun Design

The gun is based on a magnetically-shielded M-type cathode. The beam is Brillouin-focused and guided through the circuit by a 6.6 kG solenoidal magnetic field produced by a permanent magnet. A schematic of the electron gun in the TWT device is shown in Fig. 1(b). The gun uses a focus electrode (FE) and modulating anode (MA) to control the beam, allowing the cathode current to be varied over a range of ~125-150 mA while staying in the minimal range of current intercepted on the circuit walls (body current, I_body). This significant range of current adjustment is a novel aspect of the design that gives flexibility for fine-tuning of the TWT performance.



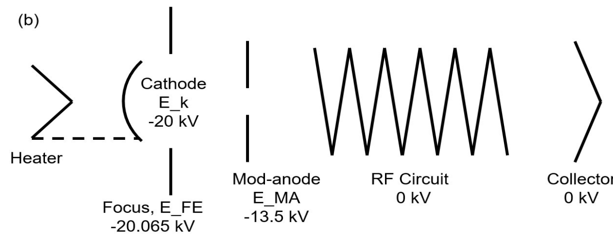


Figure 1. (a) Photo of gun assembly; (b) Schematic of electron gun in TWT device, with nominal operating voltages labeled relative to ground.

Experimental Results

The electron gun, integrated as part of a W-band TWT device, was tested using a 20 kV laboratory modulator power supply (Colorado Power Electronics) operating in 10 µs pulses at 100 Hz repetition rate [1]. Sweeps of gun operating parameters were performed using a MATLAB script to control the modulator and acquire the voltage and current measurements. For these tests, the gun was operated in cathode-pulsed mode, in which the cathode, focus electrode, and mod-anode were synchronized and pulsed together. There was no RF power input, and the TWT was operated in a zero-drive stable regime, such that the body current measured was not affected by RF. The nominal test parameters are shown in Table 1.

Table 1. Electron gun nominal test parameters

Cathode voltage, w.r.t. ground	E_k	-20 kV
Cathode current	I_k	130 mA
Focus electrode, w.r.t. K	E_FE	-65 V
Mod-anode voltage , w.r.t. K	E_MA	6.5 kV
Heater voltage, w.r.t. K	E_htr	6.1 V
Heater current	I_htr	735 mA

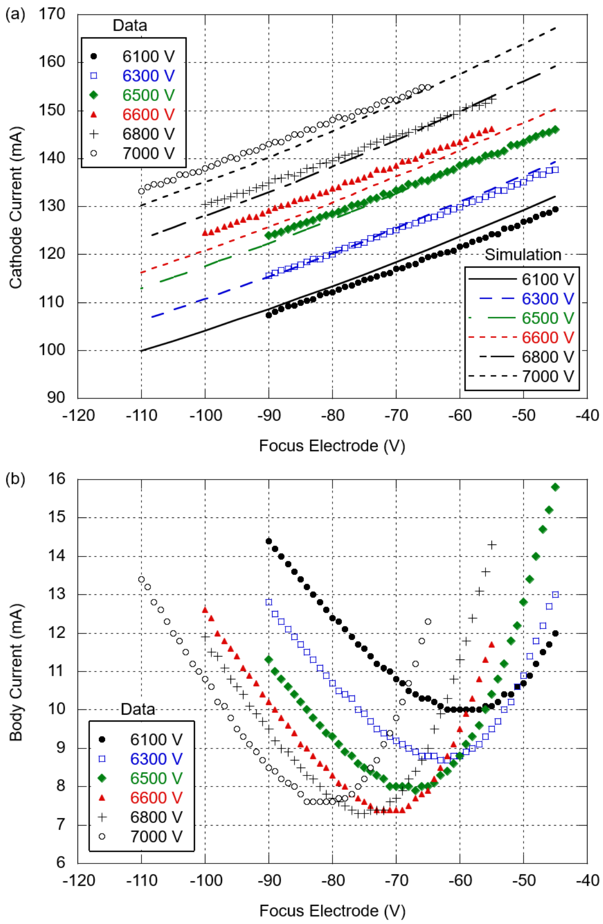


Figure 2. (a) Measured cathode current I_k vs. focus electrode voltage E_FE for various mod-anode voltages E_MA (points), with 2D MICHELLE simulations (lines); (b) Corresponding measured body current.

Figure 2(a) shows the cathode current (I_k) measured as a function of FE voltage (E_FE) at a number of mod-anode voltages (E_MA) ranging from +6.1 to +7.0 kV with respect to cathode. We observe a full range of current variation from 107 to 155 mA, corresponding to perveance values of 0.038 – 0.055 µPerv, for this range of FE and MA settings. The practical operating range that keeps I_body near a minimum is I_k ≈ 125 – 150 mA. The data are compared with 2D simulations using the finite-element gun and collector code MICHELLE [2]. The mod-anode voltages used in the simulations were adjusted empirically to reflect a 3.8% systematic error in the calibration of the high-voltage probe used to measure E_MA in the experiment. Fig. 2(b) shows the corresponding body current. We observe peak beam transmission of ~94 – 95% for E_FE in the range -70 – -80 V and E_MA in the range 6.6 – 7.0 kV, corresponding to I_body on the order of 7.5 mA. The transmission is limited by imperfect alignment of

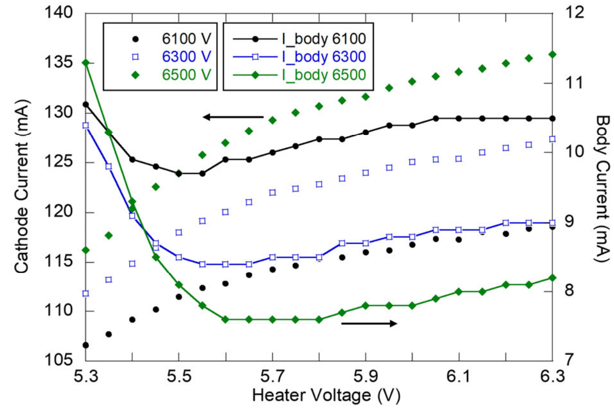


Figure 3. Measured cathode current I_k (left axis, points) and I_body (right axis, with lines) vs. heater voltage.

the gun with the circuit beam tunnel in the TWT assembly. The estimated error bar on the reported current measurements is ±0.2 mA, with shot-to-shot variation of less than 0.1 mA.

Figure 3 shows I_k and I_body measured as a function of heater voltage, at E_FE = -66 V, at three mod-anode voltages. The knee in the I_k curve that marks the transition from temperature-limited emission to space-charge-limited emission is observed near 5.6 V, corresponding to a cathode temperature of approximately 1050 ºC [3,4]. A minimum in I_body also occurs near this point. The nominal operating heater voltage used for TWT tests and the measurements of Fig. 2 was 6.1 V.

Acknowledgements

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