

INITIAL DESIGN STUDIES OF A > 200 kW, 30/60 GHz, DUAL-FREQUENCY GYROTRON

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Introduction

To address specific industrial-heating and plasma-diagnostic requirements in India, the feasibility of dual-frequency gyrotrons operating at 30 GHz and 60 GHz with output powers exceeding 200 kW is investigated. Both frequencies correspond to operation at the fundamental cyclotron harmonic ($s=1$). These requirements motivate the initial design studies reported in this work.

Motivation & Scope

- # A logical sequel of our earlier studies on medium power gyrotrons (both conventional) operating at 42 and 60 GHz.
- # The basic impetus and motivation to take up the studies on a dual-frequency gyrotron capable of delivering powers around 200-250 kW CW has been derived from their possible application in specific ISM applications.
- # Design goals and specifications for this dual-frequency gyrotron are shown in Table.
- # To perform basic experiments on such device with the existing set-up at MTRDC/ DRDO, Bangalore, India.
- # Further, the present power supply at MTRDC/DRDO, even if we assume we take it to its limitation, it will surely support testing under short pulse operation.

Design Goals & Parameters

Frequency	30/60	GHz
Output power	> 200 -250 kW	CW
Diffraction Q	≈ 500 -1500	
Beam current (I_b)	≈ 8 -12	A
Beam energy (U_b)	≈ 50 -65	keV
Magnetic field at interaction	≈ 1.00 -2.5	T
Velocity ratio (α)	≈ 1.30 -1.40	
Total output efficiency	≈ 40	%
Estimated wall losses	≈ 1.0 -2.0	kW/cm ²
Overall losses	< 10	%

Mode Selection

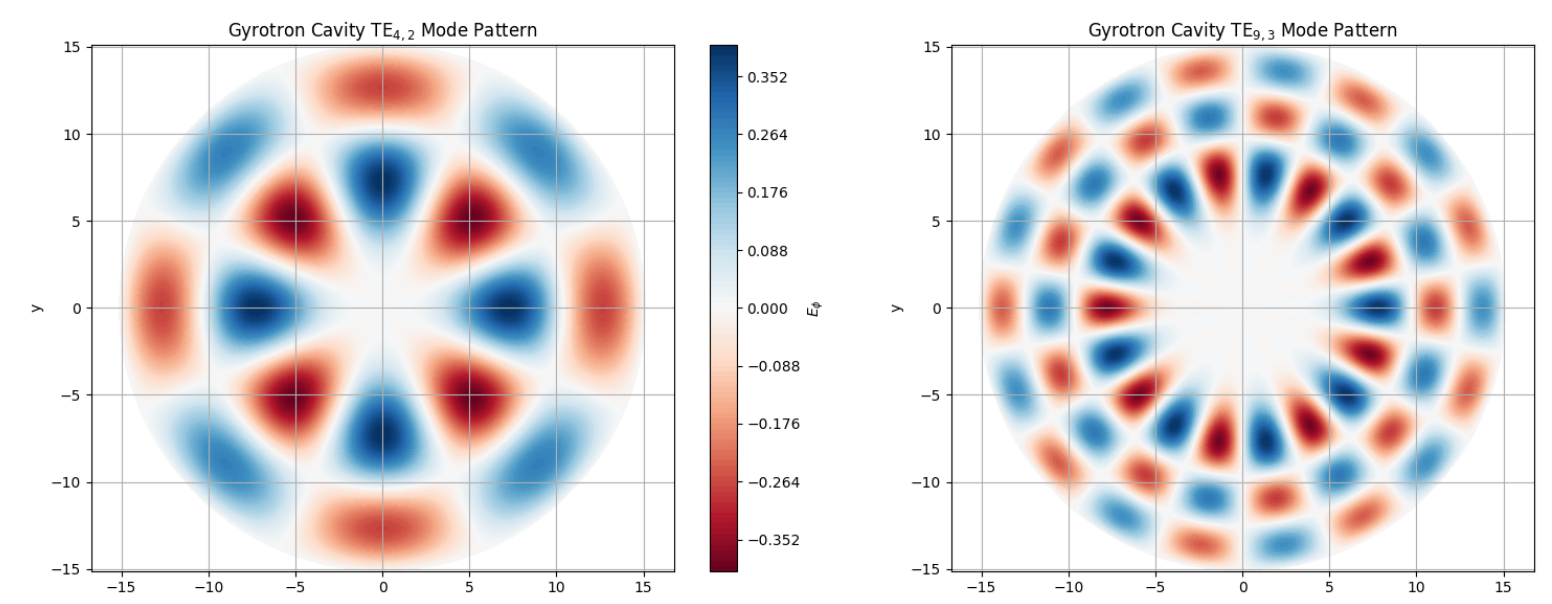
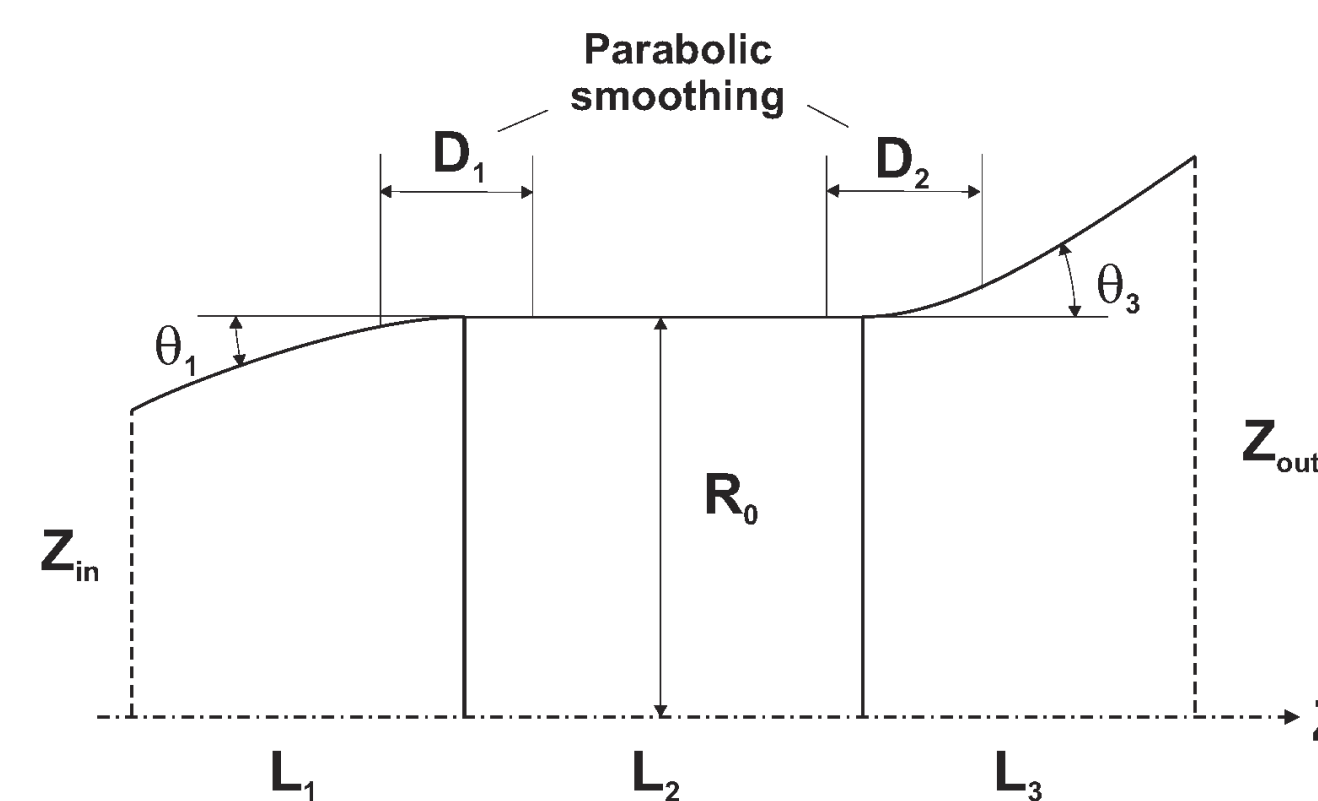
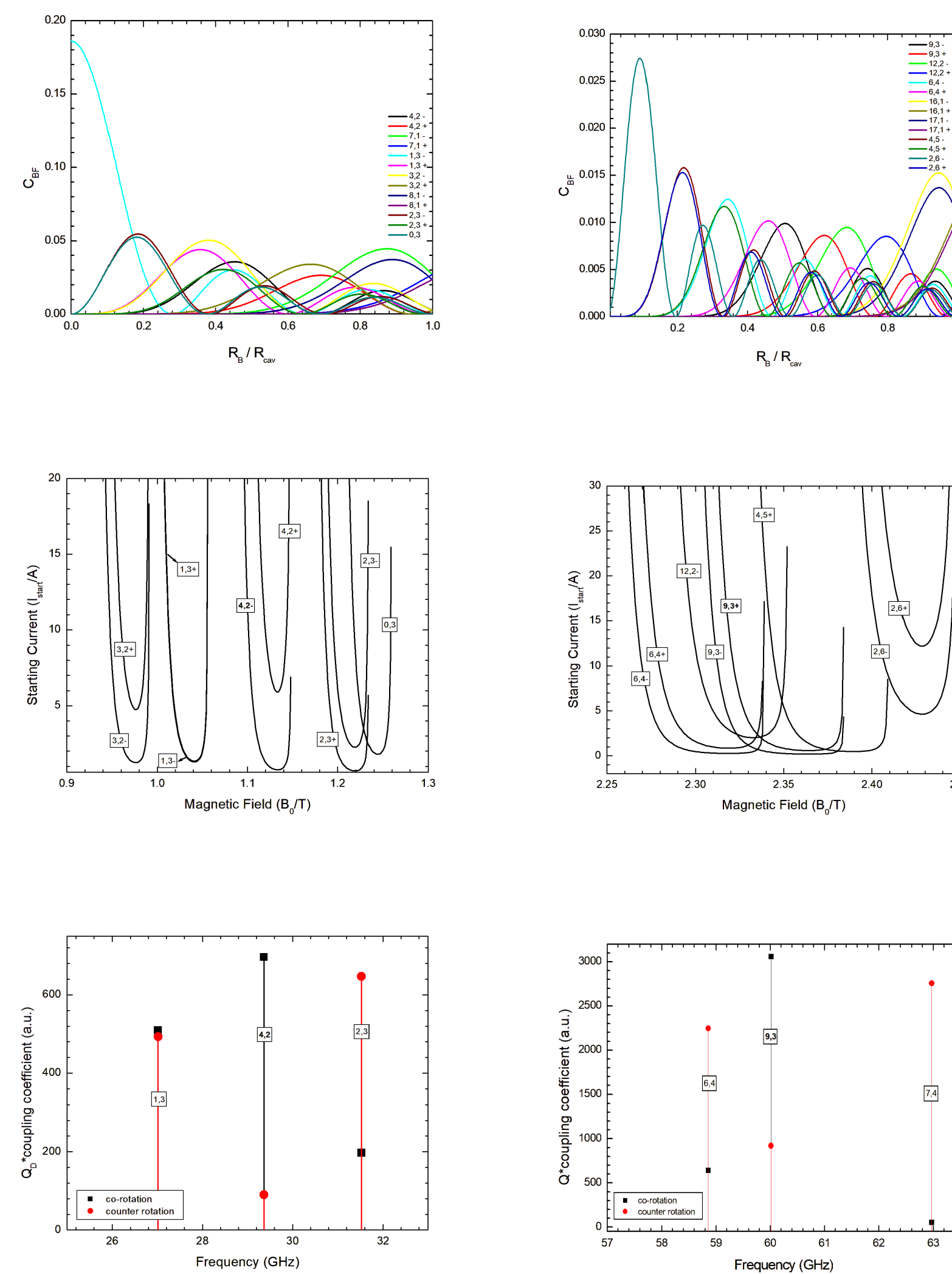
Mode selection criteria:

- Suitable mode pairs supporting the same cavity radius and caustic radius, while simultaneously satisfying the window transparency condition, are identified.
- Also, the modes selected should support the same magnetron injection gun, interaction cavity structure and output system.
- After a careful mode selection calculation for dual frequency operation at 30/60 GHz, two modes, TE_{4,2} mode at 30 GHz and TE_{9,3} mode at 60 GHz are chosen.

Mode pairs selected:

	m	p	$\chi_{m,p}$	R_0 (mm)	R_e (mm)	f (GHz) $\approx$	$m/\chi_{m,p}$ $= mc\beta$	$\Delta\varphi =$ $2\cos^{-1}(mc\beta)$	$m_2/2$ ($= \frac{360^\circ}{\Delta\varphi}$)
1.	4	2	9.282396	15.12	6.84	29.31	0.43	128.95	2.79
	9	3	19.004594	15.12	7.68	60.01	0.47	123.47	2.92
2.	5	2	10.519861	16.89	8.54	29.74	0.48	123.24	2.92
	8	4	21.229063	16.89	6.82	60.01	0.38	135.72	2.65
3.	6	2	11.734937	18.91	10.34	29.63	0.51	118.50	3.04
	10	4	23.760715	18.91	8.52	59.99	0.42	130.22	2.76

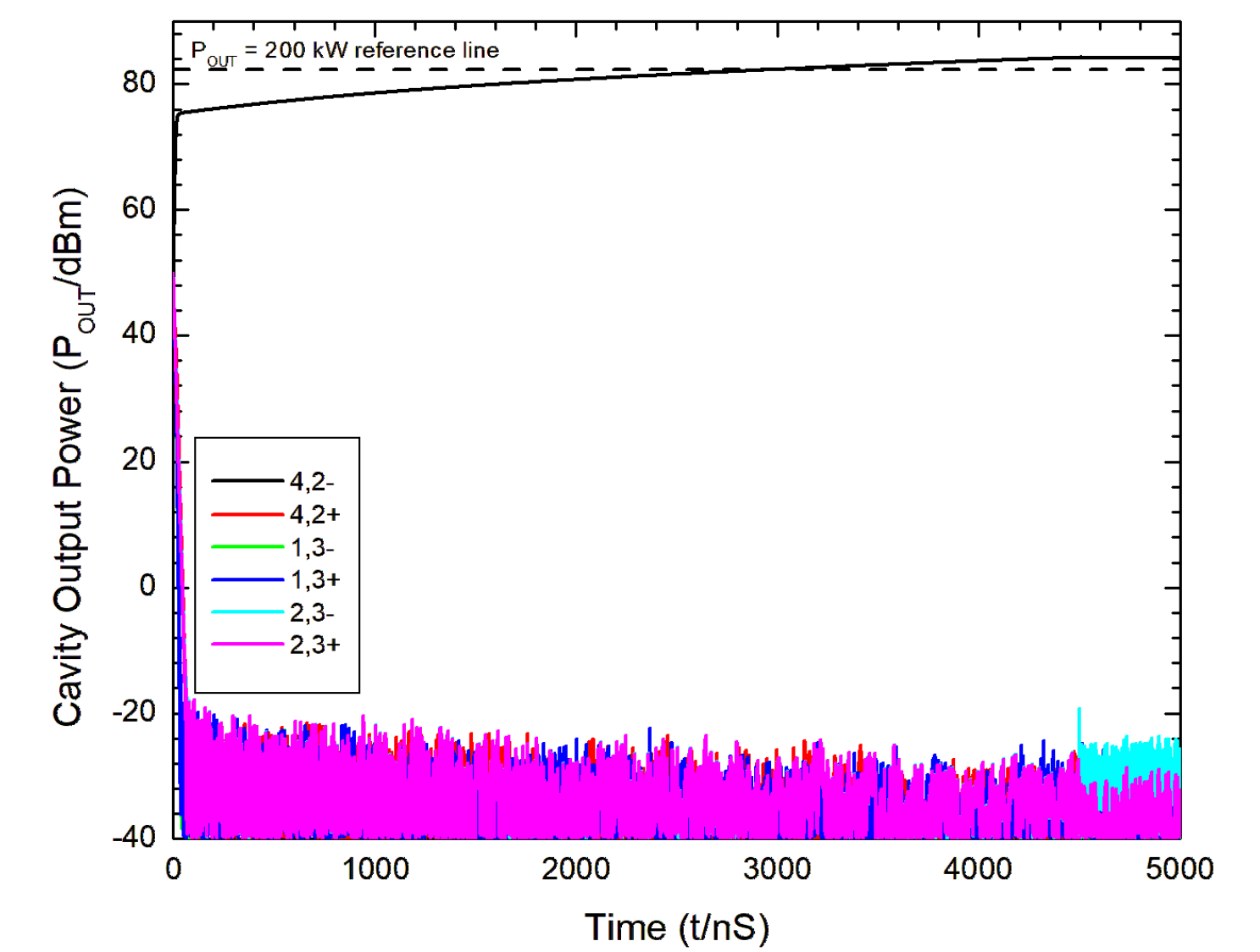
Results: C_{BF} , I_{start} & Operating Mode Patterns



Cavity Geometry & Single-mode Self-consistent Results

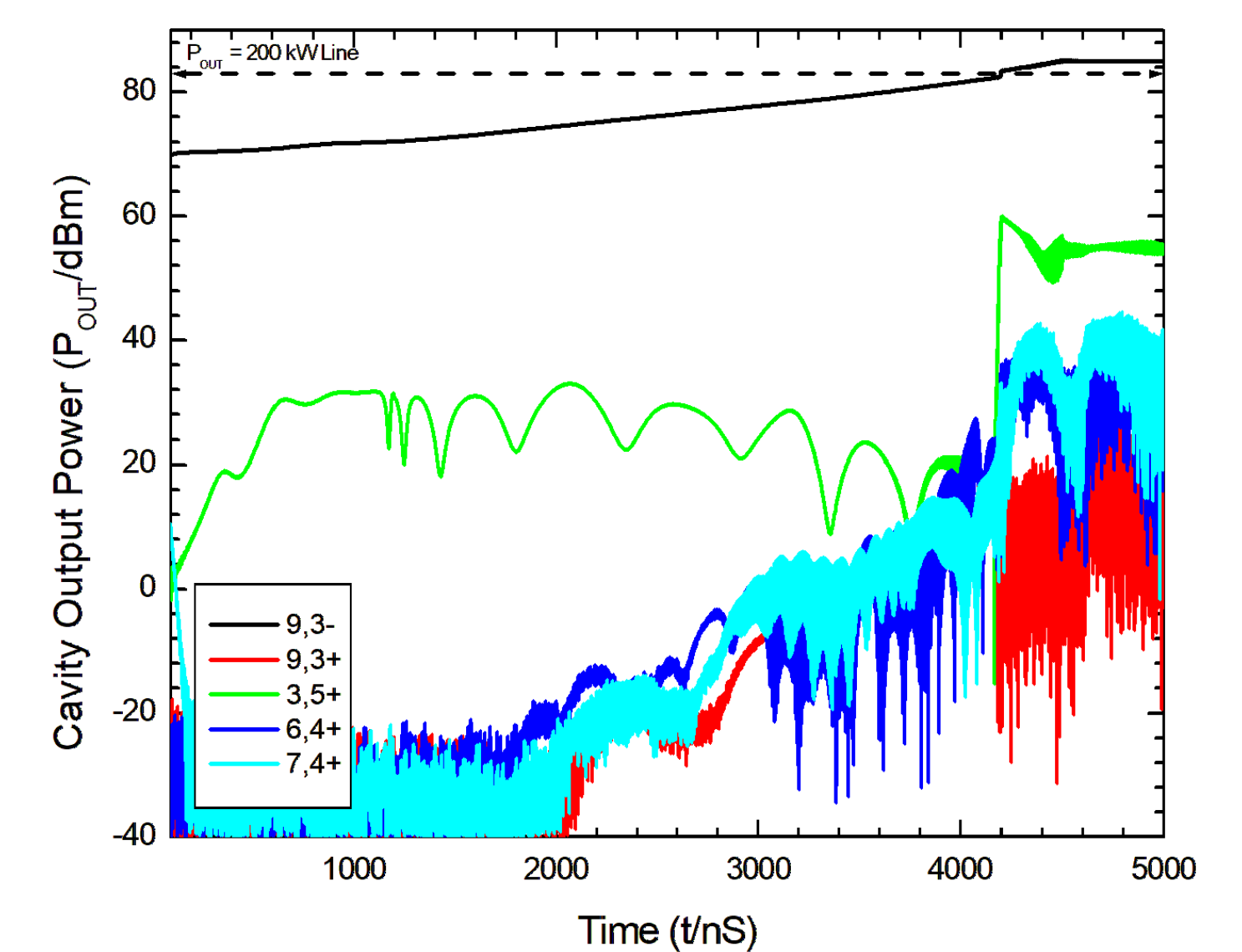
Operating Mode	TE _{4,2}	TE _{9,3}
$L_1/L_2/L_3$ (mm)	30/56/30	30/56/30
$\theta_1/\theta_2/\theta_3$ (°)	2.5/0/3.0	2.5/0/3.0
D_1/D_2 (mm)	10/10	10/10
R_{cav} (mm)	15.12	15.12
R_b (mm)	6.84	7.68
F (GHz)	29.366	60.017
Q_D	695	3051
U_b (kV)	58	72
I_b (A)	10	12
Beam pitch (α)	1.4	1.4
B(T)	1.108	2.325
η (%)	44.20	40.00
P_{out} (kW)	256	345
ρ_Ω (kW/cm ²)	0.17	0.83
I_L (A)	45.83	70.26
V_d (kV)	1.86	1.74
σ_{cav} (S/m)	2.35E+07	2.35E+07

Multi-mode time-dependent Simulations with TE_{4,2}



Here, $U_b = 45$ -82 kV, $I_b = 65$ A, B(T) = 5.55 T and α varies accordingly.

Multi-mode time-dependent Simulations with TE_{9,3} Mode



Here, $U_b = 45$ -82 kV, $I_b = 65$ A, B(T) = 5.57 T and α varies accordingly.

Conclusions

Key Findings

- The initial feasibility design studies indicate that such a dual-frequency fundamental harmonic operation is feasible for achieving output powers (200 kW) with electronic efficiency ≈ 40 % using the selected modes.
- Glidcop with conductivity $\sigma_{gc} = 2.35 \times 10^7$ S/m is used for calculations.
- All the computations are carried out with the latest version of Gyrotron Design Studio.

Outlook

- We are at present investigating the design of I/O modules for this dual-frequency gyrotron.
- Plans are there to investigate the cavity performance under hot conditions using a suitable multi-physics simulation code and further studies on the aspects of RF-Behaviour of the interaction structure are in progress at present!!

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