W-band Multi-Beam Sine Waveguide Traveling-Wave Tube with Low Current Density

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Abstract: *A W-band multi-beam traveling-wave tube (TWT) based on sine slow-wave structure is designed. The cold bandwidths of the fundamental and higher-order modes in the slow-wave circuit are analyzed using HFSS software. Through reasonable structural design, the fundamental mode and low-order mode are suppressed. The beam-wave interaction capability of the multi-beam TWT is analyzed based on the high-order mode transmission design. At the voltage of 11.7 kV, the current density of the sheet electron beam is 96 A/cm² which can be produced by the non-convergent electron gun, and the output power is over 150 W in the operating frequency 90 GHz-100 GHz.*

Keywords: high-order mode, multi-beam, traveling-wave tube, mode competition.

Introduction

Millimeter wave traveling-wave tubes (TWT) are widely used in defense and civilian fields such as radar, electromagnetic countermeasures, deep space detection and imaging [1]. The slow-wave structure (SWS) is the core component of the TWT. As the frequency rises, the size of the SWS becomes smaller, making processing of the SWS a problem that needs to be solved urgently. The overmoded SWS is proposed as one of the methods to solve the problem that the SWS is small in size and difficult to process [2]. The overmoded SWS can greatly increase the beam cross-sectional areas, further increasing the power capacity of the TWT. In this work, A multi-beam SWS based on a sine waveguide (SWG) is designed and the fundamental and low-order modes are suppressed. High-frequency transmission systems are designed and beam-wave interactions are calculated to predict performances of tube.

High frequency characteristics of SWS

Fig. 1. is a three-dimensional scheme of three sheet electron beam (SEB) overmoded SWS based on the SWG SWS [3]. Where wide side of the overmoded SWS is *a*, h_0 represents the height of electron tunnel, *h* and *p* are oscillating amplitude and period of SWG, respectively. Parameter *t* is the separation distance between two electron beam tunnels and *d* is wide side of the SEB tunnel.

Fig. 2. shows the dispersion curves of three lowest modes calculated by simulation software HFSS. The voltage line intersects with mode 3 (TE_{30}) and has a wide synchronization bandwidth (90-100GHz) which is beneficial for the TWT to achieve stable output power in a broad bandwidth.

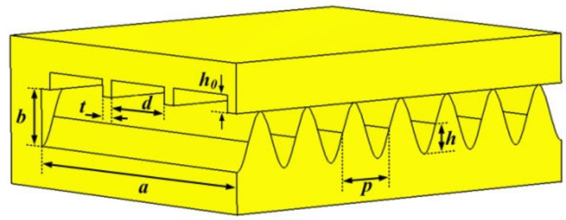

Figure 1. Dimension parameters of SWS.

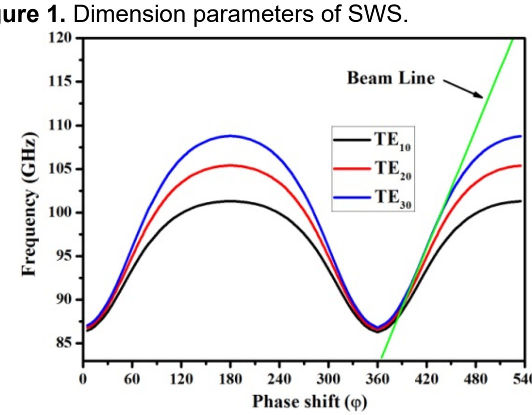

Figure 2. Dispersion characteristics of W-band overmoded SWS.

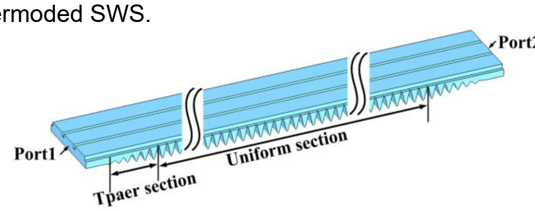

Figure 3. Transmission model of overmoded SWS.

Fig. 3. shows the transmission model. The model consists of 80 main periods and six gradient periods at each end. Fig. 4. shows the transmission and reflection parameters of TE30 mode corresponding to the transmission model above. The TE30 mode is fed into port 1. At this time, at the frequency range of 90-100 GHz, considering the surface roughness of the metal conductor, the effective conductivity is set to 3×10^7 S/m, S_{21} is greater than -4.64

dB, and the loss is 0.64 dB/cm. S_{11} is below -28 dB, which indicates that TE_{30} mode has better transmission performance in this overmoded SWS. Due to the rational design of the overmoded SWS dimensional parameters, the fundamental mode and other low-order modes are well suppressed.

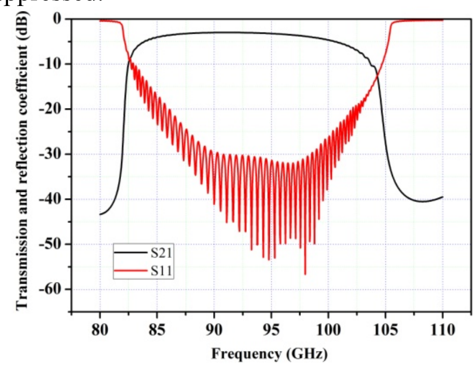

Figure 4. Transmission and reflection coefficient of TE_{30} mode.

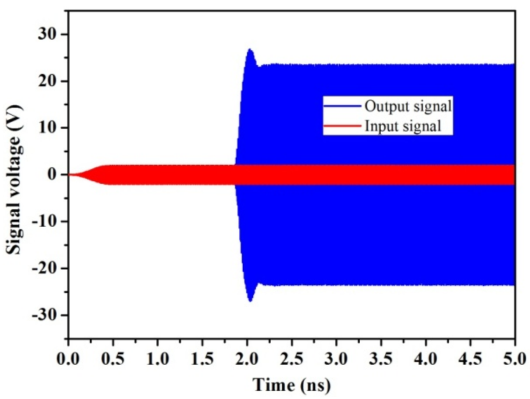

Figure 5. Beam-wave interaction simulation results at the typical frequency of 95 GHz.

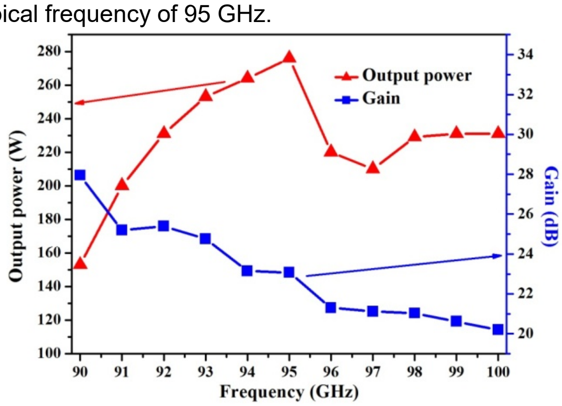

Figure 6. Output power and gain versus operating frequency.

Beam-wave interaction

Beam-wave interaction calculation were carried out to predict the performances of overmoded TWT. A SEB with a beam current of 250 mA was injected into the overmoded slow-wave circuit. The output signal is stable after 2.3 ns from Fig. 5. Output power is 276 W with saturation input power of 1.65 W when the synchronous voltage is 11.7 kV. The magnetic field strength that constrains the electron beam is about 0.5 T with current density of 96 A/cm^2 and no electrons were intercepted.

The W-band overmoded SWG TWT is simulated by the beam-wave interaction over the entire operating frequency range, and the results is shown in Fig. 6. The output power exceeds 150 W over the entire operating frequency band, especially more than 200 W from 91 GHz to 100 GHz. Gain is more than 20 dB at the frequency range from 90 GHz to 100 GHz.

Conclusion

A new overmoded SWS based on SWG with low current density is proposed and performances of overmoded TWT are investigated. Mode competition in this overmoded SWS is also well solved through reasonable design of high frequency slow-wave circuits. Fundamental mode and low-order mode are well suppressed, while TE_{30} has good transmission characteristics. The ouput power of interaction is more than 150 W from 90 GHz to 100 GHz. The multi-beams overmoded TWT is a promising mm-wave and terahertz source due to its larger structural size and higher power capacity.

Acknowledgment

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References

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