Study of Terahertz Extended Interaction Oscillator

Kaichun Zhang, Zhenhua Wu, Shenggang Liu
THz Research Center, University of Electronics Science and Technology of China,
Chengdu 610054, China

***Abstract*—A terahertz extended interaction oscillator (EIO) operating at 0.225*THz* is studied in this paper. A rectangular reentrant coupled-cavity is proposed as the slow-wave structure (SWS) of the EIO. Due to the complexity of the structure, the equivalent circuit method (ECM) is adopted to calculate the dispersion relation of the cavity mode. Circuit parameters of the cavity and the coupling slot are studied in detail and a feasible calculation method is proposed in this paper. Meanwhile, the theoretical study is compared with the simulation study by a t simulation software CST and particle in cell (PIC) code. By comparison, the theoretical result agrees well with the simulation result for a certain dimension of the period 0.3*mm*, gap length 0.1*mm*, cavity height 1.6*mm* and width 0.76*mm*. By PIC code, a 14-gap EIO is simulated, the operation mode is close to the point where $\beta L = 2\pi$ with the beam voltage 13*kV* and current 105*mA*. The simulation results show that the generating frequency is 0.225*THz* and the output peak power is 44*W*.**

I. Introduction And Background

The extended interaction oscillator (EIO) and extended interaction klystron (EIK), based on the extended interaction structure, are often the choice for high power operation [1-3] to be used in space communications and modern radar applications. The EIO is an O-type device and is available at much higher frequencies up to 280 *GHz*.

As the operating frequencies increase, circuit structure and fabrication techniques have to be changed to meet the needs for smaller circuits. Due to the complication of Hughes structure for the general EIO, it is difficult to develop higher frequency in Terahertz regime. In this paper, a rectangular reentrant coupled-cavity is proposed as the SWS of EIO, as shown in Fig.1, whose adjoining coupled slot of the cavity is staggered. The structure can be fabricated from a single copper block with fine machining technique such as LIGA fabricating methods [4].

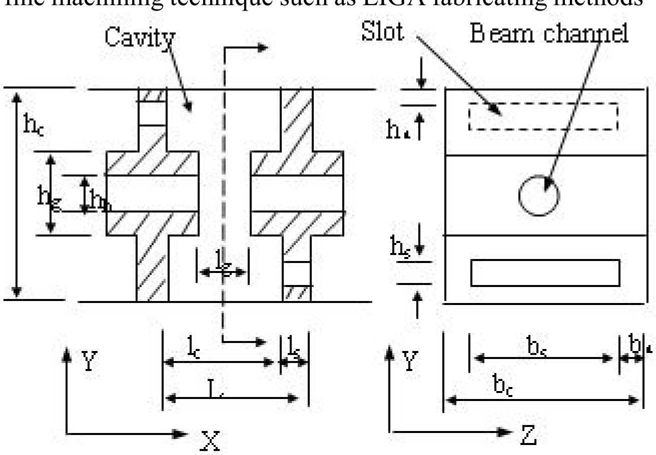

Fig. 1 Schematic diagram of a period of the EIO SMS

Due to the complexity of the structure, the equivalent circuit method (ECM) is adopted to calculate the dispersion relation of the cavity mode. The cold characteristic of the cylindrical coupled-cavity [5-6] was calculated by the ECM. However the ECM for the rectangular reentrant coupled-cavity has ever not been studied. In this paper we show how the parameters of the equivalent circuit can be calculated from the dimensions of the slow-wave structure. Comparisons between calculation and simulation by the CST software and PIC code show that the method can give useful accuracy.

II. ECM for the SWS

By equivalent circuit method of Coupled-cavity chain the dispersion relation is expressed as [7]

$$\cos\phi = 1 - \frac{2}{Kk_c}\left(1 - \frac{\omega^2}{\omega_c^2}\right)\left(1 + k_c - \frac{\omega^2}{\omega_c^2}\right) \qquad (1)$$

Where, $k_c = KL_s / L_c$, ω_c and ω_s are the angular frequency of the cavity and the slot, respectively. L_c and L_s are the inductance of the cavity and the slot, respectively. And the parameter K is the current passing the slot to the cavity.

To study the dispersion relation decides to accurately calculate these parameters.

The cavity of the SWS is composed of the ridged waveguide. The equivalent circuit parameters of the TE_{01} mode in the ridged waveguide are applied to those of the TM_{110} mode in the cavity. Thus, the circuit parameters of the cavity are expressed as

$$C_g = \frac{\varepsilon_0 b_c h_g}{l_g}\left[1 - \frac{h_h^2\left(l_c - l_p\right)}{l_c h_g^2}\right] \qquad (2)$$

$$C_d = \frac{\varepsilon}{\pi}\left[\frac{x^2+1}{x} ch^{-1}\left(\frac{1+x^2}{1-x^2} - 2\ln\frac{4x}{1-x^2}\right)\right] \qquad (3)$$

where, $x = h_g / h_c$.

$$L_1 = \frac{\mu_0\left(h_c - h_g\right)l_c}{2b_c} \qquad (4)$$

$$\omega_{c0} = \frac{1}{\sqrt{L_1\left(C_g + C_d\right)}} \qquad (5)$$

So the frequency of the TM_{110} mode in the cavity is

$$\omega_c = \sqrt{\omega_{c0}^2 + c^2 k_x^2}\ , \quad k_x = \pi / .b_c \qquad (6)$$

The Parameter of the slot are expressed as [5]

$$C_s = \varepsilon_0 b_s (l_s + h_s) / h_s \qquad (7)$$

978-1-4244-2120-6/08/$25.00 ©IEEE.

$$L_s = \frac{\mu_0 b_s h_s}{\pi^2 (l_s + h_s)} \tag{8}$$

$$\omega_s = \frac{1}{\sqrt{L_s C_s}} \tag{9}$$

And the Parameter K is

$$K = \frac{b_s h_s}{2\left[b_s h_s + h_s\left(h_c - 2h_\Delta - 2h_s\right)\right]} \tag{10}$$

III. RESULTS

Currently the specialized software, CST, is widely used to accurately simulate and compute the cold test characteristic. The eigenmode algorithm of CST can accurately simulate frequency-phase dispersion curves.

The CST simulation can be adopted to verify the calculating results by ECM. A structure of the EIO circuit is designed with the height of 1.6mm, the width of 0.76mm and the period of 0.3mm. The theoretical calculating result of the dispersion characteristic of phase shift per cavity of the cavity mode is compared with the simulation result by CST as shown in Fig.2. The trends of dispersion curve in the graphics are same as each other. Also the frequencies at the point where $\beta L = 2\pi$ are very close.

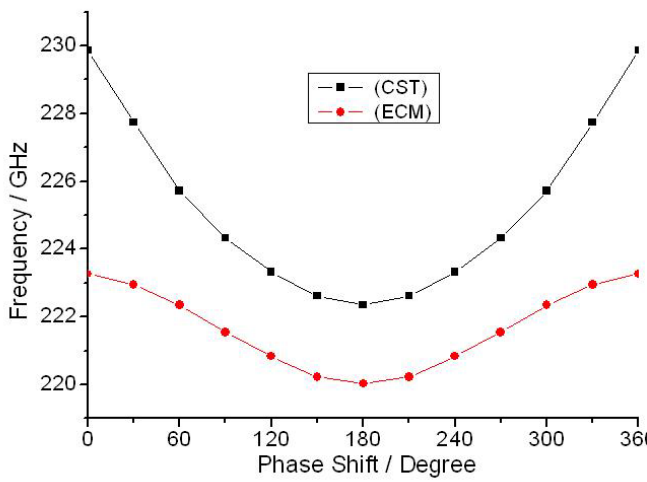

Fig.2 The dispersion curve of the SMS by CST and ECM

On the other hand, a specialized particle-in-cell (PIC) code in this paper is used to simulate the beam-wave interaction in the EIO. During the simulation, it is found that the output power is the largest and the starting time is the shortest when the gap number is 14 with a transverse output window at the last cavity. Thus the SWS of an EIO with a 14-gap is chosen to simulate the beam-wave interaction. The operation mode is close to the point where $\beta L = 2\pi$ with the beam voltage 13kV and current 105mA. The simulation results show that the generating frequency is 0.225THz and the output peak power is 44W as shown in Fig.3.

The generating frequency by PIC simulation also verifies the ECM suitable for the rectangular reentrant coupled-cavity SWS. At the point 2π, the frequencies are 0.223THz, 0.23THz and 0.225THz by ECM, CST simulation and PIC simulation, respectively.

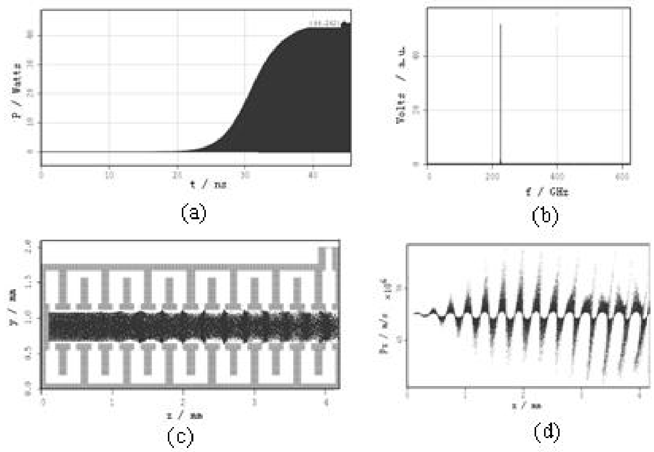

Fig.3 Simulation results of the EIO by PIC. (a), (b), (c) and (d) are the power, the generating frequency, the phase space and the bunching of the beam, respectively.

IV. CONCLUSION

A rectangular reentrant coupled-cavity is proposed as the slow-wave structure (SWS) of the EIO. The theoretical calculating result of the dispersion characteristic of the cavity mode for a certain dimension by ECM is compared with the simulation result by CST software and they are good agreement with each other. By PIC code, a 14-gap EIO is simulated. The generating frequency is 0.225THz with output peak power 44W at the point $\beta L = 2\pi$ with the beam voltage 13kV and current 105mA .

V. ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China （Grant No 10676110）and the National Basic Research Program of China （Grant No 2007CB310401）.

REFERENCES

[1] M. Chodorow, T. Wessel-Berg. “A high-efficiency klystron with distributed interaction”, IRE Trans. Electron Devices, Vol.8, pp44-55, 1961

[2] R. W. McMillan, C. W. Trussell J. C. Butterworth and et al, “An experimental 225 GHz pulsed coherent radar”, IEEE Trans. Microwave Theory. Tech. Vol.39, pp555-562, 1991

[3] K. C. Zhang, Z. H. Wu, S. G. Liu. “Study of a Rectangular Coupled Cavity Extended Interaction Oscillator in Sub-Terahertz Waves”, Chinese Physics. Vol.17(9), 2008 (Accepted)

[4] E. W. Becker, W. Ehrfeld, P. Hagmnn and et al. “Fabrication of microstructures with high aspect ratios and structural heights by synchrotron radiation lithography, galvanoformung, and plastic moulding (LIGA process)”, Microelectronic Engineering, Vo.l.4, pp35-43, 1986

[5] M. A. Allen, G. S. Kino. “On the Theory of Strongly Coupled Cavity Chains”. IRE Trans. Microwave Theory. Tech. Vol.8,pp362-372,1960

[6] R. G. Carter, S. K. Liu. “Method for calculating the properties of coupled-cavity slow-wave structures from their dimensions”. IEE proceedings, Vol.133, pp330-334,1986

[7] H. J. Curnow. “A General Equivalent Circuit for Coupled-cavity Structures”, IEEE Trans. Microwave Theory. Tech. Vol.13, pp671-676, 1965