Design and Simulation of a Sub-THz Vacuum Tube Power Amplifier

Nikita M. Ryskin,[1,2] Tatiana A. Karetnikova,[1] Andrey G. Rozhnev,[1]
Gennadiy V. Torgashov,[2] Nikolay A. Bushuev,[3] and Pavel D. Shalaev[3]
[1]Department of Nonlinear Physics, Saratov State University, 83 Astrakhanskaya st., Saratov, Russia, 410012
[2]Saratov Branch, Institute of Radio Engineering and Electronics, RAS, 38 Zelenaya st., Saratov, Russia, 410019
[3]"Almaz" R&D Co., 1 Panfilova st., Saratov, Russia, 410033

***Abstract* — Results of design and simulation of a 0.2 THz traveling-wave-tube vacuum power amplifier with a sheet electron beam and grating slow-wave structure (SWS) are presented. Electromagnetic properties of the SWS such as dispersion and interaction impedance are calculated. Small-signal and large signal gain curves are studied.**

I. Introduction

Microfabricated vacuum electron devices operating at terahertz frequency band are of great importance for numerous applications such as communications, radar, sensors, imaging, etc. Recently, miniaturized sheet-beam traveling-wave tubes (TWTs) and backward-wave oscillators (BWOs) with a sheet electron beam and planar grating slow-wave structure (SWS) have attracted a considerable interest as wideband power amplifiers at THz frequencies [1-4]. In this paper, we present the results of design and simulation of the G-band (0.2 THz) TWT with a half-period staggered SWS and a sheet electron beam.

II. Results

In [5-7], we developed a fast and accurate software code for modeling electromagnetic properties of the grating SWS. Using this code, dispersion and coupling impedance for the half-period-staggered double-grating SWS was calculated. In Figure 1(a), dispersion diagram is presented. This SWS has the wide passband about 70 GHz. In addition, in Fig. 1(a) beam lines for three different values of the beam voltage V_b are presented. At 20 kV beam voltage, beam-wave synchronism is attained in the center of the passband.

For the simulations, the code for modeling electromagnetic parameters of the SWS [5-7] was upgraded in order to account cold losses in the grating structure. In Fig. 2, transmission of the 50-period SWS circuit (2.5 cm total length) vs. frequency is presented. The calculations show that the losses are about 2 dB in the most part of the passband.

The code for fast small-signal gain calculation is developed. In Fig. 1(b), gain vs. frequency for the TWT with 50-period double-grating SWS is shown for different values of the dc beam voltage. The beam current is assumed 100 mA. At 20 kV beam voltage, gain varies from 5 to 13 dB in the 60 GHz band. Shifting the beam-wave synchronism close to the cutoff frequency provides increase of the maximal gain up to 19 dB at the cost of substantial reduce of the bandwidth.

For large-signal simulations, the 1D version of the code [8] was adopted for sheet-beam TWT modeling. The results of these simulations are presented Fig. 2.

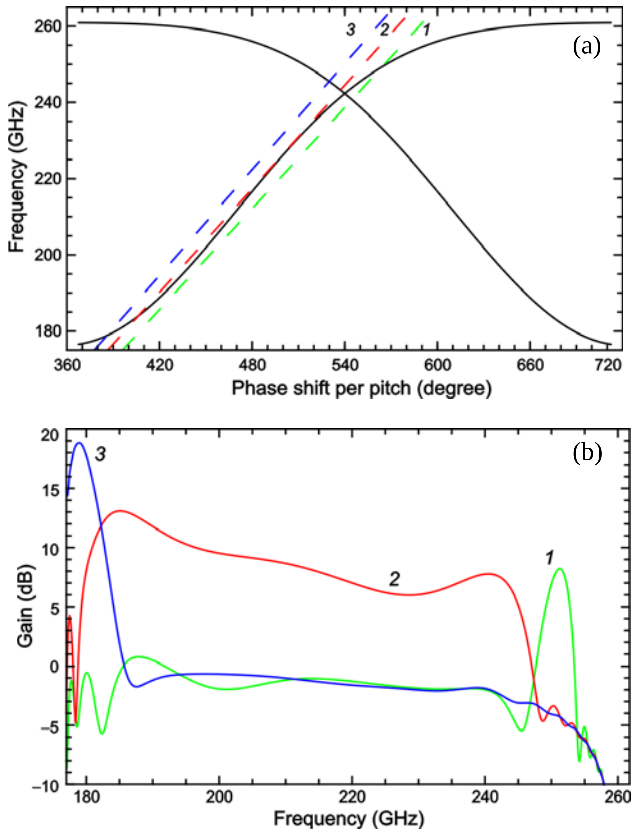

Fig. 1. (a) Dispersion for the G-band half-period-staggered SWS. Beam lines for 19 kV (*1*), 20 kV (*2*), and 21 kV (*3*) beam voltage are shown by dashed lines. (b) Small-signal gain vs. frequency at three different dc beam voltages.

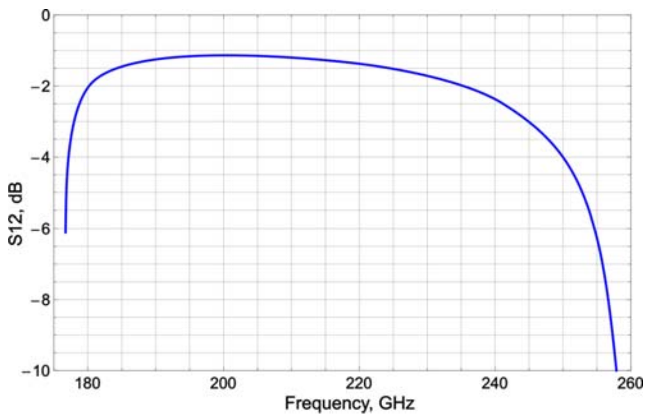

Fig. 2. Transmission characteristic for the 50-period SWS

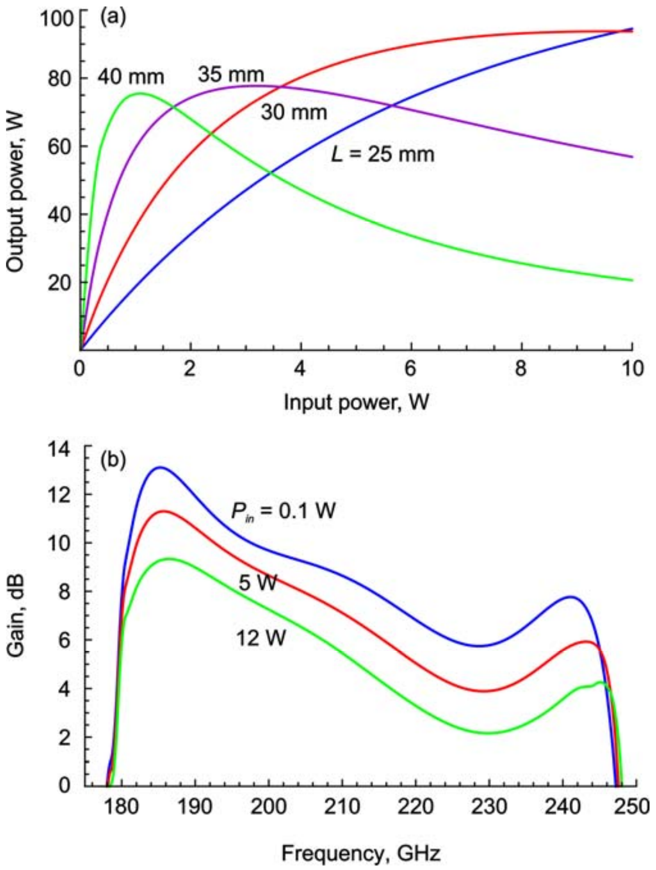

Fig. 3. (a) Driving curve for the TWT with different length of the SWS. (b) Large-signal gain vs. frequency at three different input power.

In Fig. 2(a), driving curves, i.e. TWT output power vs. input power are presented for various lengths of the SWS. These curves are plotted for 20 kV beam voltage, 100 mA beam current, and 185 GHz input signal frequency, which corresponds to the maximum of the gain curve in Fig. 1(b). The 25 mm length of the interaction space (i.e., 50 grating periods) is too short to reach saturation at reasonable values of the input power. When the system length is extended to 35 mm (70 periods), the input power corresponding saturation is equal to 2.5 W, while the saturated output power is about 75 W. For the 40-mm-long SWS (80 periods) the saturation is attained at 1W input power.

Fig. 2(b) illustrates gain compression with the increase of the input power. In this figure, gain vs. frequency is presented for 20 kV beam voltage, 100 mA beam current and different values of P_{in}. At small level of the power, the gain curve is the same as in the small-signal regime [Fig. 1(b)]. With the increase of the input power, the gain curve preserves its shape but the maximal gain decreases.

III. Summary

The results of simulation of the sheet-beam TWT with half-period-staggered grating SWS are presented. Dispersion, coupling impedance, and transmission characteristic is calculated. The coupling impedance averaged over the beam cross section is rather small and does not exceed the value of 1 Ohm in most part of the passband, except the domains close to the cutoff frequencies [5-5]. The coupling impedance can be increased by reducing the width of the beam tunnel or by reducing the vane thickness. However, the technology of fabrication of the structure imposes restrictions on minimal values of these parameters.

Small-signal and large-signal gain is calculated for various beam currents and structure lengths. The simulations show that for the 50-period TWT circuit 12-19 dB small-signal gain is attained. To increase the gain, one should increase the SWS length. However, this may cause the problem with sheet beam focusing and transportation. Saturated output power is about 80-90 W, depending on the SWS length. This power level is attained at 1-10 W input power.

IV. Acknowledgements

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