

TABLE OF CONTENT

<i>List of Figures</i>	xix
<i>List of Tables</i>	xxvii
<i>List of Abbreviation</i>	xxix
<i>List of Symbols</i>	xxxiii
<i>Preface</i>	xxxix
Chapter 1 Introduction and Literature Review	1
1.1. Introduction	3
1.2. Fast-Wave Gyro-Devices	7
1.2.1. Dispersion relation	9
<i>1.2.1.a. Beam-mode dispersion relation</i>	9
<i>1.2.1.b. Waveguide-mode dispersion relation</i>	10
1.2.2. CRM interaction mechanism	14
<i>1.2.2.a. Phase bunching</i>	16
1.2.3. Operating Principle	19
1.3. Gyrotron Oscillator and its sub-assemblies	20
1.3.1. MIG gun and beam tunnel	21
1.3.2. RF interaction cavity	22
1.3.3. Non-linear taper section	25
1.3.4. Quasi-optical mode launcher	26
1.3.5. Collector	26
1.3.6. RF window	27
1.3.7. External DC magnetic field	28
1.4. Applications	29
1.4.1. Plasma heating for fusion	29

1.4.2.	Industrial heating	30
1.4.3.	Communication, security and atmospheric science	30
1.4.4.	Spectroscopy and medical science	32
1.5.	Motivation and Objective	33
1.6.	Plan and Scope	35
Chapter 2	Analysis and Design of the Quasi-Optical Mode Launchers for Gyrotrons	41
2.1.	Introduction	43
2.2.	Vlasov Type Mode Launcher	47
2.2.1.	Geometric-optical field representation in cylindrical waveguides	47
2.2.2.	Calculations of Vlasov Launcher parameters	52
2.3.	Denisov Launchers	54
2.3.1.	Analysis of the dimpled launcher	57
2.3.2.	Calculation of waveguide field components	61
2.4.	Field Computations, Results and Discussion of Denisov launchers	64
2.4.1.	Validation of Dimpled Launcher design for $TE_{22,6}$ mode at 110GHz	64
2.4.1.a.	<i>With 4 Satellite modes</i>	66
2.4.1.b.	<i>With 8 Satellite modes</i>	67
2.4.2.	Dimpled Launcher design for $TE_{10,4}$ mode at 95GHz	69
2.5.	Analysis and Design of Output RF Window	71
2.5.1.	Disc Type Windows	72
2.5.2.	Results and Discussion	75
2.6.	Conclusions	77
Chapter 3	Design, analysis and beam-wave interaction studies of fixed frequency (95GHz 100kW CW, $TE_{6,2}$ mode) Gyrotron operated in the whispering gallery mode	81

3.1.	Introduction	83
3.2.	Design constraints and operating mode selection of Gyrotron	85
3.2.1.	Voltage Depression (V_{dep})	86
3.2.2.	Limiting Current (I_L)	87
3.2.3.	Ohmic Wall losses (dP_{loss}/dA)	87
3.3.	Design of RF interaction structure	90
3.3.1.	Coupling Coefficient (C_{mp})	94
3.3.2.	Start Oscillation Current (I_{soc})	95
3.4.	Beam-wave Interaction Time dependent Multimode Analysis	97
3.4.1.	Time dependent multimode theory	97
3.4.2.	Computational results and discussion	101
3.5.	3D PIC Simulation Studies	103
3.5.1.	Device performance under ideal condition	104
3.5.2.	Device Performance under practical conditions	107
3.6.	Thermo-Mechanical Analysis and Optimized Cooling System Design	110
3.6.1.	ANALYSIS: Calculation of ohmic losses and Fin design	112
3.6.1a.	<i>Effects of radial deformation on resonant frequency</i>	113
3.6.1b.	<i>Wall loss calculation</i>	115
3.6.1c.	<i>Cooling Fins Design</i>	116
3.6.1d.	<i>Heat Transfer Modes in the RF cavity</i>	117
3.6.2.	Heat Transfer Analysis Using “COMSOL MULTIPHYSICS”	117
3.6.2a.	<i>COMSOL Multiphysics simulation modeling</i>	121
3.6.3.	Results and Discussion	130
3.7.	Conclusions	
Chapter 4	Design, analysis and beam-wave interaction studies of fixed frequency (95GHz 100kW CW, TE_{10,4} mode) Gyrotron operated	133

in the volumetric mode		
4.1.	Introduction	135
4.2.	Design Constraints and Mode Selection of gyrotron	137
4.3.	Design of RF Interaction Cavity	
4.4.	Beam Wave Interaction Study	140
	4.4.1. Time dependent multimode analysis with misalignment effects	144
	<i>4.4.1a. Multimode analysis with ideal beam conditions</i>	
	4.4.2. 3D Particle in Cell (PIC) simulation	148
	4.4.3. Effect of electron velocity spread	149
4.5.	Design and Analysis with the Nonlinear Taper	153
4.6.	Thermo-Mechanical Studies	155
4.7.	Conclusions	160
		163
Chapter 5	Design approach and beam-wave interaction studies of the tunable frequency Gyrotron for DNP-NMR spectroscopy	167
5.1.	Introduction	169
5.2.	Tuning Techniques Used for the DNP Gyrotrons	170
	5.2.1. Mechanical Tuning	171
	5.2.2. Thermal Tuning	172
	5.2.3. Electrical Tuning	173
	5.2.4. Magnetic Tuning	175
5.3.	Design Constraints and Mode Selection of the RF Interaction Cavities for the Tunable Frequency Gyrotrons	176
	5.3.1. Tunable RF Cavity Structure Design	178
	5.3.2. Start Oscillation Current for the Higher-Order Axial Mode Indices	179
5.4.	Analytical and Simulation Study of the Beam-Wave Interaction	182
	5.4.1. Investigations via Magnetic Tuning	184

5.4.2. Investigations via Electrical Tuning	185
5.5. Output RF Window	187
5.6. Conclusions	
Chapter 6 Design modification in RF interaction cavity of a 140GHz Gyrotron to achieve wide tunable bandwidth for DNP-NMR spectroscopy applications	189
6.1. Introduction	191
6.2. RF Interaction Cavity Design Modification	192
6.3. Beam-Wave Interaction Exploration	200
6.3.1. Time-Dependent Multimode Analysis	200
6.3.2. PIC Simulation of the Gyrotron	201
6.4. Conclusions	203
Chapter 7 Summary, Conclusion, and Future Scope	205
7.1 Summary and Conclusion	207
7.2 Limitations of the Present Work and Scope for Further Studies	214
References	217
Author's Relevant Publications	227