

DESIGN STUDIES OF TRIODE MIG AND OUTPUT WINDOW FOR A 30/60 GHz, DUAL-FREQUENCY GYROTRON

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Introduction

To address specific industrial-heating and plasma-diagnostic requirements in India, the design of dual-frequency gyrotron operating at 30 GHz and 60 GHz with output powers exceeding 200 kW is carried out. Both frequencies correspond to operation at the fundamental cyclotron harmonic ($s=1$). This work focuses on the design studies of a common electron gun, magnetic coil system, and RF window supporting the dual regime operation (30/60 GHz) of this proposed gyrotron.

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.
- # A common triode type magnetron injection gun along with the magnetic guidance system is designed for generating the required electron beam for 30/60 GHz operation.
- # The single disk RF window designs for proposed dual frequency gyrotron are carried out with silicon nitride and sapphire.

Design Goals & Parameters

Frequency	30/60	GHz
Output power	> 200-250 kW	CW
Beam current (I_b)	≈ 8 -12	A
Beam energy (U_b)	≈ 50 -70	keV
Magnetic field at interaction	≈ 1.00 -2.5	T
Velocity ratio (α)	≈ 1.30 -1.40	
Total output efficiency	≈ 40	%

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) $\approx$	$m/\chi_{m,p}$ $= mcmp$	$\Delta\varphi =$ $2\cos^{-1}(mcmp)$	$m_2/2$ ($= \frac{360^\circ}{\Delta\varphi}$)
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

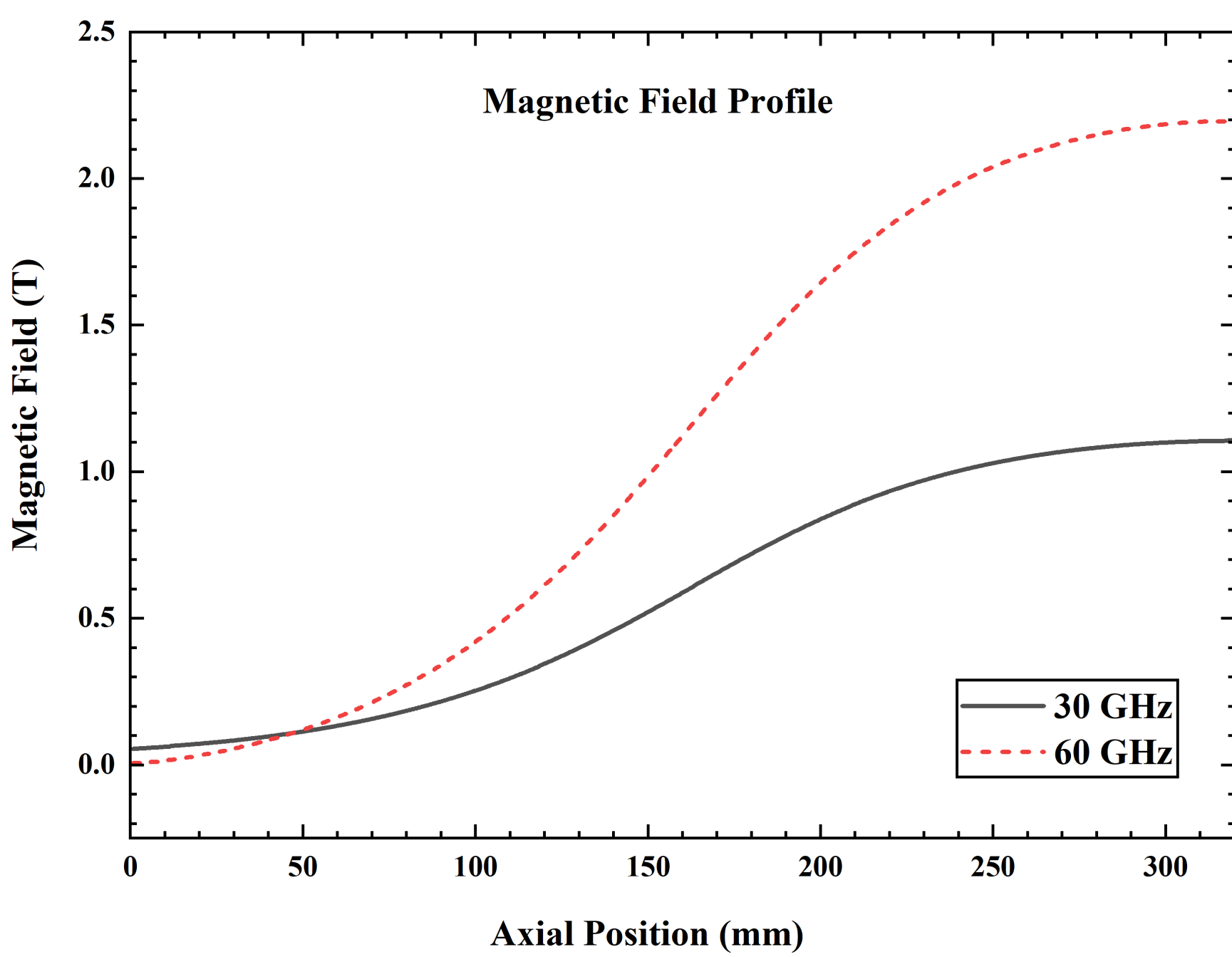
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Magnetic Coil Design for 30/60 GHz Operation

Coils	Axial Position (mm)	Radial Position (mm)	Axial Width (mm)	Radial Width (mm)	Current Density (A/mm ²) for 30 GHz Operation	Current Density (A/mm ²) for 60 GHz Operation
Main	320	97.5	320	15	64	127
Gun	30	97.5	25	15	-7.5	-21.5
Auxillary Coil 1	200	108.75	80	7.5	10	20
Auxillary Coil 2	440	108.75	80	7.5	10	20



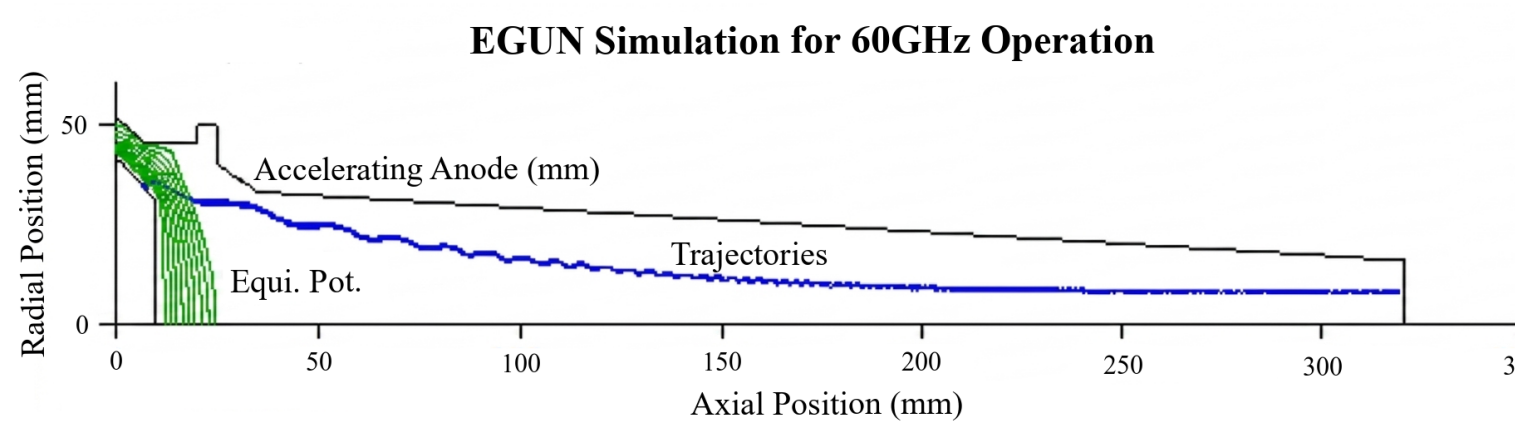
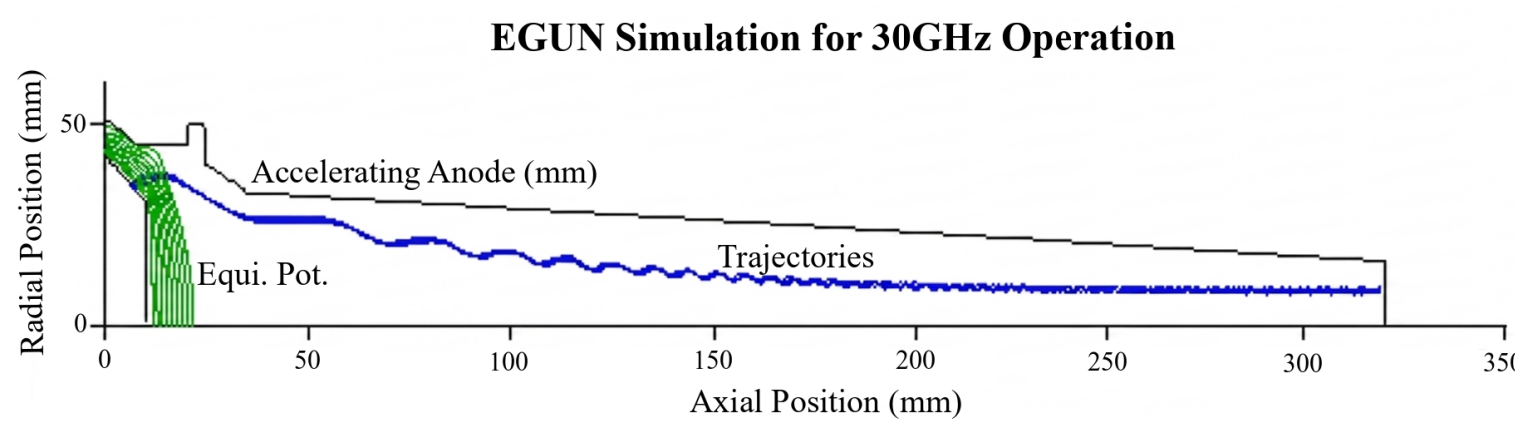
By varying the current in the magnetic coils required magnetic field profile is generated for 30/60 GHz operation. The interaction cavity center is fixed at axial distance of 320 mm from the starting position of the electron gun.

Electron Gun Design Parameters

Parameter	30 GHz	60 GHz
Accelerating Voltage (kV)	58	72
Modulating Anode Voltage (kV)	29	36
Beam Current (A)	10	12
Interaction cavity radius (mm)	15.12	15.12
Magnetic field in cavity (T)	1.11	2.32
Mag. Compression ratio	25	25
Beam radius in cavity (mm)	6.84	7.68
Average Emitter radius (mm)	34.2	34.2
Slant angle of emitter (°)	50	50
Emitter current density (A/cm ²)	2.5	2.5
Slant length of emitter (mm)	1.86	1.86
Velocity ratio, α	1.41	1.42
Perp. velocity spread (%)	2.3	0.88

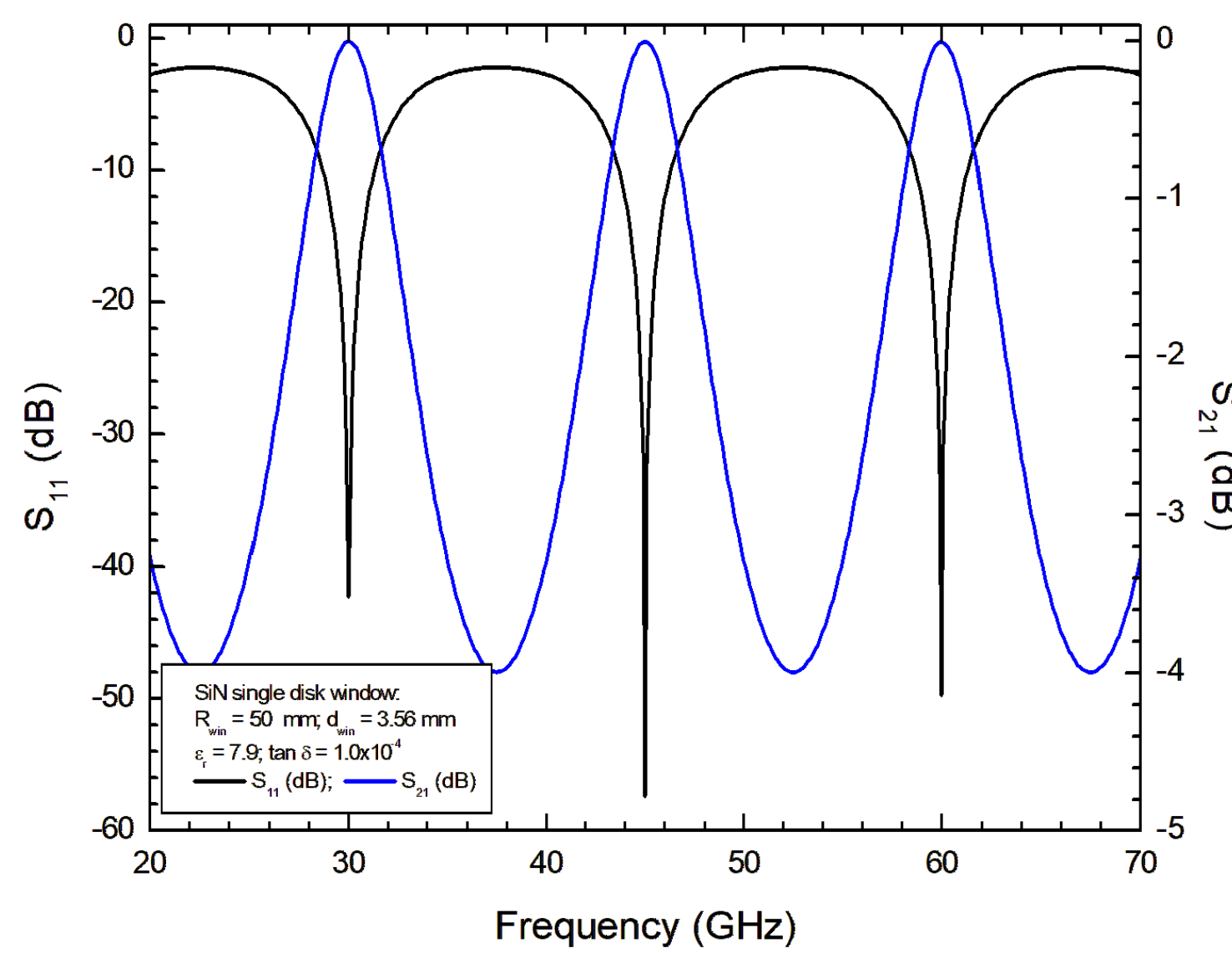
*Beam parameters are calculated at axial distance of 320 mm from the starting position of the electron gun.

Electron Beam Simulations

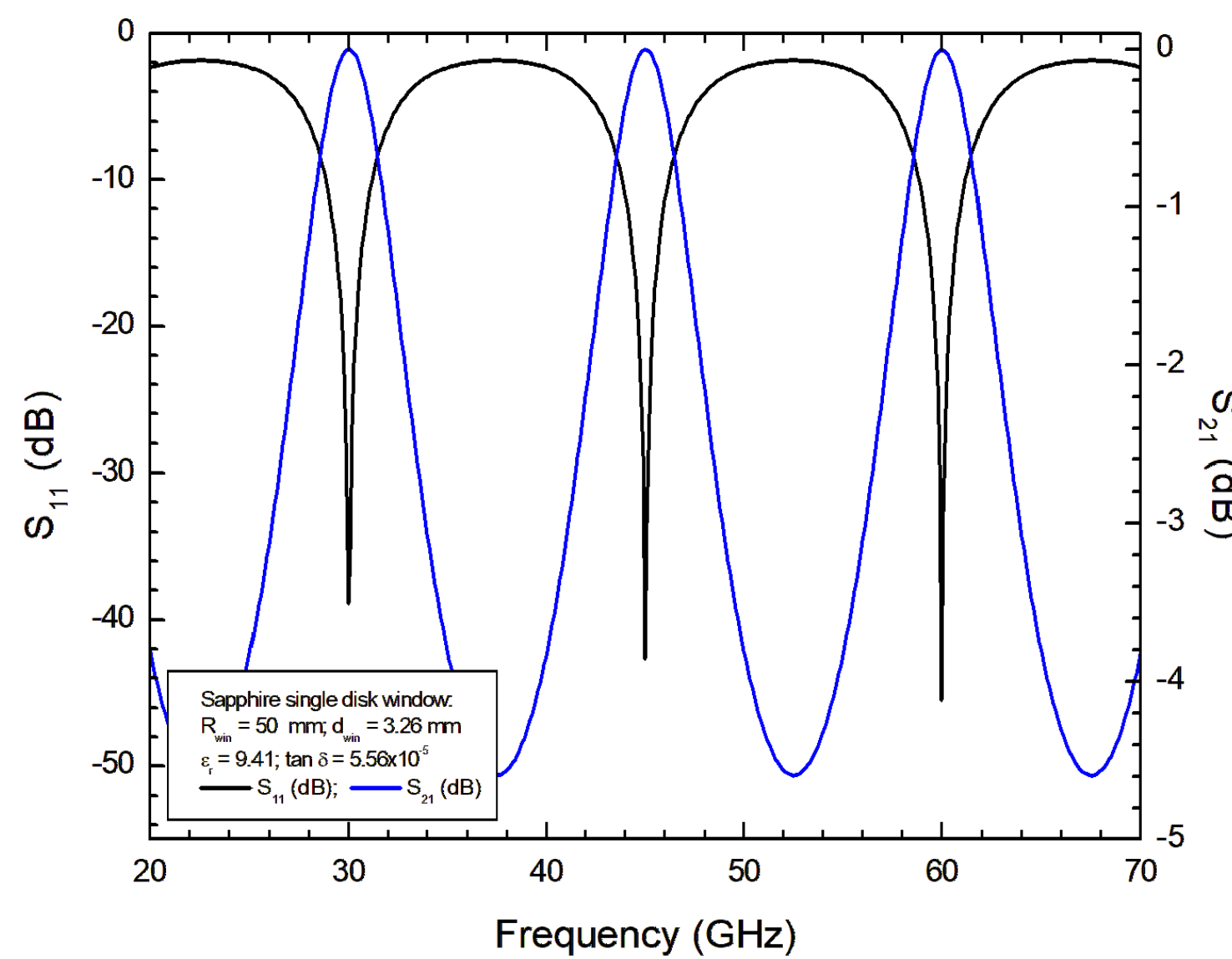


By varying the current in the magnetic coils and electrode potential required nominal beam parameters are obtained for 30/60 GHz operation. The interaction cavity center is fixed at axial distance of 320 mm from the starting position of the electron gun.

Single-Disk RF Window Design



Here, radius of the SiN ($\epsilon_r = 7.9$; $\tan\delta = 1.0 \times 10^{-4}$) RF window is 50 mm; thickness 3.56 mm.



Here, radius of the sapphire ($\epsilon_r = 9.41$; $\tan\delta = 5.56 \times 10^{-6}$) RF window is 50 mm; thickness 3.26 mm.

Conclusions

Key Findings

- A triode type MIG was designed for generating the hollow electron beam with desired beam radius and nominal parameters suitable for 30/60 GHz operation.
- Design of the magnetic guidance system was carried out for generating the required magnetic field profile to support dual frequency operation of the gyrotron.
- Design of single-disk RF window was performed using silicon nitride and sapphire materials for the proposed gyrotron.

Outlook

- We are present investigating the of quasi-optical launcher and internal mirror system for this dual-frequency gyrotron.
- Plans are also to perform three dimensional simulations of the designed electron gun assembly using suitable software package!!

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