Characteristics of Electric Field Distribution in a G-band Overmoded Extended Interaction Oscillator

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Abstract: *One kind of G-band extended interaction oscillator (EIO) with rectangle cavity model which works on 220 GHz is simulated with CST Eigenmode Solver [1]. The influences of the structural parameters of the cavity on the electric field characteristics, including the gap length and the extension length of the coupling cavity, were simulated and analyzed. In addition, the field distribution, coupling impedance and beam-loaded conductance of the EIO are derived.*

Keywords: Extended interaction oscillator; Millimeter wave; Vacuum electron; Klystrons.

Introduction

The oscillator is a kind of vacuum electron device with high power and high efficiency. Extended interaction oscillator (EIO), based on an extended interaction structure, can achieve high power and high gain in the millimeter and sub-millimeter wavelength range [2-3]. The ladder-interaction structure is composed of several coupling gaps that strongly couple to each other by slots on the walls between the adjoining gaps. The enlarged inner surface area of the multi-gap coupled cavity chain can improve the power capacity. Standing-wave modes, including π mode and 2π mode, are usually selected as the operating modes for the high beam-wave interaction efficiency. Because the manufacturing process and cathodes limitations, for improving the operating frequency, the π mode and high-order mode can be selected as the operating modes.

In this paper, we have analyzed field characteristics of an overmoded G-band EIO preliminarily. Working in high-order resonant mode, the cavity size and the cross-section area of the drift head can be increased, thus increasing the area of the electron beam and the cathode, reducing the load on the cathode, increasing the conductivity of the electron gun, reducing the working voltage of the tube and increasing the power capacity. Moreover, the resonant system working in the overmoded structure will thus obtain large cavity volume, which reduces the machining difficulty of the actual high frequency band and improves the power output. Therefore, it becomes a very important task that studying the field distribution characteristics of the high frequency overmode structure.

Model description

The sectional view of the EIO circuit is shown in *Figure 1*, which shows the discrete structure of the G-band EIO. The EIO has seven interaction gaps, two coupling cavities and a cylindrical electron beam tunnel through the gaps. The length of the whole circuit is less than 3mm, and the initial parameters are shown in Table I. The main parameters that strongly affect the EIO's performance are the geometrical dimensions of the coupling gaps and cavity.

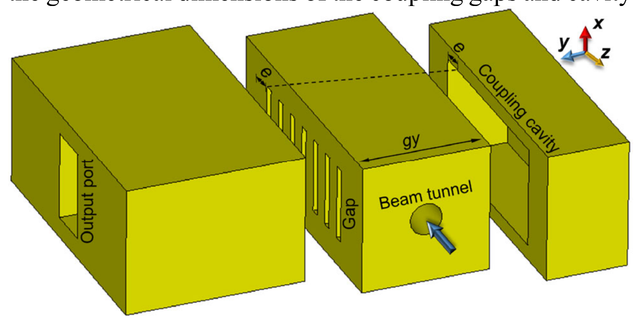

Figure 1. Three-dimensional sketch of the EIO.

Table 1. Dimensions of the EIO

Symbol	Description	Value (mm)
Rc	Beam radius	0.2
gy	Gap height	1.58
gx	Gap width	0.92
p	Period length	0.35
cx	Cavity width	1.23
cy	Cavity height	0.76

Study of field characteristics

In this section, we studied the influence of the circuit parameters on the strength and flatness of the electric field. The distribution and intensity of the electric field in the input and output cavity of the extended interaction devices have a significant impact on the loss behavior and working characteristics of the device, this due to its unique state of beam wave interaction form. Under the strong electric field, the output electric field energy produced by the coupling of the output waveguide and the cavity is easier to extract. *Figure 2* shows that when the interaction gap height *gy* is extended, the electric field strength will be weakened under the same electric field energy storage and electric field distribution. When the *gy* is extended from 1.38mm of the gy_1 to 1.58mm of the gy_3, as shown in *Figure 2*, the peak value of the electric field intensity scale will gradually decrease from 2.61e10 V/m to 2.23e10 V/m. This will reduce the working electric field strength without changing the energy storage of the cavity, thus reducing the wall current loss [4].

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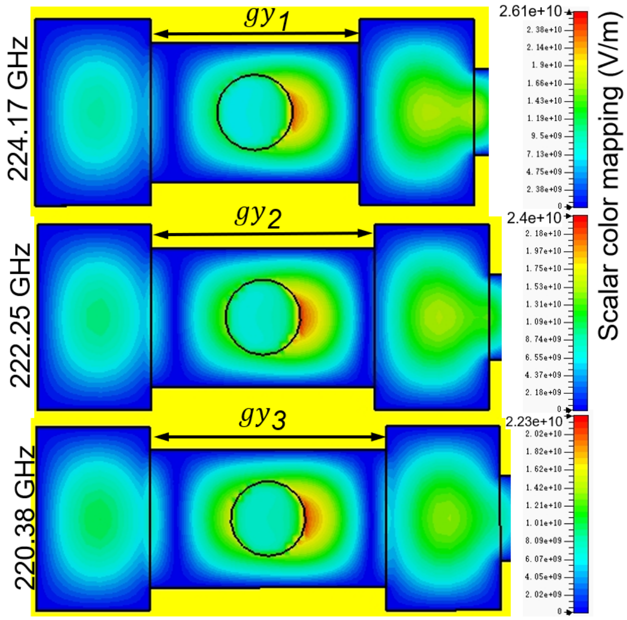

Figure 2. The changes of cavity electronic features versus the gap height *gy*.

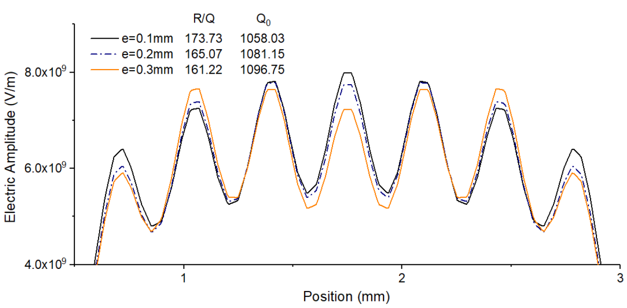

Figure 3. The electric field distribution in the electron beam center line versus the different circuit structure parameters

The distribution of electric field intensity in the center line of electron beam channel is shown in the *Figure 3*. As the *e* gradually increases, the coupling impedance *R/Q* and quality factor Q_0 will show a downward trend and an upward trend, respectively. The distribution of the electric field tends to gradually converge to both sides. Therefore, the influence of the electric field distribution on the circuit characteristics has to be considered, and a trade-off between the best output position and the circuit coupling ability needs to be made.

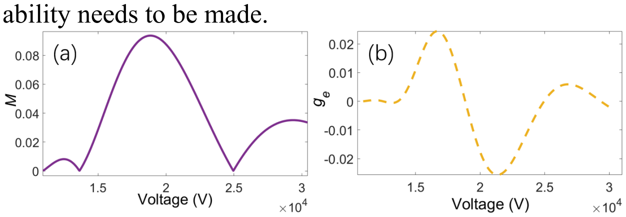

Figure 4. The normalized beam-loaded conductance g_e and coupling coefficient *M* versus operation voltage

Figure 4 shows the g_e of the 2π mode which are calculated as the beam voltage varies from 11 to 30 kV. Below the synchronous voltage, the longitudinal velocity of the beam is slower than the forward wave phase velocity in the circuit. Under the circumstances, power is transferred from the circuit to the beam, and the g_e is keeping positive. When the beam voltage is greater than the synchronous voltage, the g_e is negative we need. The g_e and the *M* can be obtained by (1) and (2):

$$M(\beta_e) = \int_{-\infty}^{+\infty} E(z)\exp(-j\beta z)dz \Big/ \int_{-\infty}^{+\infty}|E(z)|dz \tag{1}$$

$$G_e = \frac{G_0\beta_e}{4}\left[M^2(\beta_e+\beta_q)-M^2(\beta_e-\beta_q) \big/ 2\beta_q\right] \tag{2}$$

Where the G_0 stands for the DC beam conductance, I_0/V_0. $\beta_e=\omega/v_e$ and $\beta_q=\omega_q/v_e$ are the propagation constants of the DC beam and reduced plasma respectively.

Conclusions

In this paper, the field distribution characteristics of an over-mode EIO structure are analyzed. Although the *R/Q* of the third-order mode is lower than that of the fundamental mode, due to its large power capacity, the available energy storage in the cavity will increase. The effects of several structural parameters on the cavity field distribution, field strength, and circuit characteristic parameters are revealed in the simulation. As a result, we have obtained a standing wave field with relatively low ohm loss, which can provide a potential solution for the high ohm loss of the extended interaction devices in the high frequency region up to THz band.

Acknowledgements

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References

1. CST-Computer Simulation Technology. [Online]. Available:https://www.cst.com/Products/CSTPS..
2. Roitman, A., D. Berry, and B. Steer. "State-of-the-art W-band extended interaction klystron for the CloudSat program." IEEE Trans Electron Devices 52.5(2005):895-898. DOI: 10.1109/ted.2005.845799
3. Y. Yin, W. He, L. Zhang, H. Yin, C. W. Robertson, and A. W. Cross. “Simulation and Experiments of a W-band Extended Interaction Oscillator based on a pseudospark-sourced electron beam.” IEEE Trans. Electron Devices, vol. 63, no. 1, pp. 512-516, Jan. 2016, DOI: 10.1109/TED.2015.2502950.
4. L. Bi, L. Meng, Y. Yin, C. Xu, S. Zhu, R. Peng, F. Zeng, Z. Chang, B. Wang, H. Li, P. Zhang. "Power enhancement for millimeter-wave extended interaction radiation sources by using the TM31-mode scheme." Phys. Plasmas, vol. 26, no. 6, Jun. 2019, DOI: 10.1063/1.5086148