Simulation and design of an X-band overmoded input cavity *

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Abstract: The RF input cavity is an important component for velocity-modulating types of microwave device, providing velocity modulation and density modulation. Conventional RF input cavities, however, encounter the problem of power capacity in the high frequency band due to the scaling law of the working frequency and device size. In this paper, an X-band overmoded input cavity is proposed and investigated. A resonant reflector is employed to reflect the microwave and isolate the input cavity from the diode and RF extractor. The resonant property of the overmoded input cavity is proved by simulations and cold tests, with PIC simulation showing that with a beam voltage of 600 kV and current of 7 kA, an input power of 90 kW is sufficient to modulate the beam with a modulation depth of 3%.

Keywords: X-band, overmoded input cavity, relativistic klystron amplifier, phase-locked oscillator

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1 Introduction

Combining the output powers from multiple phase-locked high power amplifiers or oscillators is considered an effective way to enhance the output power of high power microwave (HPM) sources [1]. In low frequency ranges like the L- and S-bands, the relativistic klystron amplifier (RKA) has proved to be an appropriate candidate as the output frequency and phase can be controlled quite well by the external signal [2, 3]. The biggest disadvantage of the conventional annular beam RKA with cylindrical drift pipe, however, is low output power at the high frequency range [4]. To realize sufficient isolation between cavities, the drift pipe radius of the RKA is selected to cut off the working mode TM_{01}. As the frequency increases to the X-band, the size of the drift pipe is too small to transfer enough beam current. Moreover, the power capacity of the device is also restricted by the structural size. In order to enhance the output power capability at high frequencies, the geometrical size of the RKA must be increased. In other words, some new types of RKA with overmoded structures should be developed. On the other hand, the relativistic backward wave oscillator (RBWO) has been investigated intensely in recent years due to significant advantages such as high output power and high efficiency at high frequency ranges [5,6]. The output power of the RBWO, however, is influenced by the waveform of the pulsed power supply, which cannot be combined coherently. For this reason, phase locking of the RBWO by an external signal is currently of interest. There are two main methods to accomplish phase locking of the RBWO. One is by means of direct injection [7]. The other is accomplished by modulation of the electron beam [8]. Compared with direct injection, this configuration has advantages such as low injected power requirement and low leaked power into the driver, but in this configuration, an independent input cavity is needed to prebunch the beam.

Whether the overmoded RKA or the phase-locked RBWO by use of modulated electron beam is used, how to produce a modulated electron beam with an acceptable injected RF power requirement is the key issue in these velocity modulating types of microwave devices. In this paper, an X-band overmoded input cavity is presented and investigated. Compared with the input cavity used in the conventional klystron amplifier, the resonant reflector working at the TM_{02} mode is employed to maintain the isolation and resonance of the overmoded input cavity instead of the cut-off drift tube. The resonant property of the overmoded input cavity has been proved by simulations and cold tests. PIC simulation shows that with a beam voltage of 600 kV and current of 7 kA, an input power of 90 kW is sufficient to modulate the beam with a modulation depth of 3%. The remainder of this paper is organized as follows. In Section 2, we present the physics model and detailed description of the overmoded

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input cavity structure. The PIC simulation results and cold test of the overmoded input cavity are given in Section 3. Finally, some conclusions are given in Section 4.

2 Physics model

The RF input cavity is the most important part of the velocity modulating type of device, as it is responsible for producing the initial velocity modulation. Its functions include: 1) pre-modulating the electron beam by use of the electric field inside the input cavity established by the injected RF power; 2) reducing the leakage power and isolating the input cavity from the diode and RF extractor. The structure of the overmoded input cavity is shown in Fig. 1.

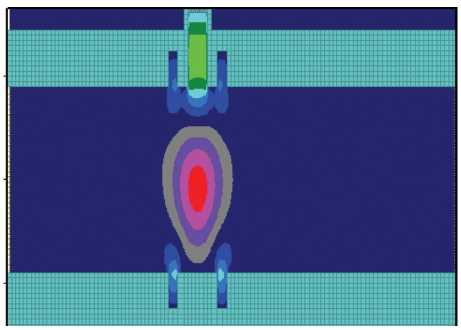


Fig. 1. (color online) Overmoded input cavity structure and its electric field distribution.

The input cavity is composed of three parts: two resonant reflectors working in TM_{02} mode and a rectangular input waveguide. The seed RF signal is injected into the input cavity through the input waveguide, and then confined inside the input cavity by the use of two reflectors. In a conventional RKA, the drift pipe radius is selected to cut off the working mode to ensure the injected RF power is confined inside the input cavity, while in the overmoded input cavity discussed here, the function of the drift pipe is replaced by a resonant reflector. The mechanism of the resonant reflector is similar to that used in the oversized RBWO. Figure 2 is the S21 curve of the resonant reflector (S21 describes the transmission coefficient of the RF network). It is shown that the transmission coefficient is near zero at a frequency of 9.32 GHz. Owing to the use of the resonant reflector instead of a cut-off drift tube, the drift pipe diameter is increased to 1.05 times the microwave wavelength, and the space-charge-limited current could be enhanced significantly, as shown in Fig. 3. In the figure, the horizontal coordinate γ is the relativistic factor.

The resonant characteristic of the input cavity is related to the amplitude of the electric field and the matching between cavity and input waveguide, and it is an important parameter to evaluate the performance of the input cavity. The resonant characteristic of the input cavity is shown in Fig. 4, and it is clear that the input cavity has an excellent resonant characteristic at a frequency of 9.36 GHz with the Q-factor of 37 (as shown in Fig. 5). This Q-factor is close to that in conventional RKAs.

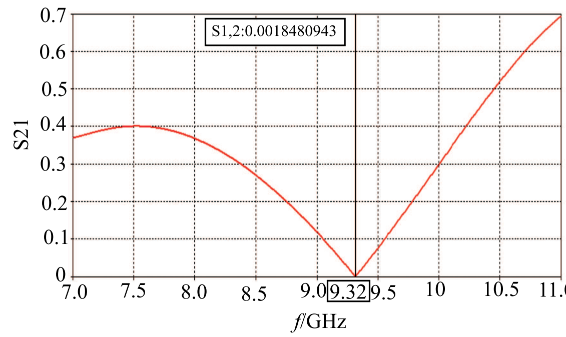


Fig. 2. (color online) S21 curve of the resonant reflector.

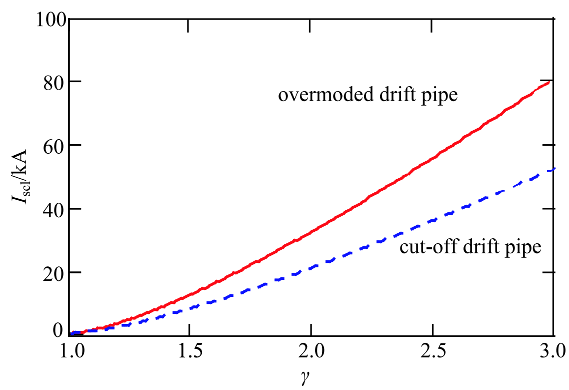


Fig. 3. (color online) Space-charge limited current for the conventional input cavity and overmoded input cavity.

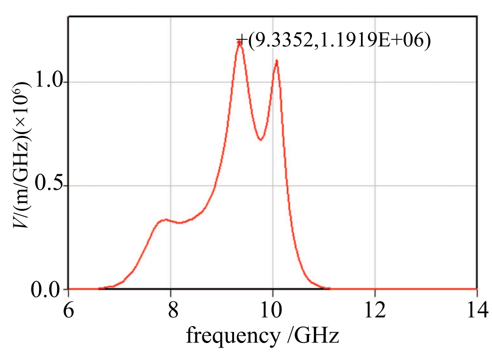


Fig. 4. (color online) Resonant characteristic of the overmoded input cavity.

Figure 6 shows the RF power injected into the input cavity without electron beam. It is shown that the resonant reflector plays a key role in confining the input RF power in the input cavity since the leakage power is only about 120 W with input power of 90 kW.

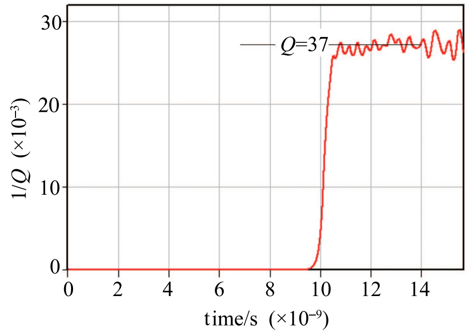


Fig. 5. (color online) $1/Q$ curve of the overmoded input cavity.

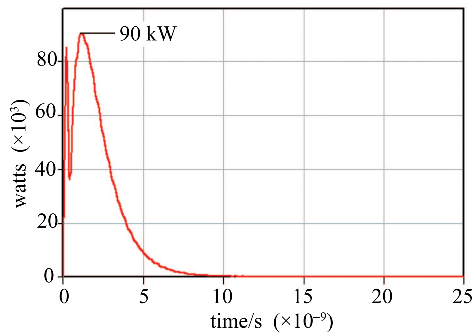


Fig. 6. (color online) RF power injected into the input cavity without electron beam.

The electric field distribution along the beam path in Fig. 7 also proves that the injected power is confined well inside the input cavity as the field amplitude is almost zero outside the cavity gap. Moreover, the field distribution, which is related to the coupling coefficient of the cavity, could be improved by optimizing the distance between the two reflectors. From the field distribution, the coupling coefficient can be calculated. In the structure, the coupling coefficient is about 0.6, which is comparable with the conventional single gap input cavity used in klystrons.

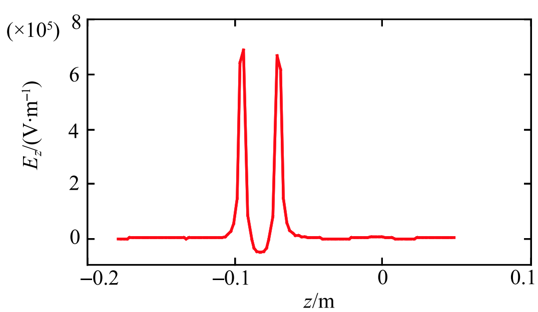


Fig. 7. (color online) Electric field distribution along the beam path.

3 PIC Simulation and cold-test

To evaluate the performance of the overmoded input cavity, the PIC simulation code CHIPIC, which has been developed by the University of Electronic Science and Technology of China [9], was used to investigate the beam-wave interaction process. In the simulation, 3D Cartesian coordinates were used and the mesh size was 1 mm in three dimensions. Benefitting from the multi-gap input structure, the overmoded input cavity has higher characteristic impedance while the Q-factor and coupling coefficient are comparable with the conventional cavity, so the modulating capability of the overmoded input cavity is better than the conventional single gap cavity. With a beam voltage of 600 kV and current of 7 kA, an input power of 90 kW is sufficient to modulate the beam with a maximum fundamental current of 210 A at a distance 12 cm downstream from the input cavity. The corresponding modulation depth is about 3%. The fundamental harmonic current distribution is shown in Fig. 8.

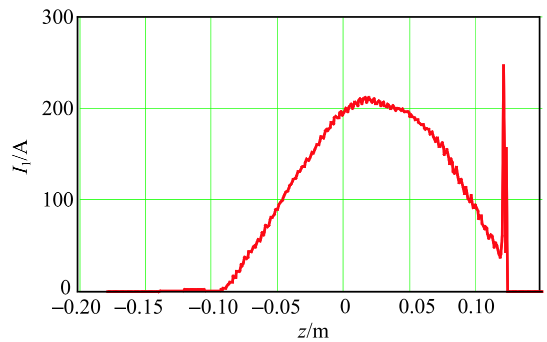


Fig. 8. (color online) The fundamental harmonic current distribution modulated by input cavity.

In order to validate the physical design of the overmoded input cavity and promote its application in the overmoded amplifier and phase-locked oscillator, a cold test of the input cavity was carried out. Figure 9 is the simulation model of the input cavity for the cold test. In the cold test, the RF signal is injected into the cavity through the rectangular waveguide. By measuring the RF signal coupled to an electric probe located on one side of the input cavity, we can obtain the transmission and reflection coefficients of the cavity, as shown in Fig. 10. The test results fit well with the simulation results in the relevant frequency ranges.

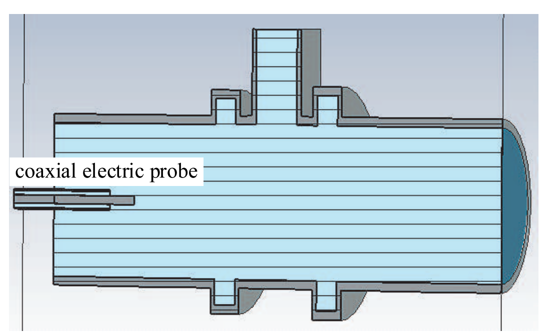
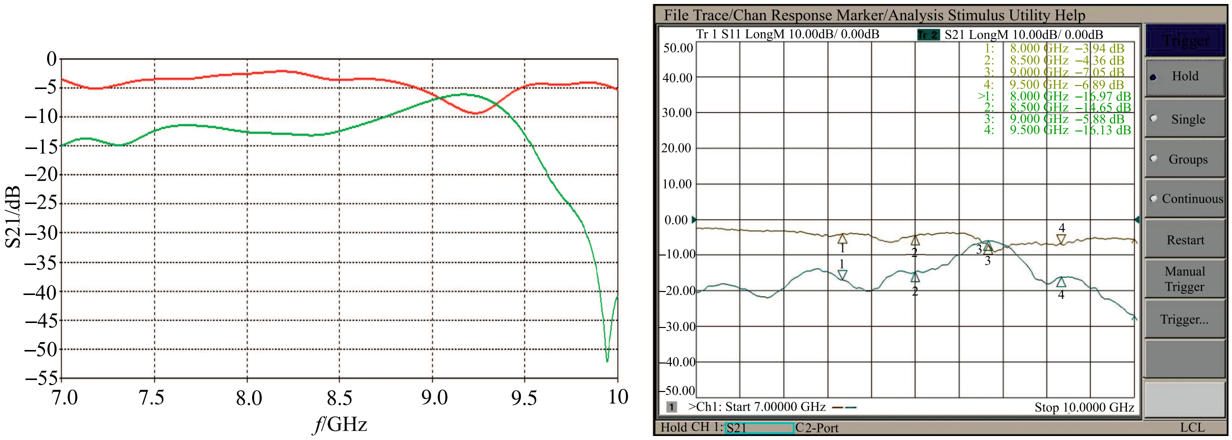


Fig. 9. (color online) Simulation model of the overmoded input cavity for cold test.



(a) simulqtion (b) cold-test

Fig. 10. (color online) S11 and S21 curves of the overmoded input cavity.

4 Conclusions

In conclusion, an X-band overmoded input cavity has been proposed and studied in this paper. Owing to the use of a resonant reflector instead of a cut-off drift tube, the power capacity and the space-charge-limited current could be enhanced significantly. Moreover, the modulating capability of the overmoded input cavity is better than the conventional single gap cavity. An input power of 90 kW is sufficient to modulate the beam with a modulation depth of 3%. The overmoded input cavity could be used to produce initial modulated electron beams for an overmoded RKA and phase-locked RBWO, and has potential applications in high frequency amplifiers and phase-locked oscillators.

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