RF Behavior of a 42/84 GHz, 0.5 MW, Dual Frequency Gyrotron

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Abstract— **In this paper, the RF behavior studies of a 500 kW 42/84 GHz dual frequency gyrotron is presented. The operating modes selected for 42/84 GHz dual regime operation are $TE_{6,3}$ and $TE_{15,4}$ respectively. The present study includes the mode competition, cold cavity design, single-mode and time dependent multi-mode self-consistent computations.**

I. INTRODUCTION

Typically gyrotrons are used for pre-ionization, electron cyclotron resonance heating, current drive and stabilization of plasma in thermonuclear fusion reactors. Successful experiments of gyrotrons have been done till sub-terahertz frequencies. Gyrotrons are also used for medical spectroscopy, mm-wave heating, deep space radars, and other ISM applications [1-3]. Step-tunable and multi-frequency gyrotrons offer a convenient solution for plasma heating and stabilization in magnetically confined plasma fusion reactors [4] without a major change in the system where high powers are required at several frequencies depending on the requirement. These gyrotrons are capable of delivering hundreds of kilowatts of long-pulse to continuous wave output powers. In this work, we have investigated the RF-behavioral aspects of a dual frequency regime gyrotron for its probable application in an experimental Tokamak in India.

This paper deals with feasibility analysis of dual frequency gyrotron operating at 42 and 84 GHz with two different transverse electric mode $TE_{6,3}$ and $TE_{15,4}$ respectively.

The design goals and parameters are given in Table 1.

Table 1. Design Goals

Frequency	42/84 GHz
Output power	≈ 0.5 MW, CW
Beam current (Ib)	≈ 15-20 A
Beam energy (Ub)	≈ 65-70 kV
Magnetic field at interaction	≈ 1.6-1.7 T / 3.2-3.3 T
Velocity ratio (α)	≈ 1.20-1.30
Total output efficiency	≈ 40 %
Estimated wall losses	≈ 2.0 kW/cm^2
Overall losses	< 8 %

II. DESIGN STUDIES AND RESULTS

Mode selection for multifrequency gyrotron plays a vital role in designing process. Modes should satisfy following conditions to be mode pair for dual regime operation [4]:

1. Caustic radius to cavity radius ratio should be same (m/χ_{mn}).
2. Cavity radius should be same.
3. Frequency should satisfy transparency condition of window.

After a careful study for the dual regime operation at 42/84 GHz, two modes, namely, $TE_{6,3}$ and $TE_{15,4}$ are chosen among various modes as shown in Table. 2 to carry out the RF-behavior studies.

Table 2. Mode Selection

F_0	m	p	R_0 (mm)	R_e (mm)	$m/\chi_{m,p}$
42	**6**	**3**	**17.357**	**7.293**	**0.398**
82.302	**15**	**4**	**17.357**	**9.270**	**0.501**
42	7	4	22.670	8.528	0.351
83.807	12	8	22.670	7.308	0.302
42	10	4	27.012	12.177	0.421
84.130	18	8	27.012	10.842	0.378

The modes selected should support the same magnetron injection gun, interaction structure and output system [5]. Mode competition is taken into account for selection of cavity geometry. As shown in Fig. 1 and 2, our chosen modes are well separated from their competing counterparts for a conventional cylindrical cavity resonator geometry ($L_1/L_2/L_3$ = 10/36/10 mm, $\theta_1/\theta_2/\theta_3 = 2.2^0/0^0/2.5^0$, R_{cav} = 17.357 mm).

Cavity midsection length is optimized such that it should have proper Diffractive Quality factor (Q_D) to support sufficient power transfer from electron beam for both the desired modes at respective frequencies.

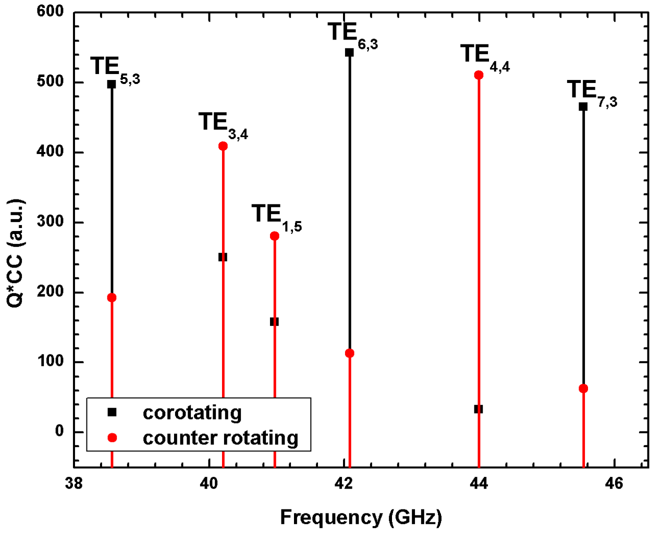

Fig. 1. Q times coupling coefficient as a function of frequency for Q_D=542.

By suitable considering this cavity geometry, single-mode and time dependent multimode simulations are carried out for cavity output power and efficiencies [6]. Single mode self-consistent calculation result is given in Table 3.

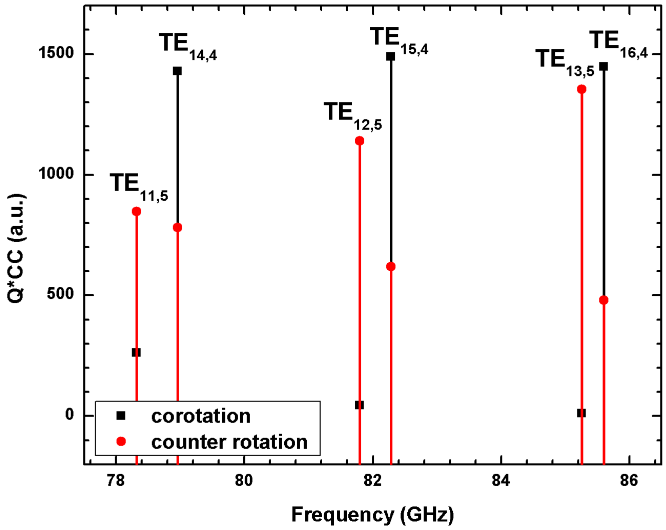

Fig. 2. Q times coupling coefficient as a function of frequency for Q_D=1488.

Table 3. Conventional Cavity Data and SELFC results

	42 GHz	82.305 GHz
$L_1/L_2/L_3$ (mm)	10/36/10	10/36/10
$\theta_1/\theta_2/\theta_3$	$2.2^0/0/2.5^0$	$2.2^0/0/2.5^0$
R_{cav} / R_b (mm)	17.357/7.293	17.357/9.270
Q_D	542	1488
U_b (kV)	68	65
I_b (A)	17	17
α	1.3	1.25
B_0 (T)	1.62	3.18
η (%)	43.52	46.65
P_{out} (kW)	504	521

Multimode time dependent simulation results are shown in Fig. 3 and 4 which shows considerable growth of desired modes with respect to competing mode for both frequency operation.

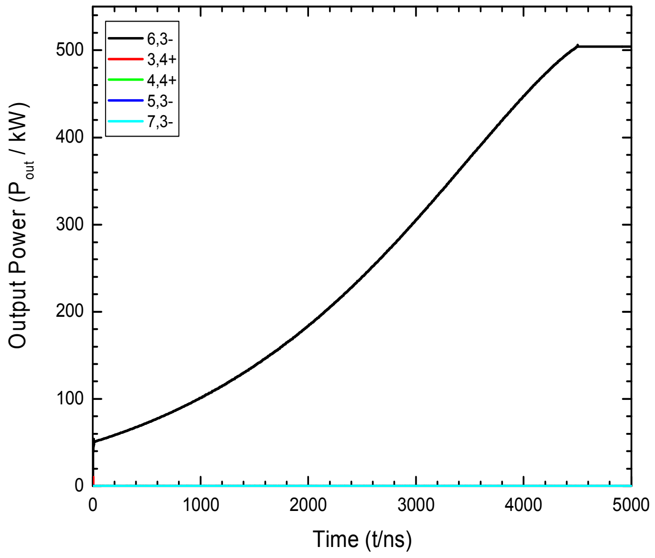

Fig. 3. SELFT [6] simulation results for the operation at 42 GHz, with $TE_{6,3}$ as operating mode considering the probable competing modes. Here, U_b = 68 kV, I_b=17 A, B(T) = 1.62 T and α = 1.3.

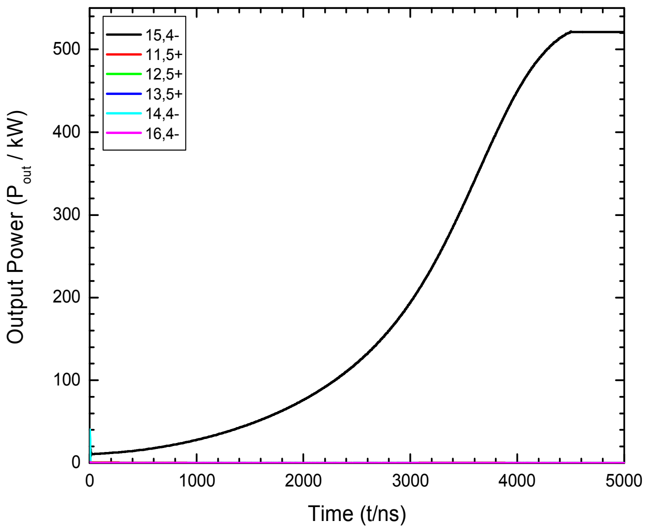

Fig. 4. SELFT [6] simulation results for the operation at 84 GHz, with $TE_{15,4}$ as operating mode considering the probable competing modes. Here, U_b = 65 kV, I_b=17 A, B(T) = 3.18 T and α = 1.25.

III. CONCLUSION

Initial studies on RF-behavior suggest that it is very much feasible to obtain an output power in excess of 0.5 MW with a dual frequency regime operation at 42/84 GHz. SELFC computations show that power/efficiency is 504 kW/43% and 521 kW/46% for 42 GHz and 84 GHz operation respectively. Further studies for the design of a suitable output system are in progress.

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