Particle-In-Cell Simulations of Beam-wave Interacion for Sub-Terahertz Folded Waveguide Traveling Wave Tubes

Zhengyuan Zhao [1,2],WenXin Liu*[1,2], LongLong Yang [1,2] , Yue Ou [1,2]

[1]Aerospace Information Research Institute, Chinese Academy of Sciences

[2] School of Electronic, Electrical and Communication Engineering, University of Chinese Academy of Science

* Corresponding author's email: lwenxin@mail.ie.ac.cn

Abstract: *In this paper, we modelled a sub-Terahertz at the frequency of 0.108THz folded waveguide traveling-tube (FWTWT) by utilizing a 3-D particle-in-cell (PIC) in CST STUDIO SUITE, and we investigated the beam and electromagnetic field of 108GHz FWTWT. The process of the interaction for FWTWT are presented, including working voltage, the structural parameters, working frequency. The radiation power and gain of the FWTWT at 108GHz is 42.32W and 26.26dB. The output of the FWTWT changes only 1.2dB across the 7Ghz bandwidth ranging from 103Ghz to 110GHz, which is useful in many fields, such as communications, electronic countermeasures, radar.*

Keywords: FWTWT; CST STUDIO SUITE;3-D particle-in-cell particle simulation.

Introduction

In the middle and late 19th century, Maxwell and others theoretically improved the classical electromagnetic theory, predicted the existence of electromagnetic wave, and proved it by Hertz with experiments. Since then, scientists have carried out a lot of researches on the generation and application of electromagnetic wave. At present, there is a section of spectrum (0.1Thz ~10THz) in the transition region of electromagnetic spectrum from microwave to infrared light, which has not been effectively developed due to the lack of electromagnetic wave sources and related electronic equipment in this frequency band. THz wave has many characteristics that other frequency band electromagnetic waves do not have, and it has a great application prospect under this spectrum, which makes the development and utilization of THz wave become a hot spot in the field of electromagnetic research.

Folded waveguide slow-wave structure is a kind of metal structure, has a large capacity of power, wide frequency band, strong cooling capacity, weak dispersion, open circuit structure is simple, solid structure, and integral sex is good, easy to control in the process of machining the waveguide surface roughness, machining accuracy and assemble the advantage of high accuracy, can realize high frequency, high power millimeter wave amplifier and broadband taken down.

Determination and modeling of initial parameters

The folded waveguide was first proposed by G.Dohler. It is an all-metal slow-wave structure with excellent heat dissipation capacity and relatively wide operating frequency band. Trough waveguide is a kind of waveguide structure proposed by F. J. Tischer. According to the cross-section shape, it can be divided into rectangular groove, V-shaped groove and circular groove waveguide, etc. The research results of F. J. Tischer showed that the channel waveguide has a wide single-mode operating frequency band, low loss, large size and high power capacity, making it an ideal transmission line for millimeter wave and submillimeter wave. With the increase of frequency folded waveguide is chosen as the TWT slow-wave structure, is because of its characteristics such as high power, broadband, easy processing.

By use the following formula to calculate the simulation parameters. The parameters obtained are shown in table 1.

$$
\begin{aligned}
&\frac{p}{a}=\frac{(v_0/c)\overline{\varphi_0}}{(f_0/f_c)}\\
&\frac{L}{a}=\frac{(\overline{\varphi_0}-1)}{\sqrt{(f_0/f_c)^2-1}}\\
&\frac{1}{2}\tan\left(\frac{\pi\overline{\varphi_0}}{2}\frac{b}{p}\right)=\left(\frac{\pi\overline{\varphi_0}}{2}\frac{b}{p}\right)\\
&\frac{R}{a}=0.8\sim 0.1\\
&\frac{R}{b}=0.25\sim 0.5\\
&\frac{v_0}{c}=\frac{(v_e/c)}{(1+\omega_q/\omega)},\frac{v_e}{c}=\sqrt{1-1\Big/\left[1+\frac{U_0}{c^2}\eta\right]^2}
\end{aligned}
\tag{1}
$$

Table 1. The calculated parameters

Long side(mm)	1.74
Narrow side(mm)	0.25
Straight waveguide height(mm)	0.7
Half cycle(mm)	0.49
Aperture radius(mm)	0.2
Number of cycles	80

We used CST software for simulation, and built the model in the 3-D particle-in-cell particle studio. The electron beam and particle flow worked in a vacuum environment, and FWTWT was made of oxygen-free copper. The established model is shown in figure 1.

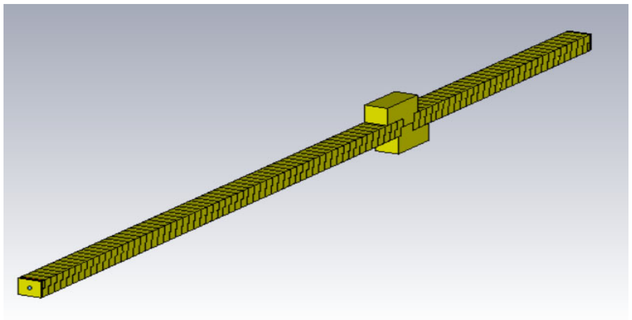

Figure 1. Simulation model established in CST

The simulation results are analyzed

In CST, the applied voltage is 13.2kV, the current is 80mA, the deflecting magnetic field strength is 0.5T, and the excitation is 100mW. After simulation, the results can be obtained as shown in figure 2.

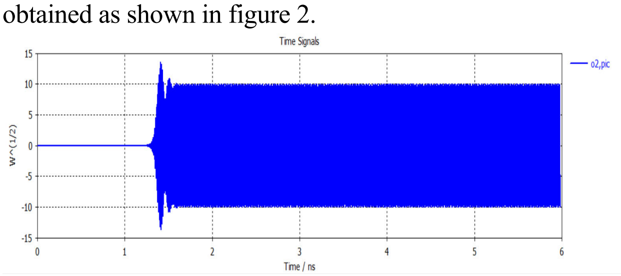

Figure 2. The output power

As can be seen from figure 2, under the conditions of the initial setup, the folded waveguide TWT can reach the output of 42.32W, and the gain of 26.26dB can be obtained through calculation.

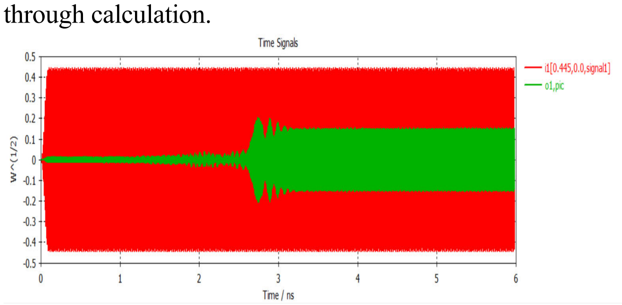

Figure 3. Excitation signal and reflection signal contrast

It can be seen from figure 3 that the signal reflected from the input port is much smaller than the input excitation signal, indicating that the folded waveguide TWT designed in this way is good.

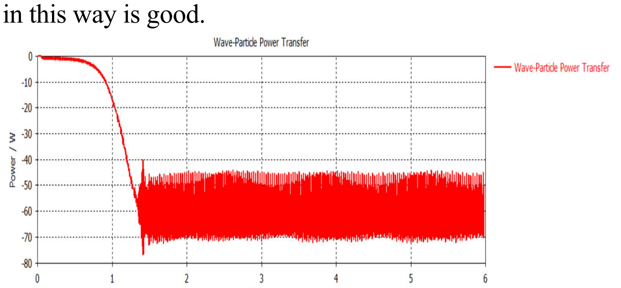

Figure 4. Wave-Particle Power Transfer

As can be seen from figure 4, the energy conversion between the injection waves starts to reach the stable value after 1.4ns, which indicates that the interaction between the injection waves starts after 1.4ns, and the conversion stabilizes around 50W thereafter.

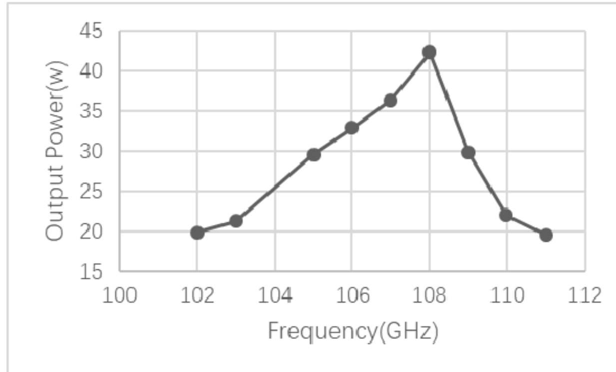

Figure 5 bandwidth

As can be seen from figure 5, the output power at 108GHz is 42.32W, 21.29W at 103GHz and 21.98W at 110GHz. The 3dB bandwidth is about 7GHz and the frequency range is (103-110) GHz.

Conclusion

In this paper, the basic parameters of the 108GHz folded waveguide TWT were determined by the formula, and then the model was established in CST for simulation analysis under different conditions. Finally, the output power was 42.32W, the gain was 26.26dB, and the bandwidth was 7GHz.

Acknowledgements

This work is partly supported by National Key R&D Program of China (grant number: 2017YFE0130000 and 2017YFA0701003) and National Natural Science Foundation of China (11675181,61831001,U1832193)

References

[1] T. Stander, “A review of key development areas in low-cost packaging and integration of future.

[2] 2.Magic User’s Manual, ATK Mission Res. Inc., Newington, VA, 2004.

[3] 3. S.T. Han, J.I. Kim, K.H. Jang, J.K. So, S.S. Chang, N.M. Ryskin and G.S. Par“Experimental investigation of millimeter wave folded-waveguide TWT”, in Proc. Int. Vacuum Electronics Conf. May 2003, pp. 322-323.

[4] 4. Ghosh, T.K.,Tokeley, A.,Duffield, M.J.,Rushbrook, K.,Scott, D.,Poston, I.,Bowler, D.. Design and development of a 2–7 GHz helix TWT[P]. Vacuum Electronics Conference, IEEE International,2014.