S Band Miniaturized Reversed Cherenkov Oscillator with Uniform Magnetic Focusing System

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Abstract: *Based on the reversed Cherenkov radiation of metamaterials (MTMs), an S band reversed Cherenkov oscillator (RCO) is designed. In order to make it practical, a coaxial coupling output structure and uniform magnetic focusing system are used. The simulation results using the particle-in-cell solver in CST 2017 Particle Studio show that the average output power of 55 kW at 2.219 GHz with 27.8% electronic efficiency is generated under the conditions of the beam voltage of 29 kV, the beam current of 6.8 A and the uniform axial magnetic field of 1300 G. The diameter of the metamaterial slow-wave structure (MSWS) is ~1/6-1/2 of its conventional counterparts of the backward wave oscillators (BWOs). The RCO can be applied to communication, radar, microwave heating, and so on.*

Keywords: metamaterial, reversed Cherenkov oscillator (RCO), uniform magnetic focusing system

Introduction

Metamaterial (MTM) is a kind of sub-wavelength structure of artificial design which shows unique electromagnetic properties [1-3]. In recent years, MTM has been widely researched due to its unique physical properties, such as negative index of refraction, reversed Cherenkov radiation and reversed Doppler effect. Although the existing vacuum electronic devices (VEDs) based on MTMs have many advantages such as high power and high efficiency, the characteristics of large volume, high beam voltage and high axial magnetic field also restrict the development and mass production of the vacuum electronic devices [4, 5]. The reversed Cherenkov oscillator (RCO) is a product of introducing MTMs into the field of VEDs. The problem in today's scenario is to make the implementation of MTMs in VEDs practical and reliable.

This paper is devoted to the design of miniaturized output coupling structure and magnetic focusing system. In section II, the transmission characteristics of the RCO are simulated by using the frequency domain solver in CST 2017 Microwave Studio. Section III shows the simulation results of beam-wave interaction with uniform axial magnetic field by using the particle-in-cell solver in CST 2017 Particle Studio. The research has been concluded in Section IV.

Transmission characteristics

Considering the miniaturization and practicality of the RCO, the metamaterial slow-wave structure (MSWS) consisted of 8 complementary electric split-ring resonators (CeSRRs) as in [5] with coaxial electric coupling structure is designed. The simulation model of the MSWS is shown in Fig. 1(a). The period P is 12 mm, the thickness of CeSRRs t is 1 mm and the length L is 10 mm. The parameters of the coaxial electric coupling structure are optimized as follows: h_1=5 mm, h_2=6 mm, r_1=0.525 mm, r_2=1.7 mm, r_3=1.9 mm. The diameter of the MSWS is ~λ/6, which is smaller than the size ~λ/3-~λ of its conventional counterparts of the backward wave oscillators (BWOs) (λ is the wavelength in free space) [3]. The simulated transmission characteristics are shown in Fig. 1(b). |S21| can reach -0.5 dB at maximum, which is beneficial for the transmission of waves and beam-wave interaction.

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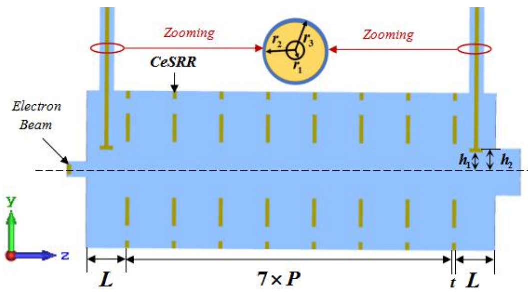

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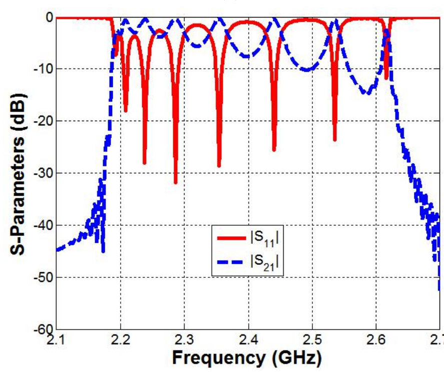

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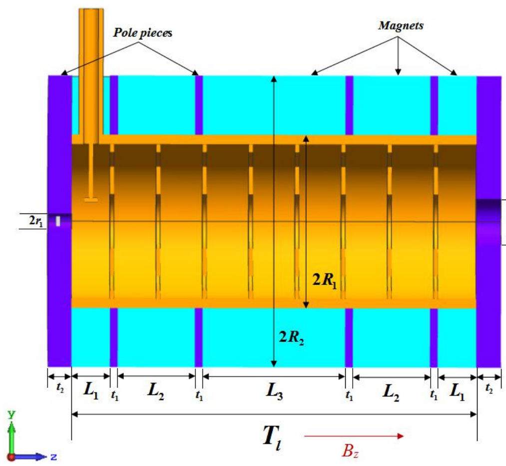
Fig. 1. (a) Simulation model of the MSWS and (b) simulated transmission characteristics.

Simulation of beam-wave interaction with uniform axial magnetic field

In order to produce a uniform axial magnetic field, the focusing system is designed to a magnet combination system, the parameters are shown in Table I and the weight of the entire focusing system is ~3 kg (density is ~8.4 g/cm^3). The simulation model of the magnetic focusing system is shown in Fig. 2(a). The magnet used here is samarium cobalt (Sm_2Co_{17}), which has a linear demagnetization characteristic with the remanence (B_r) of 1.18 T and the coercivity (H_c) of 796 kA/m, and the pole pieces are made of pure iron. The simulated axial magnetic field distribution is shown in Fig. 2(b). The length of beam-wave interaction T_l is 105 mm. The permanent magnet focusing system provides a 1300 G axial magnetic field. The axial magnetic field at both ends will be shielded in further simulations. The beam transmission rate of 100% is achieved.

Table I. Parameters for the magnetic focusing system

Symbol	Value (mm)
L_1	10
L_2	20
L_3	37
t_1	2
t_2	6
R_1	22.5
R_2	37.8
r_1	2
r_2	6



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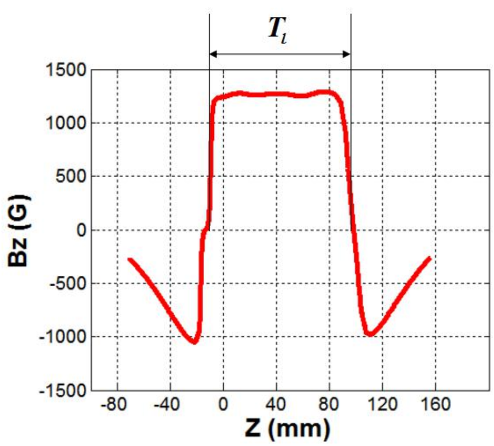

(b)

Fig. 2. (a) Simulation model of the magnetic focusing system and (b) simulated axial magnetic field distribution.

In the simulation of beam-wave interaction with the above simulated axial magnetic field and considering the ideal electron emission surface, the beam current is 6.8 A, beam radius is 1.3 mm, the results with different beam voltages are shown in Fig. 3 and the beam transmission rate is achieved to be 97%. It can be seen that when the beam voltage is 29 kV, the average output power at 2.219 GHz is ~55 kW, and the electronic efficiency is 27.8%. The entire length of the MSWS is only 105 mm and the overall volume is also much smaller than the conventional BWOs. Compared with the conventional BWOs [6, 7], the RCO has been found to be more advantageous in terms of electronic efficiency.

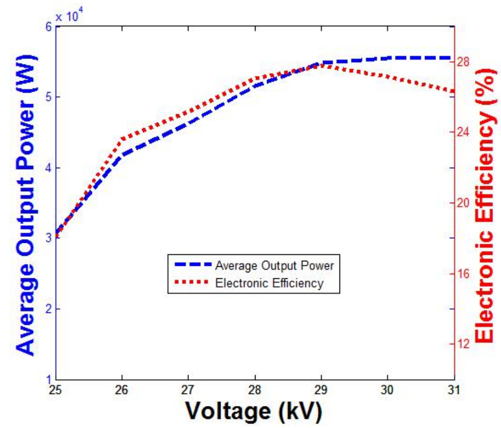

Fig. 3. Average output power and electronic efficiency of the RCO versus beam voltage.

Conclusion

Based on the above study, an S band RCO with coaxial coupling output structure and uniform magnetic focusing system is proposed. The RCO has the advantages of low beam voltage, miniaturization, high power and high efficiency. It is beneficial to the development and applications of RCO. The applicable electron gun design will be the further research task to be taken. The RCO has wide prospects in narrowband communications, accelerators, radars and other fields.

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