Design of Ka-Band High-Power TWT

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Abstract: *A Ka-band traveling wave tube (TWT) with an output power above 5kw, an electronic efficiency above 10% in the bandwidth of 33-37GHz was designed. The structure of slow wave adopts folded waveguide. The folded waveguide TWT has a saturated gain of 43.5dB, peak power of 6.7kW and electronic efficiency of 10.54% at 35GHz. We also have designed the electronic optical system, simulation results show the electron gun voltage is 28Kv, and transmitted beam current is 2.54A.*

Keywords: Ka-band, traveling wave tube (TWT), folded waveguide, electronic optical system

Introduction

High power TWT is mainly used as microwave power amplifier in high power millimeter wave electronic countermeasure system and high precision millimeter wave radar system [1-3].

In 2012, CPI successfully developed and tested a ka-band traveling wave tube for commercial and military satellite markets. The output power of the single-line wave tube is 700W, the bandwidth is 2GHz, and the efficiency of the whole tube is up to 52% [4]. NASA's KABOOM (Ka-Band Objects Observation and Monitoring) program at Kennedy space center is designed to detect, characterize and track near-earth Objects, ensuring the safety of earth and aerospace activities. Its core part is a radar system with high power and high resolution, which requires the total output power of 33-37ghz at Ka band to reach more than 225kW, and the output power of a single radar transmitter to reach more than 25kW. There is no doubt that TWT is the preferred amplifier in this radar system due to its high output power and wide operating band [5].

This paper designs a Ka-band high-power folded waveguide traveling wave tube. The goal is to produce a power output greater than 5kW in the 33-37GHz frequency band. However The design is with potential to increase the output power up to 30kW.

Slow wave structure

The traveling wave tube works by the mechanism of interaction between high-frequency electromagnetic fields and electron beams. Therefore, the study of slow-wave structure is of great significance. The design of the slow-wave structure is directly related to the energy exchange efficiency, operating frequency range, bandwidth, and operating mode of the traveling wave tube. As a core component of the traveling wave tube, the slow wave structure largely determines the bandwidth and power level of the traveling wave tube.

Folding waveguide traveling wave tube is the representative of high-power traveling wave tube due to its all-metal slow-wave structure, which has the advantages of large power capacity, wide bandwidth, high mechanical strength, easy processing, strong reproducibility, and good heat dissipation.

Fig.1 is a three-dimensional structure diagram of a folded waveguide slow-wave structure. Since dispersion flatness and coupling impedance are a pair of contradictory requirements, the design target is emphasized on bandwidth. Therefore, in order to ensure that the dispersion in the frequency band is flat and the coupling impedance is high, a suitable slow-wave structure parameter must be selected.

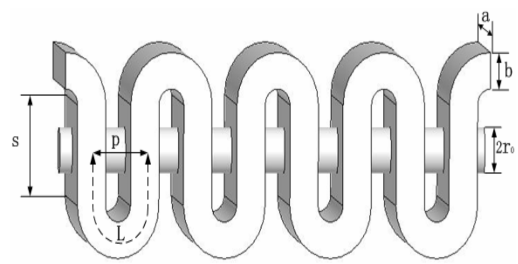

Fig.1 Structure diagram of slow wave structure

Fig.2 and shows the high frequency characteristics of FWSWS which are simulated by the Eigenmode solver of HFSS for single period structure. The FWSWS phase shift corresponding to the operating frequency band is "1.34π-1.55π" which is far from the 2π point corresponding to the upper cutoff frequency, and the coupling impedance is high.

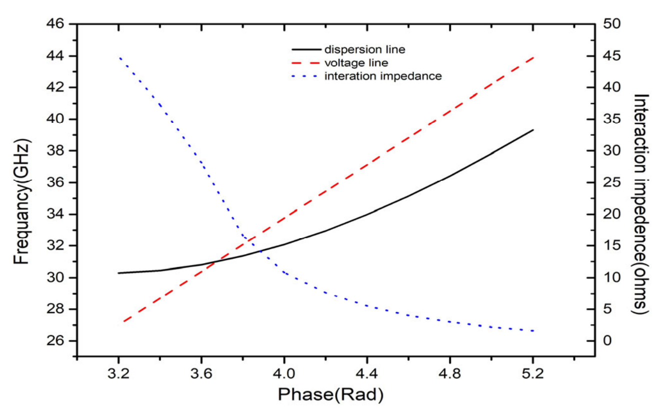

Fig. 2 The high frequency characteristics of FWSWS

The beam-wave interaction simulation is carried out to predict the gain and output power by nonlinear beam wave interaction calculation software FWGTWT4.0 [6], which are shown in Fig. 3. The operating voltage of folded waveguide TWT is set at 24.75kV, and the current is set at 2.5A.

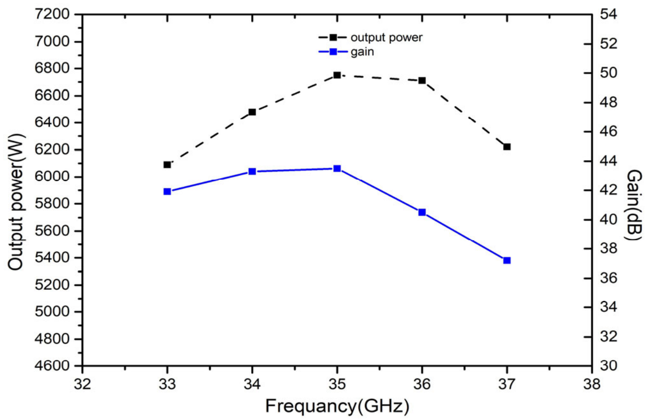

Fig. 3 The simulation curve of beam-wave interaction

Fig. 3 shows that the saturated gain exceeds 37dB and output power above 6kw over the whole bandwidth. The peak power is up to 6.7KW at 35GHz. The electron efficiency is over 10% in the whole bandwidth.

Electron optical system

Electron optical system is also critical for the TWT. A Pierce gun with double anodes, uniform magnetic focusing system are designed by OPERA which adopted to ensure the stable performance of TWT.

The current of 2.54A is emitted by the gun under the voltage of 28kV. The value of magnetic focusing system is above 4200Gs.

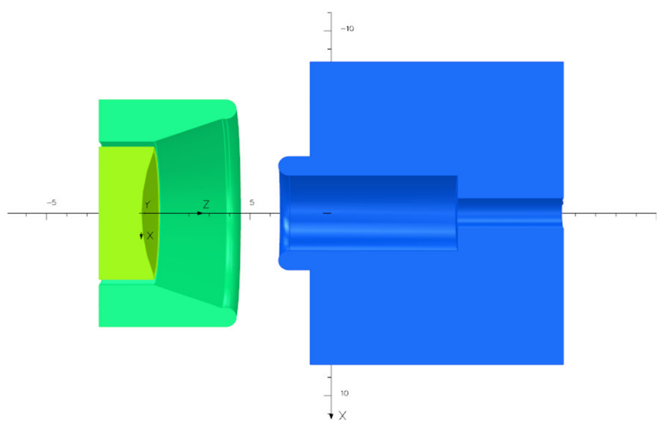

Fig. 4 Profile of electron gun simulation model in Opera

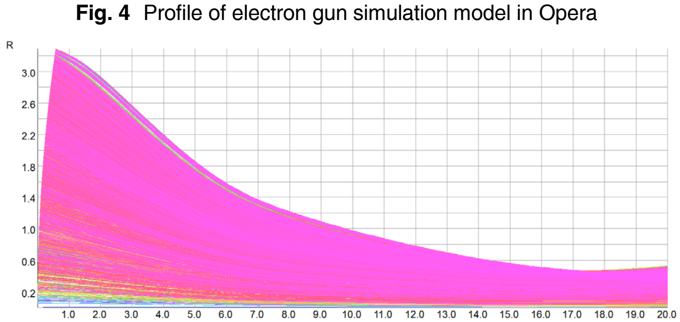

Fig. 5 The r-z plane electron injection trajectory in Opera

Fig. 5 shows that The waist radius of electron beam is about 0.5mm, and the range is slightly greater than 17mm.

Conclusion

This paper proposes a design of ka-band high power TWT. The slow wave structure adopts folded waveguide. The simulation results show that the device can reach above 5 kW output-power in the bandwidth of 33-37 GHz. The next step is to further optimize the simulation results and carry out experimental research overall tube.

The perveance of the electron gun is 0.54 in our design. The beam current can reach to 6 A if the voltage increased to 50kV. The total power of electron beam is about 300kW. According to the efficiency of the beam wave interaction is about 10%. The device have potential to output more than 30kW power without to change the structure of the electron gun. So, it will provide a reference for the development of an even high - power Ka-band TWT.

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