MODELING OF A COMPLEX CAVITY RESONATOR BY THE NONFIXED FIELD THEORY FOR THE 0.4 THZ SECOND-HARMONIC FREQUENCY-TUNABLE GYROTRON

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I. INTRODUCTION

CONTINIOUS-WAVE (CW) gyrotrons operating at THz frequencies are widely used for various scientific applications such as spectroscopy, material science, and biomedical applications. Operation on higher-order cyclotron harmonics is effective to avoid using extremely high magnetic fields in THz-band gyrotrons. For second-harmonic (SH) gyrotrons, competition with fundamental-harmonic (FH) modes is most dangerous. Using complex-cavity resonators with mode conversion (CCMC resonators) may improve mode selectivity properties and, in particular, may prevent FH oscillation. In [1], we studied a CCMC resonator with $TE_{8,4}$-$TE_{8,5}$ coupled modes for the 0.4 THz SH gyrotron for spectroscopic applications. However, in the experimental test SH operation was hampered by TE_{52} FH oscillation with frequency about 0.2 THz. In this paper, in order to obtain SH oscillation, we continue to develop a CCMC resonator design with coupled $TE_{8,3}$-$TE_{8,5}$ modes [2,3].

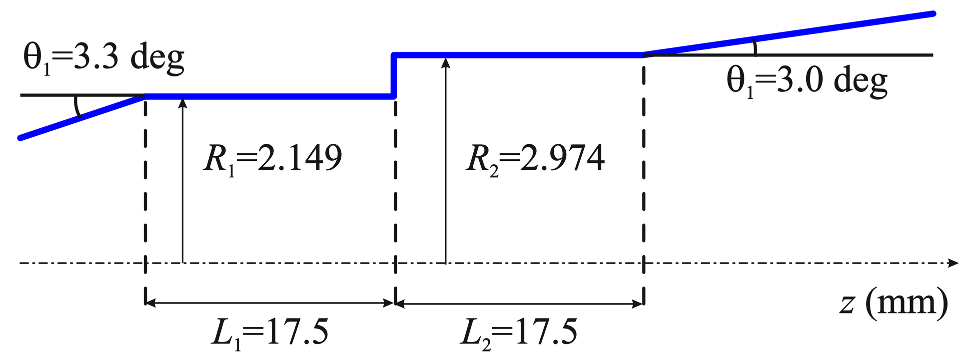

Fig. 1. Schematic drawing of the complex-cavity resonator. The dimensions are given in mm.

II. NUMERICAL SIMULATION

Schematic of the CCMC resonator is presented in **Fig. 1**. The cavity radii $R_{1,2}$ are adjusted to obtain resonant coupling of $TE_{8,3,q}$ modes of the first cavity with $TE_{8,5,q}$ modes of the second cavity. For frequency-tunable operation, we need to maintain effective conversion of not only fundamental (q=1) but also higher-order (q=2,3,…) axial modes. Thus, lengths of the two cavities $L_{1,2}$ should be chosen equal [1].

First, cold-cavity modes were simulated using COMSOL Multiphysics simulator [4]. Eigenfrequencies and Q-factors for different axial modes were calculated. Note that for each q, there exist two modes, namely in-phase and anti-phase [1].

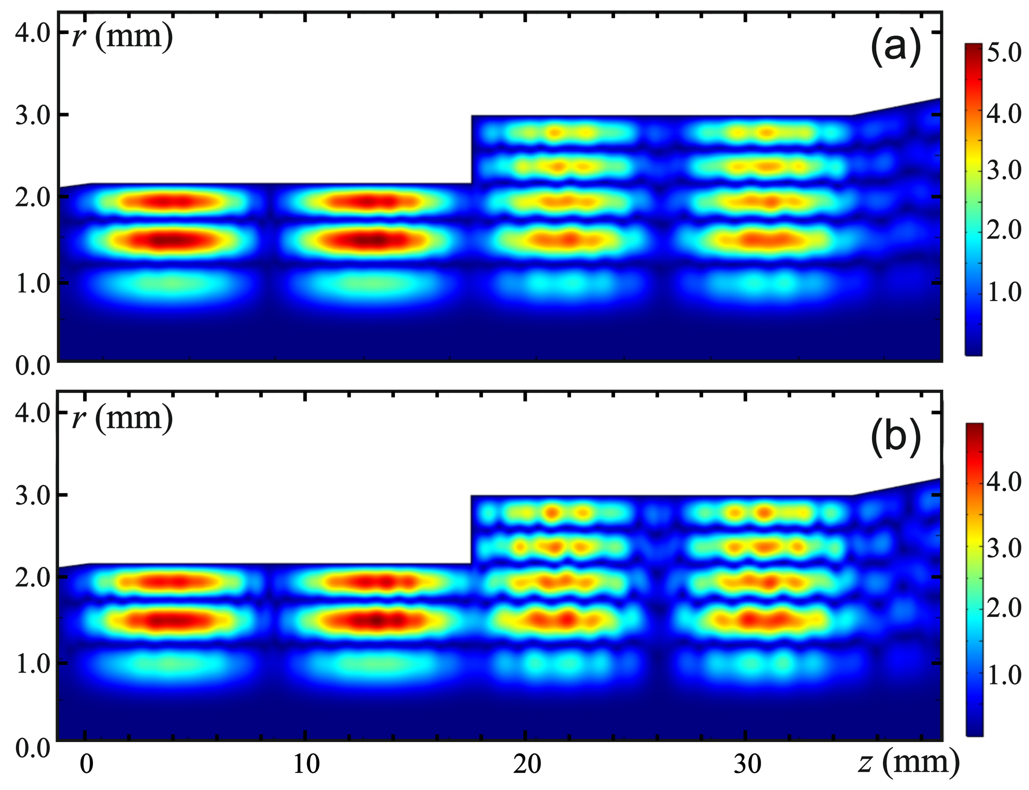

Fig. 2. Cold-cavity simulation. Patterns of the azimuthal electric field component for the anti-phase (a) and in-phase (b) $TE_{8,3,2}$-$TE_{8,5,2}$ modes.

Fig. 2 illustrates electric field patterns for the in-phase and anti-phase modes with q=2.

We develop the small-signal theory of a CCMC-resonator gyrotron with a self-consistent field profile.

We are taking into account a single transverse mode in each part of the cavity. Coupling coefficients between different axial modes are evaluated from the elements of scattering matrix on the transition between the two parts. To calculate the scattering matrix, we are using a 3-D finite-element solver.

In **Fig. 3**, RF field profiles of anti-phase and in-phase modes with different axial indexes in both sections of the cavity are presented.

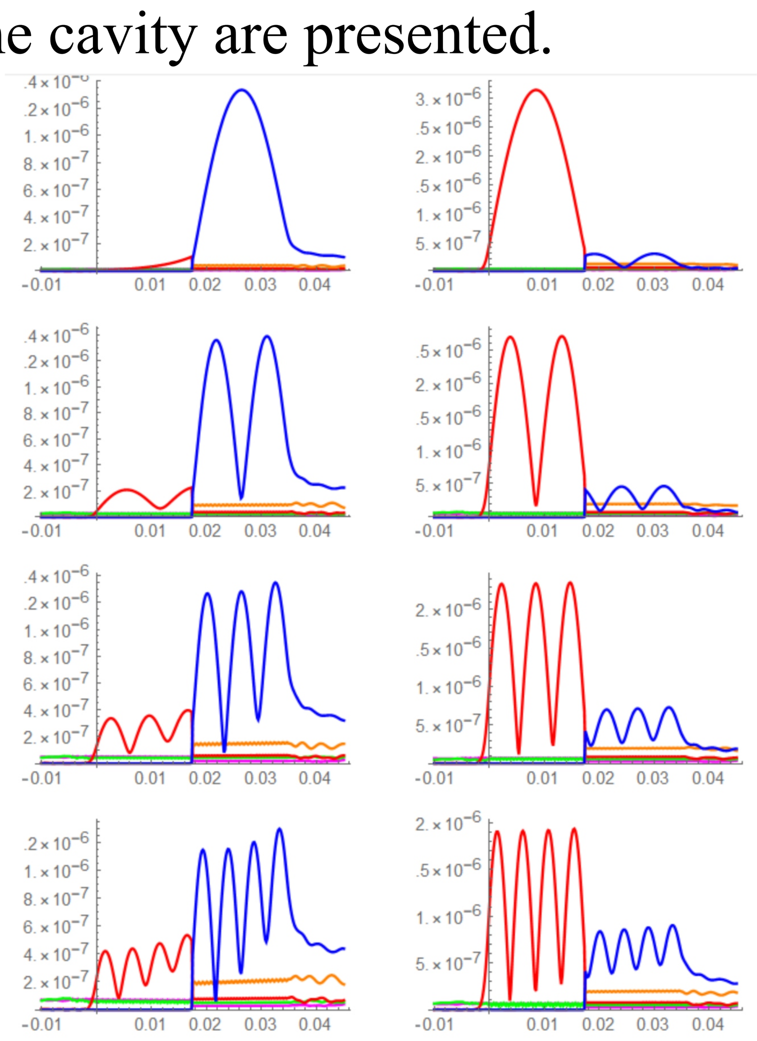

Fig. 3. Fields profiles of $TE_{8,3,q_1} - TE_{8,5,q_2}$ modes in complex-cavity; the in-phase modes (left column), antiphase modes (right column). Different $TE_{8,n}$ radial modes are shown by magenta ($n=1$), green (2), red (3), orange (4), and blue (5).

Fig. 3 shows cold-cavity field profiles for different axial modes calculated by COMSOL. For the fundamental modes, coupling between the fields in two parts of the cavity is very week, in fact, we observe separate oscillation in one of the parts.

However, for the higher-order axial modes the coupling increases.

COMSOL simulation is used to evaluate coupling coefficients between different radial modes required for simulation of beam-wave interaction.

Calculation of start-oscillation currents and oscillation frequencies for different axial modes shows that the theory with cold-cavity field profile fails to describe excitation of high-order axial modes (see **Fig. 4**). A possibility to achieve smooth frequency tunability in nearly 1.5 GHz frequency range is discussed.

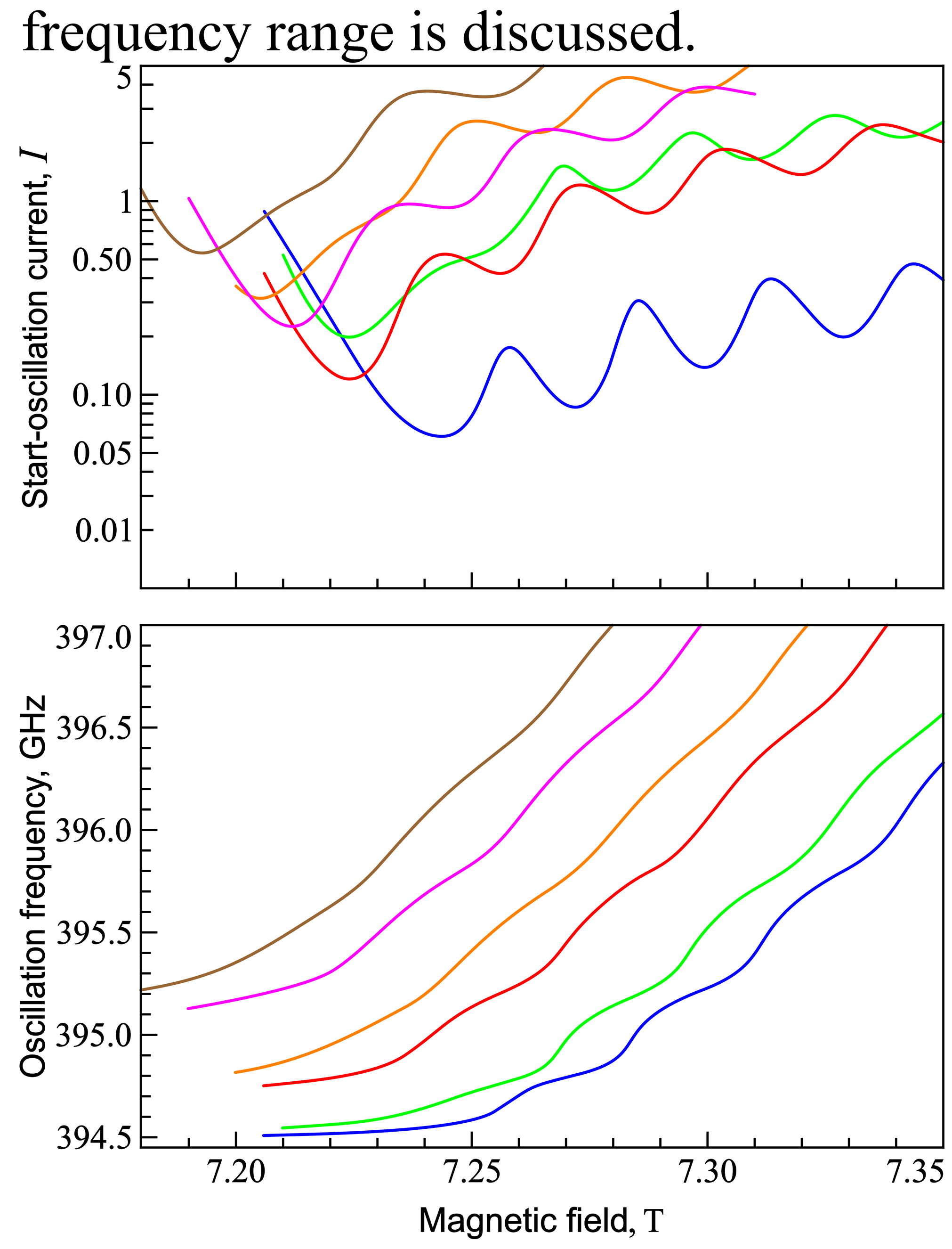

Fig. 4. Start-oscillation currents and start-oscillation frequencies versus magnetic field for complex-cavity with $R_1 = 2.150$ mm and $R_2 = 2.974$ mm.

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