# The Circuit Design and Particle-in-cell Simulation for a Ka-band Extended Interaction Klystron

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***Abstract*—An interaction circuit with a double-gap coupled cavity chain for a Ka-band extended interaction klystron (EIK) is designed in this abstract. By the 3D particle-in-cell (PIC) simulation, the output power of 1.26kW is achieved, and the efficiency and the gain reach 22.5% and 33.2dB under the beam voltage and beam current is 14kV and 0.4A, respectively.**

## I. INTRODUCTION

THE extended interaction klystron(EIK) is a hybrid of a coupled-cavity slow-wave structure and a klystron reentrant cavity. Compared to the conventional klystron, it can achieve higher power, broader bandwidth, and higher gain in the millimeter/sub-millimeter wave range, and has been widely used in airborne radars, radio astronomy, communications, and electronic countermeasures [1-3]. The EIK beam-wave interaction circuit is comprised of an input cavity, several intermediate cavities and an output cavity and each individual cavity is a shorted section of a multi-gap coupled cavity. The multi-gap coupled cavity has a higher interaction impedance R/Q than a conventional klystron cavity, resulting in higher output power as well as broader operating bandwidth. In addition, the drift distance between the adjacent cavities is a key factor to ensure sufficient beam bunching and maximize the RF beam current [4-5]. The optimum location of the output cavity is where the maximum RF current occurs. In this abstract, the design of the beam-wave interaction circuit and 3-D PIC simulation are presented.

## II. THE INTERACTION CIRCUIT

The extended interaction circuit discussed here is shown in Fig.1. It is composed of seven stagger-tuned reentrant resonant cavities, and these cavities are all double-gap coupled cavities except for the penultimate cavity which is a single-gap cavity to improve the efficiency.

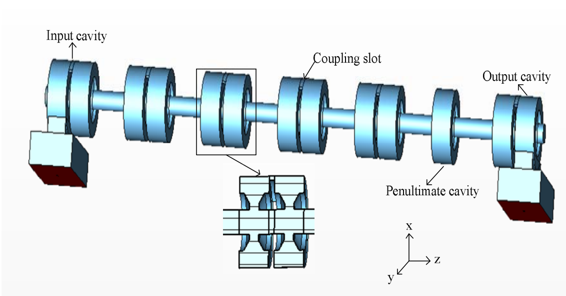



**Fig.1.**The model of the extended interaction circuit

The power is injected into and extracted from the standard WR28 waveguides (7.112mm×3.556 mm) attached to the cavities through the rectangular apertures. To ensure the effective beam-wave interaction, all the double-gap coupled cavities operate in 2π mode and the electric field distribution is shown in Fig.2. The distance between two gaps in the coupled cavity is designed to 2mm, corresponding to a transit angle of 2π for a 14kV beam.

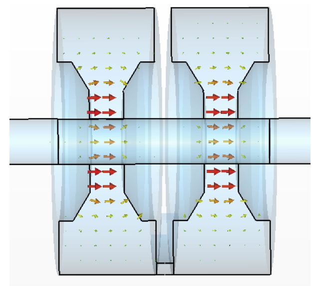
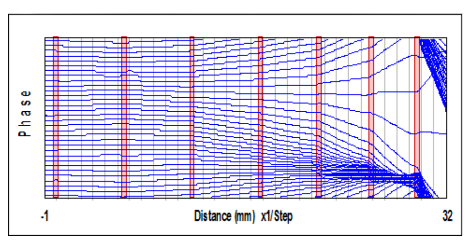
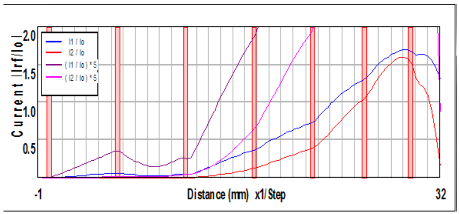


**Fig.2.**The electric field distribution of 2π mode

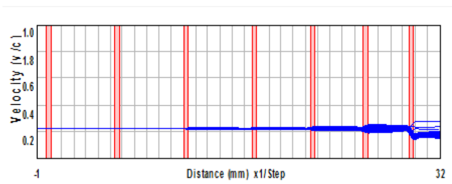
The cold circuit parameters, including the cavity resonant frequency f, the quality factor Q, the external quality factor $Q_e$, the cavity impedance R/Q, the coupling coefficient M and the cavity-to-cavity distance (the interval from the center of a coupled cavity to the center of the adjacent coupled cavity) are obtained by the 1D code AJDISK, in which the properties of the single-gap cavities are modified in an approximate way in order to account for the actual double-gap extended interaction [6]. Fig.3 shows the large signal beam-wave interaction results of AJDISK. In Fig.3 (a), the particles are modulated by each cavity, bunch gradually, and obviously bunch in the output cavity. In Fig.3 (b), the normalized current is small at the first three cavities because the bunching is not obvious. With the axial distance increases, the normalized current grows dramatically and the normalized fundamental current reaches about 1.6 in the output cavity. In Fig.3 (c), the axial velocity of the particles gradually becomes significant with the increase of the distance and most of the particles are decelerated in the output cavity and the energy is transferred to the microwave power.




(a) the phase of the particles along the axial direction




(b) the normalized beam current $I_{rf}/I_0$ along the axial direction




(c) the particle velocity along the axial direction

**Fig.3.**AJDISK output results

## III. THE 3-D PARTICLE-IN-CELL SIMULATION

By optimizing the cold cavity parameters with the AJDISK code, the stagger-tuned cavity frequencies are 34.86 GHz (the input cavity), 34.89 GHz, 35.06 GHz, 35.12 GHz, 35.14 GHz, 35.20 GHz (the penultimate cavity), and 35 GHz (the output cavity). The $Q_e$ of 350.58 and 262.67 are assigned to the input and the output cavities, respectively. To verify the cavity parameters, 3D PIC simulation was performed by CST code [7]. In the PIC simulation, the circuit was driven by a 14kV, 0.4A electron beam. To prevent the electron beam divergence due to the space-charge forces, the electron beam is guided by a uniform axial magnetic field of 2400gauss, the filling factor of the beam is 60%, and the radius of the drift tube is 0.6mm.

The PIC phase space monitors are set to observe the electron beam momentum distribution along the axial direction in different time. As can be seen from Fig.4, in the output cavity, most of the electron momentum is reduced and the effective energy modulation indicates the sufficient signal amplification.

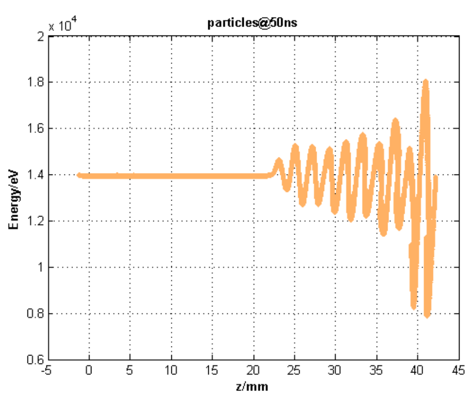



**Fig.4**.The electron beam momentum distribution along the axial direction

Fig.5 and Fig.6 show the amplification and the spectrum of the output signal. The EIK operation frequency is 35GHz and when the input power is 0.6W, the output power reaches about 1.26kW corresponding to a gain and an electronic efficiency of 33.2dB and 22.5%.

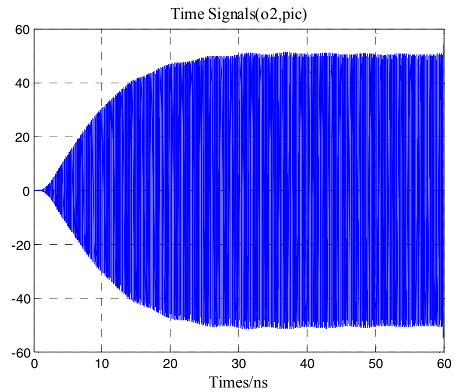



**Fig.5.**The signal of the output port

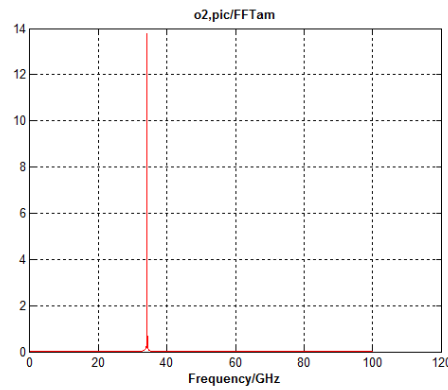



**Fig.6.**The spectrum of the output signal

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