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## ACKNOWLEDGEMENTS

I express my immense gratitude to my supervisor Dr. M. Thottappan, for his excellent guidance and motivation. The completion of this research work is indeed an outcome of his constant tireless support, valuable ideas, and suggestions during my research work. The insightful discussions with him always provided me with great enthusiasm.

I wish to extend my sincere gratitude towards my research performance evaluation committee (RPEC) members, Prof. R. Mahanty and Dr. Smrity Dwivedi, for their encouragement and insightful comments. I would also like to thank all the faculty members, especially to Dr. Somak Bhattacharyya for their kind cooperation and encouragement during this journey.

I would like to express my special thanks to Dr. Madan Singh Chauhan, Dr. Yuvraj, Dr. Gargi Dixit, Dr. Swati, Dr. Manpura Mahto, Dr. Amit Arora, and Mr. Siva V. Rao for their valuable assistance at my initial stage of research work.

I am thankful to my colleagues Mr. Rajan Agrahari, Mr. Vikram Kumar, Mr. Akhileendra Singh, Mr. Arjun Kumar, Mr. Sudheer Bhaskar, Dr. Debanjan Sadhya, Dr. Gaurav Modanwal, Dr. Lalit Chandra, Dr. Mayank Agarwal, Dr. Chandan Kumar, Mr. Ashis Bahera, and Mr. Praveen Kumar Sahu for their personal and technical support.

I am very much thankful to many research scholars of the CRMT laboratory for providing a stimulating and friendly environment. My thanks go to Mr. Mumtaz A. Ansari, Mr. Akash, Mr. Rajanish Kumar Singh, Mr. Vineet Singh, Mr. Prabhakar Tripathi, Mr. Shyam Gopal Yadav, Mr. Vikram Rawat, Mr. Gundu Venkatesh, Mr. Saurabh Sharma, Mr. V.V. Reddy, Mr. Veerababu, Mr. Soumojit Shee, Mr. Sambit Ghosh, Mr. Deepti, Mr. Nilotpal, Mr. Nishith and Mr. Priyesh Jain.

I am thankful to the UGC, GoI, New Delhi for the financial assistantship during Ph.D. through the UGC-NET JRF/SRF fellowship (UGC Ref. no. 3956/NET-JUNE 2013).

Finally, I heartily express sincere thanks to my family. For their unconditional love, extreme patience and constant support over the years. They provide me strength and confidence to attain this task.

**Date:**

**(Anshu Sharan Singh)**





*Dedicated*  
*To*  
*My Mother*  
*Anju Devi*

**(1<sup>st</sup> July 1967 to 09<sup>th</sup> November 2017)**



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## ABBREVIATIONS

<b>Abbreviation</b>	<b>Full Form</b>
BeO-SiC	Beryllium Oxide-Silicon Carbide
BWOs	Backward Wave Oscillations
CARM	Cyclotron Auto-Resonance Maser
CPI	Communication and Power Industries
CRM	Cyclotron Resonance Maser
CST	Computer Simulation Technologies
DC	Direct Current
ECRM	Electron Cyclotron Resonance Maser
EM	Electromagnetic
FDTD	Finite-Difference Time-Domain
FEM	Finite-Element Method
FIT	Finite Integration Technique
GHz	Gigahertz
MW	Megawatt
Gyro-amplifier	Gyrotron Amplifier
Gyro-BWO	Gyrotron Backward Wave Oscillator
Gyro-TWAs	Gyrotron Travelling Wave Amplifiers
Gyro-TWT	Gyrotron Travelling Wave Tube
IAP	Institute of Applied Physics
LHC	Large Hadron Collider
MHz	Megahertz
MIG	Magnetron Injection Gun

MoM	Method of Moments
MW	Megawatt
NRL	Naval Research Laboratory
OFHC	Oxygen free High conductivity
PBA	Perfect Boundary Approximation
PBG	Photonic Band Gap
PDL	Periodic Dielectric Loading
PIC	Particle-in-Cell
PML	Perfect Matched Layer
RF	Radio Frequency
SOC	Start Oscillation Current
SSDs	Solid State Devices
SWSs	Slow wave Structures
TE	Transverse Electric
TM	Transverse Magnetic
TeV	Tera Electron Volt
THz	Terahertz
TWAs	Travelling Wave Amplifiers
TWTs	Travelling Wave Tubes
UDL	Uniform Dielectric Loading
VEDs	Vacuum Electronic Devices

## LIST OF SYMBOLS

<b>Symbol</b>	<b>Details</b>
$\gamma$	Relativistic mass factor
$\alpha$	Pitch factor
$V_b$	Beam voltage
$I_b$	Beam current
$r_w$	Radius of waveguide
$r_g$	Electron guiding centre radius
$r_{cav}$	Radius of cavity
$r_L$	Larmor radius
$r_d$	Radius of drift tube
$L_c$	Length of cavity
$L_d$	Length of drift tube
$L_{wg}$	Length of waveguide
$v_t$	Transverse electron velocity
$v_z$	Axial electron velocity
$\omega$	Angular frequency of RF wave
$\Omega$	Electron cyclotron frequency
$c$	Velocity of light in free space
$\lambda$	Operating wavelength
$e$	Electron charge
$m_e$	Mass of electron
$B_0$	DC magnetic field
$s$	Electron beam harmonic number

$m_q, n_q$	Azimuthal, and radial indices of $q^{th}$ mode
$N_q$	Total number of modes
$q$	Particular number of mode
$p$	Normalized momentum of electrons
$p_t$	Transverse momentum of electrons
$p_z$	Axial momentum of electrons
$\theta$	Phase of electron
$I_o$	Normalized beam current
$\mu$	Normalized interaction length
$J_t$	Transverse AC current density
$H_{mn}$	Azimuthal coupling coefficient
$x_{mn}$	The $n^{th}$ zero of $J_m$ (Bessel function)
$\varepsilon$	Complex permittivity
$\varepsilon_0$	Free-space permittivity
$\mu_0$	Free-space permeability
$I_{soc}$	Start oscillation current
$F$	Normalized field amplitude
$X$	Bunching parameter of the electron beam
$\eta_{\perp}$	Transverse efficiency
$\eta_{ele}$	Electronic efficiency
$P_{in}$	Driver power at the input cavity
$E$	RF electric field
$B$	RF magnetic field
$E_0$	Electric field amplitude at the input cavity
$Q$	Quality factor
$Q_{cpt}$	Coupling quality factor



$k_t$	Transverse propagation constant
$k_z$	Axial propagation constant
$\beta_t$	Normalized transverse electron velocity
$\beta_z$	Normalized axial electron velocity
$V_d$	Voltage depression
$I_l$	Limiting current
$G$	Gain
$s_d$	Skin depth
$\sigma$	Conductivity
$t_w$	Window thickness
$r_{win}$	Radius of window
$\epsilon_{rw}$	Relative permittivity of RF window



## PREFACE

---

The work of the present thesis focus on the beam-wave interaction study of the gyro-twystron amplifier. The thesis aims to develop studies on the most unexplored gyrotron variant of vacuum electron device (VED), i.e. gyro-twystron, to create a solid theoretical background for future experimental studies. In addition to VEDs, the historical developments of gyro-twystron is scrutinised to bring out the research gap and problems. The Identification of oscillations and its suppression have been done, in a series of works on the gyro-twystron amplifier, and the part of these works has been published in *IEEE Transaction on Electron Devices*. Further, the aim, introduction and scope of the thesis are briefly discussed below.

As compared to solid state devices, VEDs generates high RF power to serve the various applications from space exploration to nuclear researches. At higher frequencies, the fabrication difficulties and operational limitation of conventional microwave tubes push the research and development activities towards Gyrotron devices. With high power generation/ amplification and handling capabilities, gyrotron devices find applications in plasma heating, ceramic sintering, RADAR and particle accelerator application. Gyrotron oscillator finds application in plasma heating in popularly known thermonuclear fusion reactors while its amplifier counterparts are found suitable for RADAR and particle accelerator applications.

Gyro-twystron amplifier derived from the gyroklystron and gyro-TWT amplifier (*TWystro*n) and combines the advantages of both amplifiers thereby possess high power-bandwidth product and gain-bandwidth product. A slow-wave counterpart of Gyro-twystron have a successful services history in the US AN/TPS RADAR system and

renders as a veteran tube. Despite these aspects, the gyro-twystron is the most unexplored device in gyrotron family. These advantages and applications attract authors to extend the study of gyro-twystron to answer the challenges of vacuum electronics.

For the megawatt-class operation, the stability of gyro-twystron is an issue as the output waveguide section is vulnerable to parasitic instabilities and backward wave oscillations. A nonlinear multimode code has been developed to investigate the growth of operating as well as competing modes in RF interaction structure of X-band gyro-twystron and predicted the second harmonic  $TE_{02}$  is most troublesome mode. To suppress the second  $TE_{02}$ , the periodic dielectric rings are introduced in the output waveguide section of gyro-twystron, and the design and stability study of PDL waveguide has been made. A multimode study of PDL gyro-twystron has been made to investigate the suppression of parasitic modes in addition to the growth of operating mode. A study has also been made for the performance improvement of the gyro-twystron amplifier by introducing an intermediate cavity. The particle emitter and collector is designed/optimized to improve the electron beam quality for beam-wave interaction and improve the energy extraction at collector electrode, respectively. The work of author is supported by UGC, Government of India, New Delhi through the UGC-NET JRF Fellowship under Grant 3956/NET-JUNE 2013.