Studies on High-Power Millimeter-Band Traveling Wave Tube Amplifiers With Multiple Sheet Electron Beams

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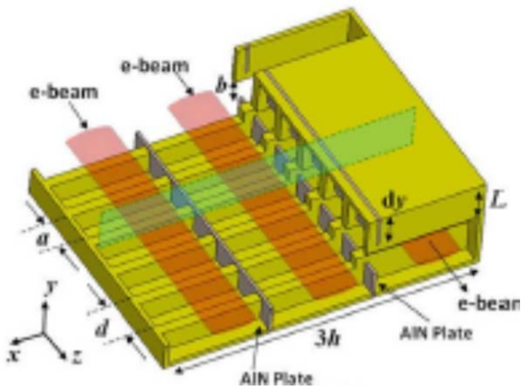
INTRODUCTION

Many applications require high-power, compact sources of sub-THz (0.1-0.3 THz) radiation. Using of high-aspect-ratio sheet electron beams in sub-THz vacuum-tube amplifiers and oscillators is very promising. Using multiple sheet beam allows further increase in the power level. Several multiple-sheet-beam traveling-wave tubes (TWTs) have been proposed.



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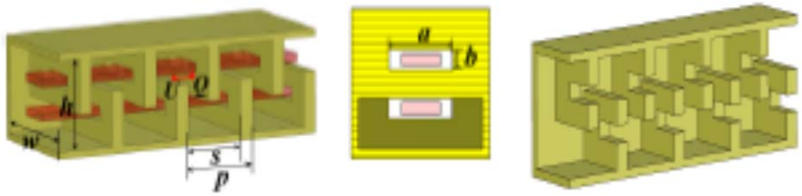

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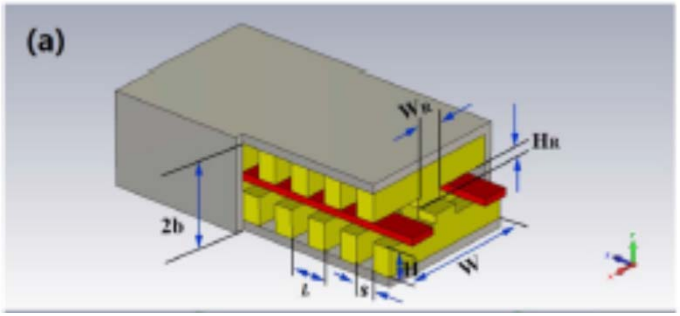

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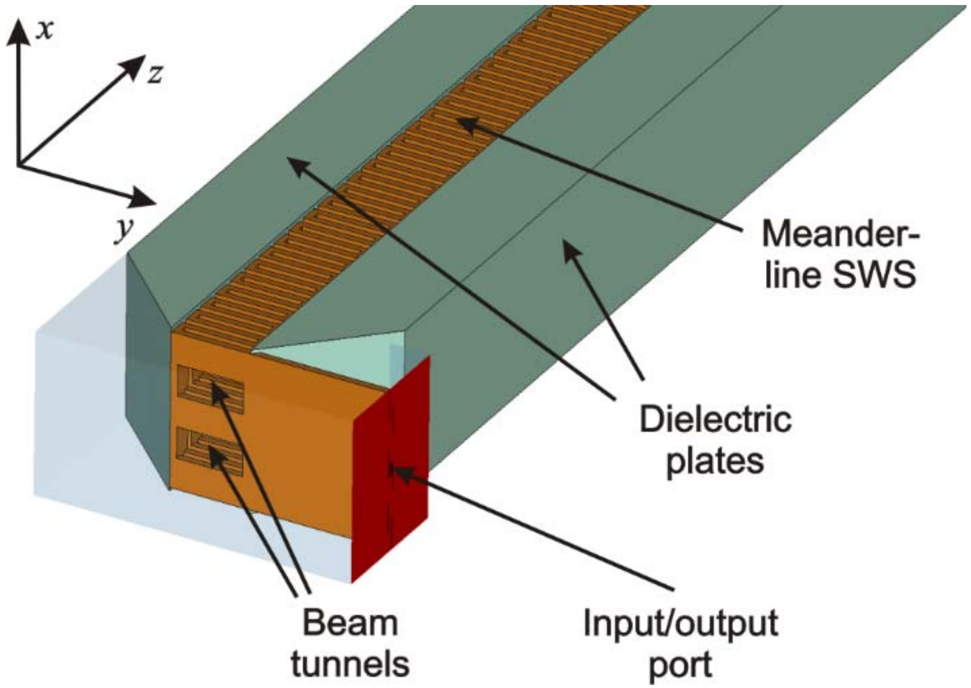
In this paper, we present the results of design and development of two such TWTs:

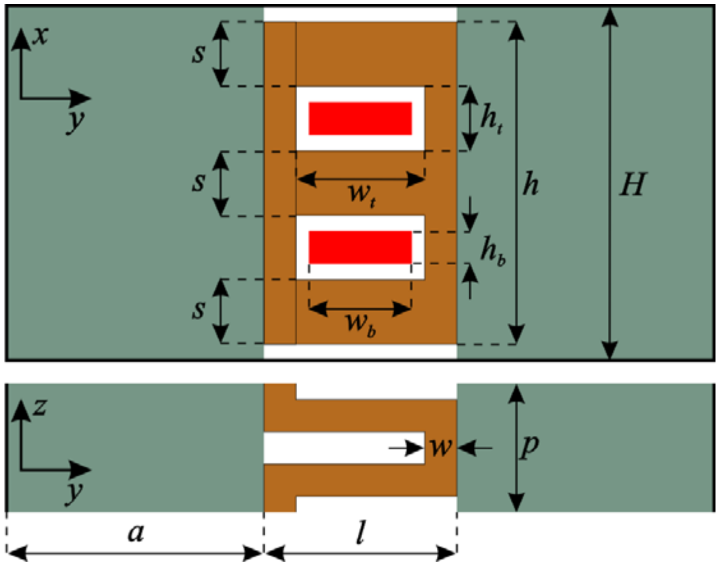
- The V-band TWT with multiple-tunnel meander-line slow-wave structure (SWS) and vertically arranged sheet beams.
- The second G-band TWT with a horizontally arranged multiple sheet beam interacting with a higher-order transverse mode of a staggered dual-grating SWS.

Double-Tunnel Meander-Line SWS

The TWT with multiple-tunnel meander-line slow-wave structure (SWS) and vertically arranged sheet beams has been proposed in:

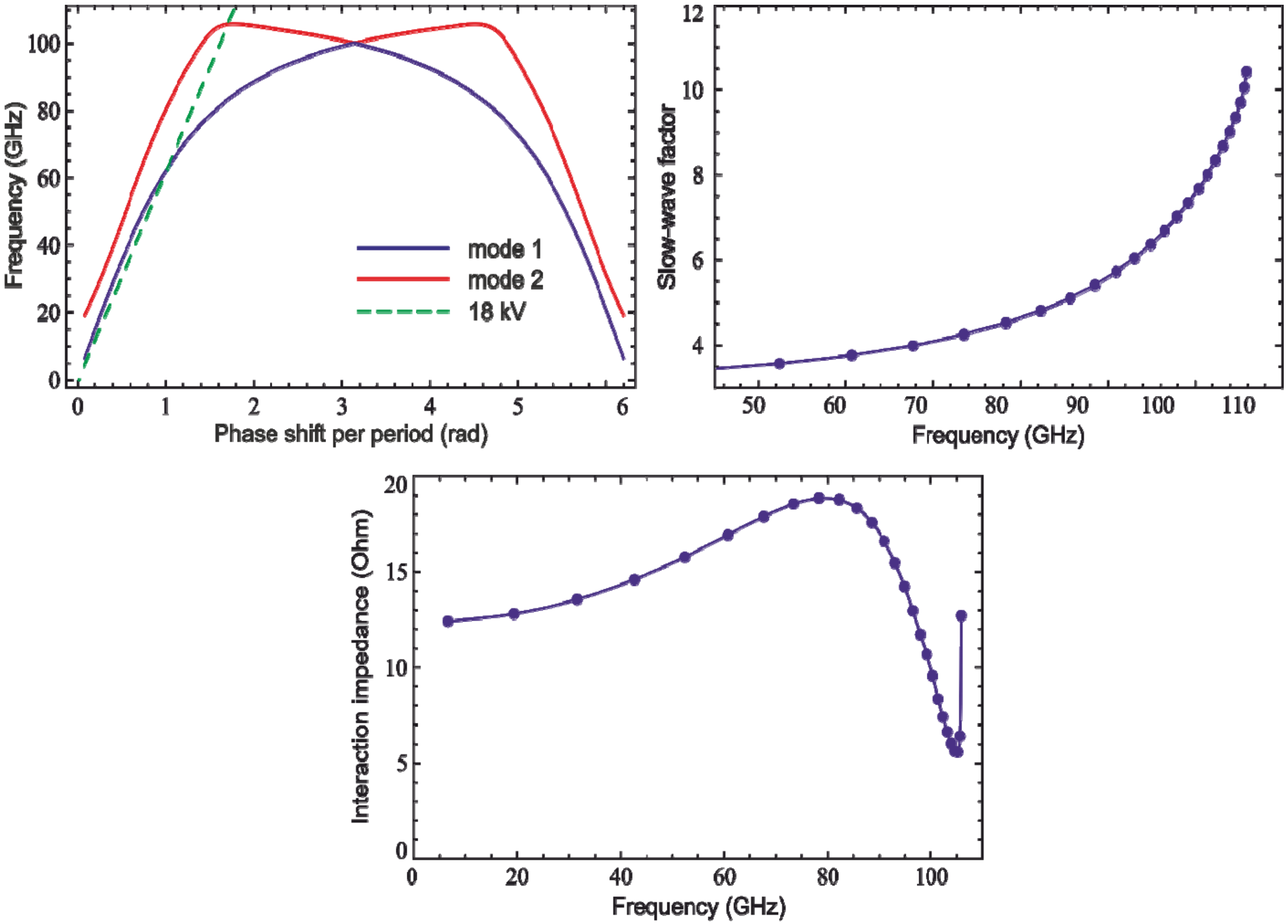
G.V. Torgashov, R.A. Torgashov, V.N. Titov, A.G. Rozhnev, and N.M. Ryskin, “Meander-line slow-wave structure for high-power millimeter-band traveling-wave tubes with multiple sheet electron beam,” IEEE Electron Dev. Lett. **40**, 1980-1983 (2019).





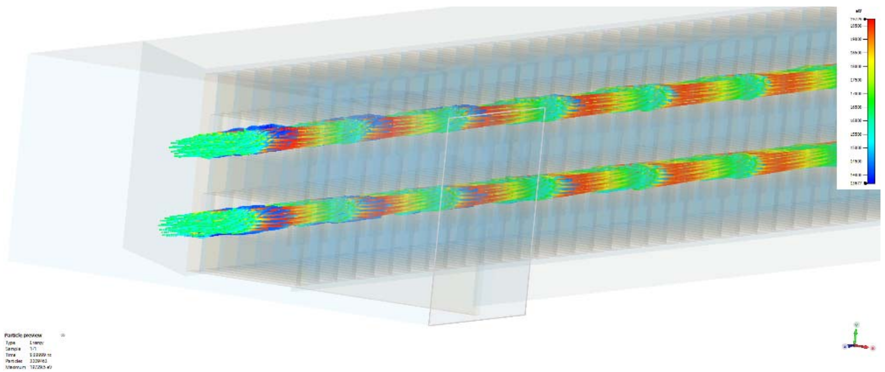
Schematic view of the double-tunnel meander-line SWS

ELECTROMAGNETIC PARAMETERS

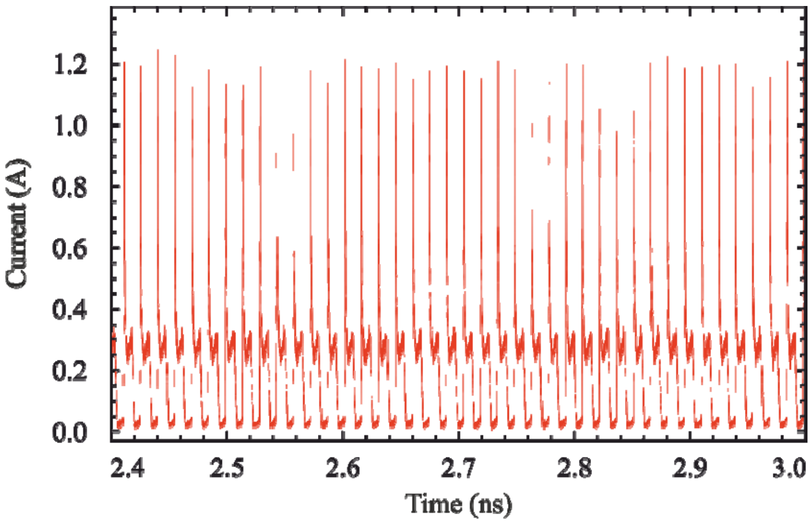


The V-band SWS is designed and simulated. This Figure presents dispersion diagram, slow-wave factor c/v_{ph}, and Pierce interaction impedance of the SWS.

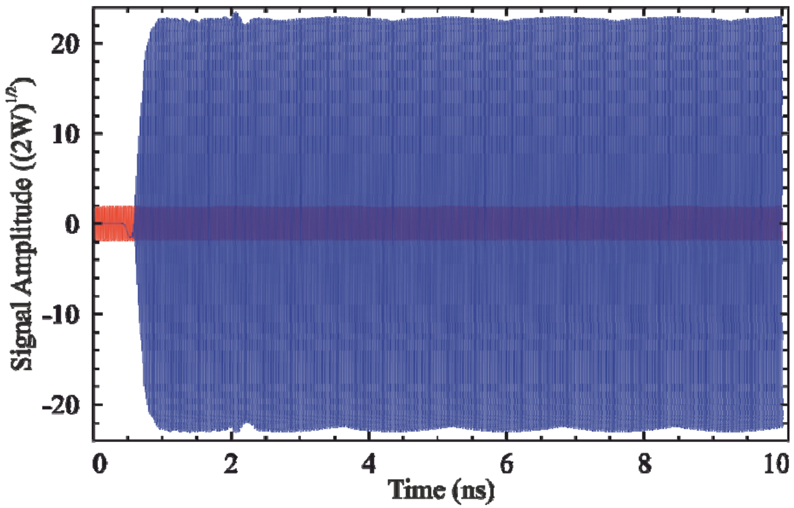
PIC Modeling



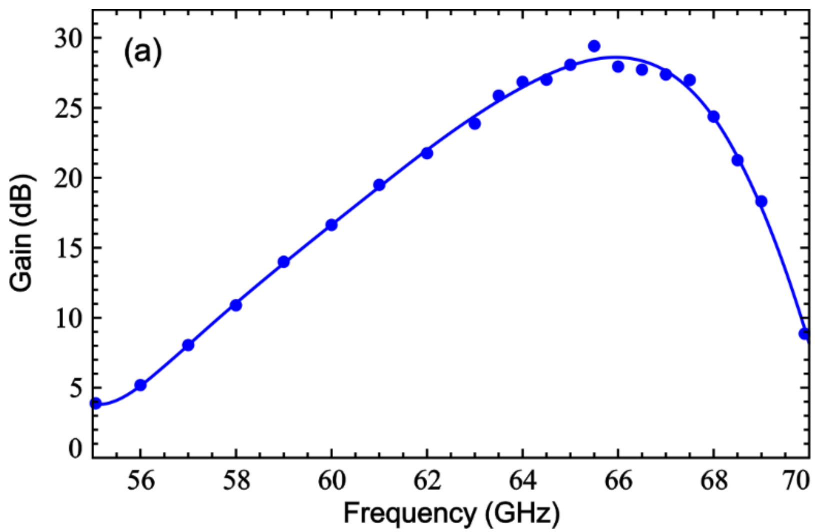
In the simulation, the SWS is driven by two 100-mA, 18-kV sheet electron beams. The beams are focused by a 0.7-T solenoidal magnetic field.



Collector current time history



Example of the input (red) and output (blue) signal time history



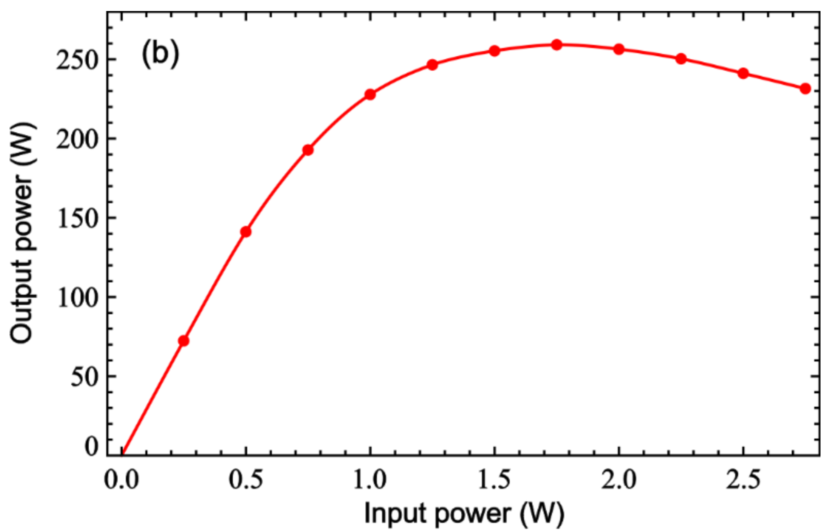
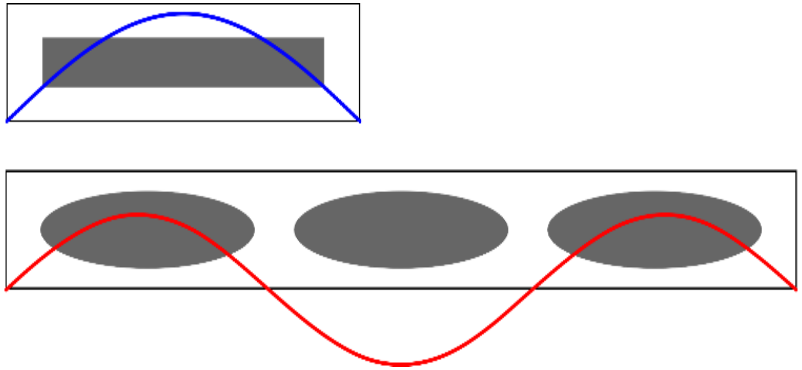


Figure (a) shows the small-signal gain versus frequency plot. The driving power is set to 10 mW. The simulation predicts maximal gain of 29.5 dB at 65.5 GHz and 4 GHz –3-dB bandwidth. The output signal is stable over the entire frequency range and we observe a clean single-frequency spectrum without any spurious mode excitation.

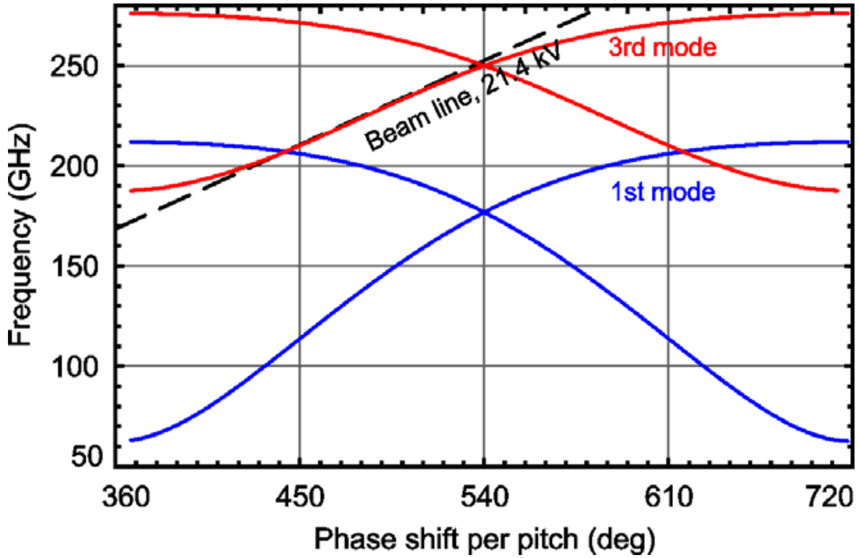
Figure (b) shows the power transfer curve at 68.1 GHz. At this frequency, average output power at saturation reaches its maximal value, which exceeds 250 W at 1.5–2.0 W driving power.

TWT with Staggered Sual-Grating SWS and Triple Elliptic Electron Beam



The beam is supposed to interact with a higher-order mode with three variations the electric field in horizontal direction. For that mode, the cutoff frequency is close to that of the TE_{30} mode, while for the fundamental TE_{10} mode it is about 60 GHz.

Multiple-beam design allows increase of the total power, while the gain remains the same as for the single-beam one.

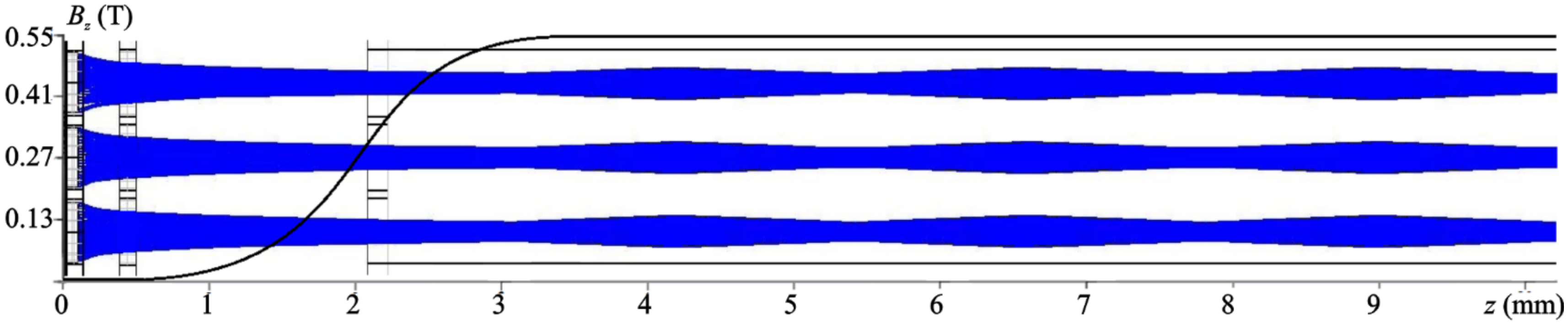


Dimensions of the SWS

Period of the structure *d* (um)	500
Vane thickness *s* (um)	100
Beam tunnel height 2*a* (um)	150
Slot depths *l* (um)	300
Width of the structure *b* (um)	2400
Relative shift *w* (um)	250
Beam height H_b (um)	300
Beam width W_b (um)	600

Triple-Beam EOS Design and Fabrication

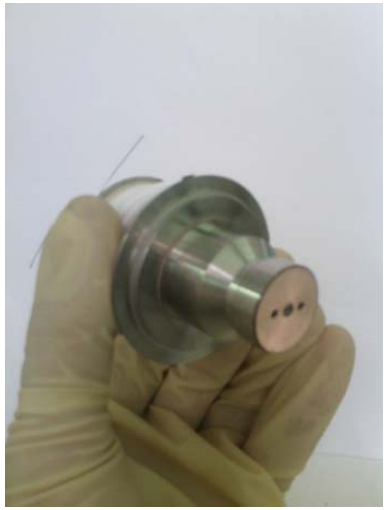
The electron-optic system (EOS) with three elliptic-shaped beams was designed, simulated and fabricated. For trajectory analysis of three elliptical electron beams focusing in the beam tunnel, Lorentz-3EM code is used. Each elliptic beam provides 30 mA current, and the total current is 90 mA with non-significant pulsations of the beam. DC beam voltage is 20 kV. The cathode-to-anode distance is 2 mm. The magnitude of the magnetic field in the tunnel is approximately 0.55 T.



The *y*-*z* projection of electron beam together with the magnetic field profile.

Triple-Beam EOS Design and Fabrication

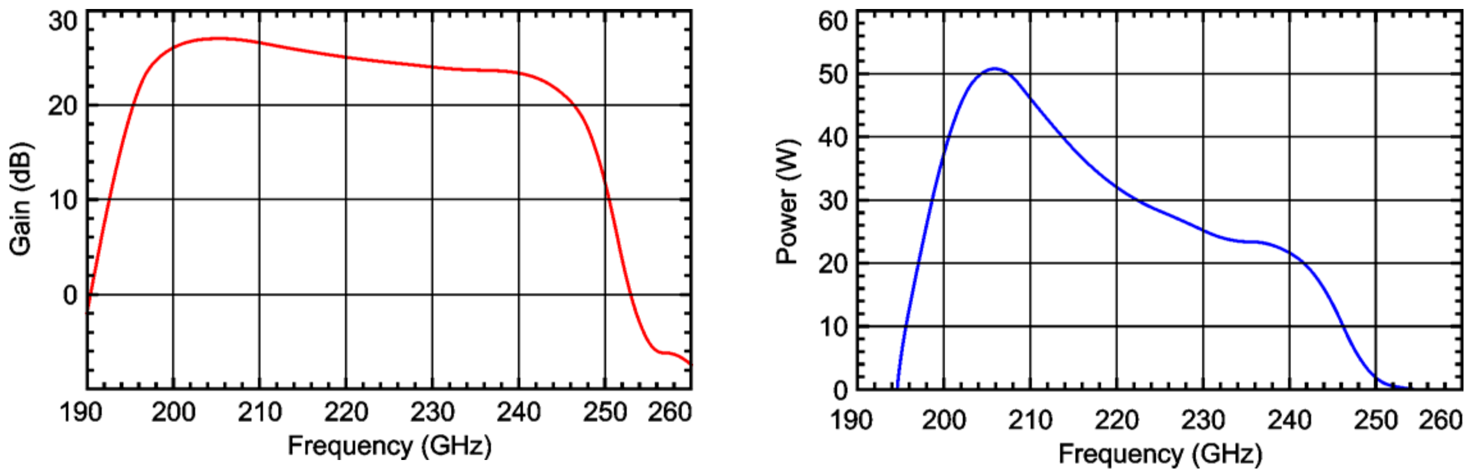
Based on the results of trajectory modeling, the EOS was fabricated. The magnetic focusing system consists of NdFeB permanent magnet and magnetic pole-pieces.



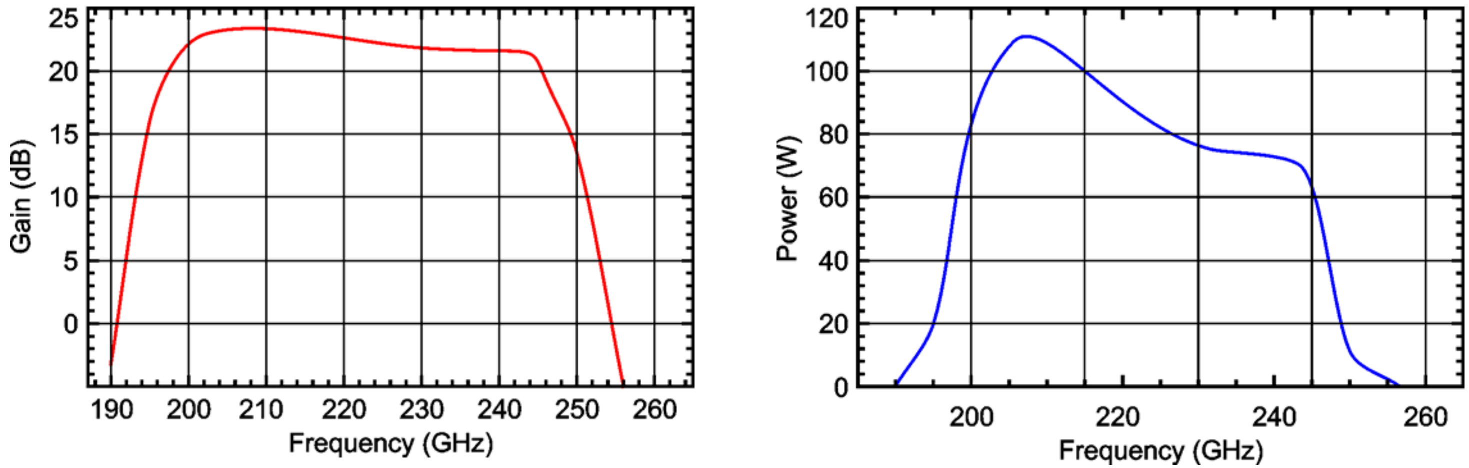
The electron gun assembled with a shadow and control grid. The gun consists of three elliptical cathodes, shadow grid, control grid, and anode.

Assembled EOS

Results of 3D PIC Simulation



Gain and power in a small-signal regime (100 mW driving power)



Gain and power in a large-signal regime (500 mW driving power)

Conclusion

Miniaturized TWTs with multiple sheet electron beams may offer high power (hundreds of Watts) in millimeter and sub-THz bands.

The V-band TWT with a double-tunnel meander-line SWS is designed and simulated. The TWT is driven by a 200-mA, 18-kV double sheet beam. Over 250 W average output power and 25–30-dB small-signal gain can be attained with 1-2 W input power at 68 GHz.

The G-band TWT with triple sheet beam and staggered dual-grating SWS is designed. Over 100-W output power at saturation and over 25-dB small-signal gain is predicted by the simulations.

The triple-beam EOS is designed, fabricated, and tested.

This research was supported by the Russian Science Foundation under Grants No. 17-12-01160 and 20-12-18034.