Particle-in-Cell Simulation and Optimization for a 108GHz Folded Waveguide Traveling-wave Oscillator

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***Abstract*—The design of a 108GHz folded waveguide (FW) traveling-wave oscillator is presented in this paper. The dispersion of the FW was calculated by theoretical method and electromagnetic software simulation. To make the designed oscillator work at the best operating point, the beam voltage, number of periods, magnetic field, and radius of beam tunnel are all need to be optimized. Particle-in-cell (PIC) simulations were carried out to optimize the performance of the FW oscillator. As a result, the optimized FW oscillator can obtain the output power of 527W at 108GHz with the beam voltage of 20.1kV.**

I. INTRODUCTION

LIGHTWEIGHT, low voltage and broadband sources of high-power coherent THz radiation are attracted in numerous applications such as military radar, electronic countermeasure system, and communication[1]. Traveling-wave tubes (TWTs) and oscillators based on folded waveguide (FW) slow-wave structures are promising devices in millimeter and sub-millimeter wavelength ranges[2]. The folded waveguide circuit has advantages over others in low-cost fabrication, high reproducibility, high power handling capability with a moderate bandwidth in the millimeter wave frequency range[3].

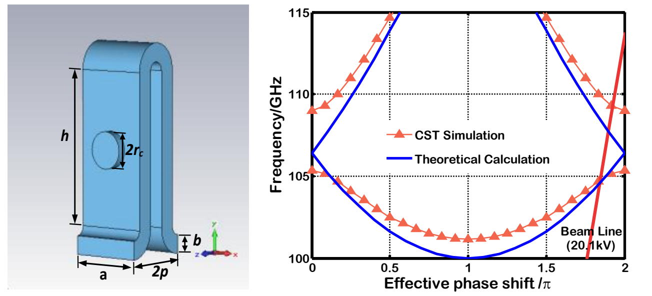
In this paper, a 108GHz FW traveling-wave oscillator is designed. Both of the theoretical method and software simulation were applied to analyze the dispersion of the FW. The distribution of the electric field in the FW was also analyzed using CST Microwave Studio (MWS). The 3-D Particle-in-Cell (PIC) simulation code CHIPIC was applied to simulate the nonlinear beam-wave interaction in the FW oscillator. The designed oscillator need a lot of PIC simulations to be optimization. The beam voltage, number of periods, magnetic field and radius of beam tunnel are all need to be optimized. After a lot of simulations, the optimized operating parameters were obtained. The optimized FW oscillator can obtain the output power of 527W at 108GHz with the beam voltage of 20.1kV

II. HIGH-FREQUENCY CHARACTERISTICS

As shown in Fig.1 (a), CST MWS was applied to calculate the dispersion of the FW. To make the operating point to be 108GHz, the structural parameters were selected as TABLE I.

TABLE I
STRUCTURAL PARAMETER OF 108GHZ FW

Parameters	Value
Half a period	p=0.72 mm
Waveguide cross-section width	a=1.50 mm
Waveguide cross-section height	b=0.36 mm
Height of the straight waveguide	h=3.00 mm
Radius of the beam tunnel	r_c=0.36 mm
Radius of the electron beam	r_b=0.26 mm



(a) (b)

Fig. 1. (a) CST model of one period of FW; (b) Dispersion of the FW, comparing CST simulation and theoretical calculation

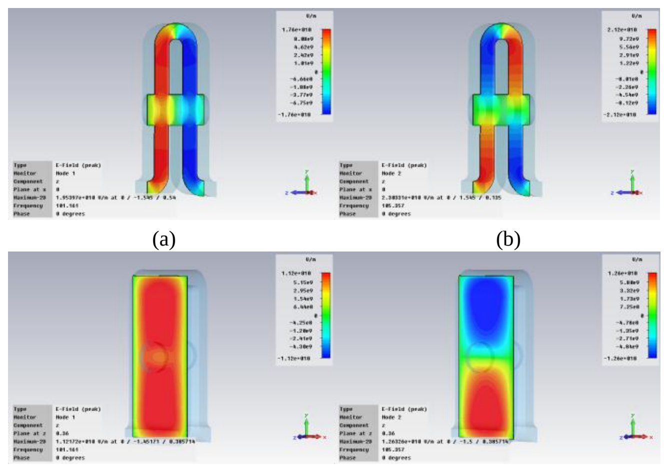


Fig. 2. Distribution of Electric field (a) Longitudinal cross-section of Mode 1; (b) Longitudinal cross-section of Mode 2; (c) Transverse cross-section of Mode 1; (d) Transverse cross- section of Mode 2

As shown in Fig.1 (b), the two dispersion curves were calculated from CST simulation and theoretical calculation, respectively. As can be seen, the curve of theory is lower than that of simulation. In the oscillator, the electron beam interacts with the Mode 2 in the FW. When the beam voltage is set to be 20.1kV, the points of interaction in the theory and simulation are 107.7GHz and 109.2GHz, respectively.

Fig.2 shows the electric field distribution of different modes in the FW. As shown in Fig.2, the cutoff frequencies of Mode1 and Mode 2 are 101.2GHz and 105.4GHz, respectively. It agrees with the dispersion of the FW. Fig.2 (a) and (b) show the longitudinal cross-section of Mode 1 and Mode 2, respectively. Fig.2 (c) and (d) show the transverse cross-section of Mode 1 and Mode 2, respectively.

III. PARTICLE-IN-CELL SIMULATION AND OPTIMIZATION

In this part, a 3-D PIC simulation code CHIPIC is applied to simulate the beam-wave interaction in the FW oscillator. Fig.3

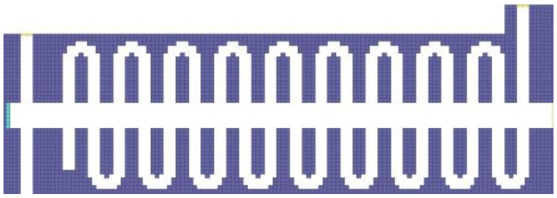


Fig. 3. CHIPIC model of a FW traveling-wave oscillator

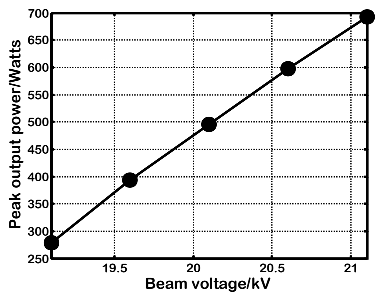


Fig. 4. Peak output power versus beam voltage (10periods)

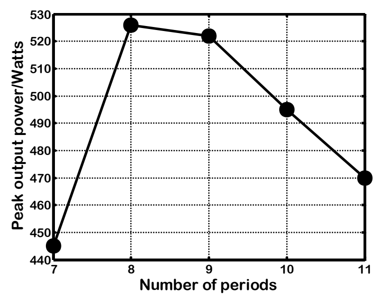


Fig. 5. Peak output power versus number of periods (20.1kV)

shows the CHIPIC model of FW traveling-wave oscillator. The right port is the output port. The parameters in TABLE I were applied to construct the simulated model. The beam voltage is set as 20.1kV. The beam current is set as 100mA. The magnetic field is 0.5T. The number of periods is set as 10.

At first, PIC software was applied to optimize the beam voltage. Fig.4 shows the peak output power versus beam voltage. It can be seen that the peak output power obtains the maximum 692W when the beam voltage is 21.1kV. However, the output power of 20.6kV and 21.1kV is not stable; thus, the beam voltage is selected as 20.1kV.

Next, the number of periods should also be optimized. The beam voltage is fixed at 20.1kV. The simulated number of periods is range from 7 to 11. As can be seen in Fig.5, the maximum output power 526W is obtained when the number of periods is 8. The optimized number of periods is selected as 8.

After the optimization of beam voltage and number of periods, the magnetic field should also be optimized. Here, the simulated magnetic field is range from 0.3T to 0.7T. The result is shown in Fig.6. When the magnetic field is 0.5T, the maximum output power is obtained. The optimized magnetic field is selected as 0.5T.

The radius of beam tunnel determines the interaction impedance. However, both too big and too small radius of beam tunnel will decrease the output power. Hence, the radius of beam tunnel should be optimized as well. Here, the duty ratio is fixed as 0.72. As shown in Fig.7, when the radius of beam tunnel

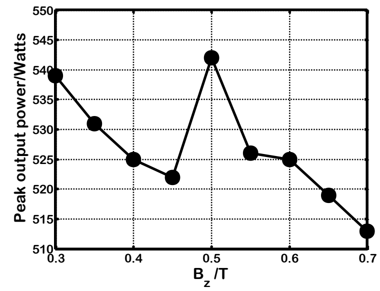


Fig. 6. Peak output power versus magnetic field (8periods, 20.1kV)

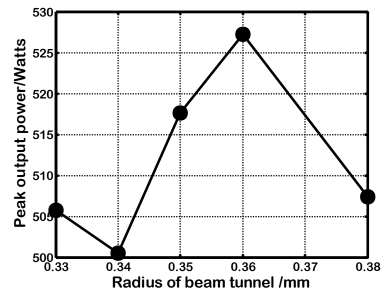


Fig. 7. Peak output power versus radius of beam tunnel (8periods, 20.1kV)

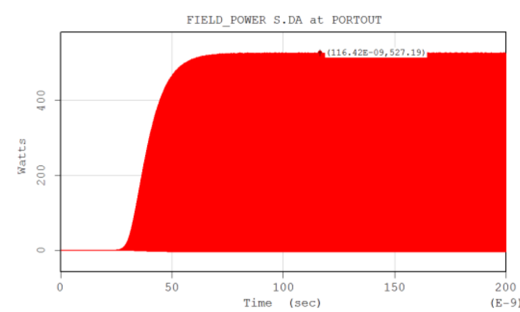


Fig. 8. Optimized peak output power (8periods, 20.1kV, 0.5T, r_c=0.36mm)

is 0.36mm, the maximum output power 527.19W is obtained. When the radius of beam tunnel is 0.37mm, there is no oscillation. As a result, the optimized radius of beam tunnel is selected as 0.36mm. The radius of electron beam is 0.26mm.

The final optimized parameters were applied to the PIC simulation. The peak output power 527W is shown in Fig.8. The output frequency is 107.93GHz.

IV. Summary

In this paper, a 108GHz FW traveling-wave oscillator is designed. The dispersion is analyzed by theoretical method and CST simulation. The transmission modes in the FW are also analyzed. The PIC simulation is applied to simulate the FW oscillator. The operating parameters are optimized by the PIC simulation. The optimized oscillator obtains 527W at 108GHz.

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