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I, **Vangalla Veera Babu**, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of **Dr. Smrity Dwivedi** and **Dr. M. Thottappan** from **"25/07/2017" to "26/12/2022"**, at the Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc.*, reported in journals, books, magazines, reports, dissertations, theses, *etc.*, or available at websites and have not included them in this thesis and have not cited as my own work.

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Date: **Vangalla Veera Babu**

Dedicated

To

My Mother

Vangalla Koteswaramma

(1950 to 2022)

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
AlN-SiC	Aluminium Nitride-Silicon Carbide
BWO	Backward Wave Oscillator
BeO-SiC	Beryllium Oxide-Silicon Carbide
CPI	Communication and Power Industries
CRM	Cyclotron Resonance Maser
CST	Computer Simulation Technologies
DC	Direct Current
EM	Electromagnetic
FIT	Finite Integration Technique
FDTD	Finite-difference Time-domain
GHz	Giga-hertz
Gyro-TWT	Gyrotron Travelling Wave Tube
Gyro-BWO	Gyrotron Backward Wave Oscillator
MIG	Magnetron Injection gun
NMR	Nuclear Magnetic Resonance
NRL	Naval Research Laboratory
OFHC	Oxygen Free High Conductivity
PDL	Periodic Dielectric Loading
PIC	Particle-In-Cell
RF	Radio Frequency
SOC	Start Oscillation Current
SOL	Start Oscillation Length
SSDC	Single Stage Depressed Collector

TE	Transverse Electric
TeV	Tetra Electron Volt
THz	Terahertz
TM	Transverse Magnetic
TWT	Travelling Wave Tube
UDL	Uniform Dielectric Loading
VEDs	Vacuum Electron Devices

LIST OF SYMBOLS

Symbol	Details
α	Velocity ratio
r_w	Radius of the interaction waveguide
r_b	Electron beam radius
r_g	Guiding center radius
r_L	Larmor radius
v_t	Transverse electron velocity
v_z	Longitudinal electron velocity
ε_0	Permittivity of free space
Δr	Lossy layer thickness
ε_r	Relative permittivity of the dielectric material
δ	Skin depth
ρ_{Cu}	Resistivity of copper
μ_0	Permeability of free space
ω_c	Cutoff angular frequency of the waveguide
Ω	Cyclotron frequency
f	Frequency
K_0	Beam-wave coupling impedance
H_{sm}	Beam-wave coupling coefficient
G_{mn}	Geometry factor
m_e	Mass of an electron
s	Cyclotron harmonic number
B_0	Static magnetic field
v_p	Phase velocity of RF wave
v_g	Group velocity of RF wave
β_t	Transverse normalized velocity
β_z	Longitudinal normalized velocity
E	Electric field
H	Magnetic Field

φ, r, z	Azimuthal, radial, and axial cylindrical coordinates
c	Speed of light
L_{dB}	Total loss of the circuit in *dB*
V_0	Beam voltage
I_0	Beam current
η_e	Electronic efficiency
η_0	Efficiency of gyro-twystron with RF losses
η_{col}	Collector efficiency
η_{Total}	Total efficiency of gyro-twystron after recovery of spent beam energy
P_{RF}	Generated output power
P_{DC}	DC electron beam power
k_{Z}	Axial wavenumber
k_c	Cut-off wavenumber
m	Azimuthal wavenumber
n	Radial wavenumber
χ'_{mn}	The n^{th} zero of Bessel function
$J_m(\chi'_{mn})$	$\mathrm{m^{th}}$ order ordinary Bessel function of first kind
λ_g	Wavelength inside the disk medium
F_m	Compression ratio
l_s	Slant length
r_c	Emitter radius
$\Delta v_z / v_z$	Axial velocity spread
$\Delta v_t / v_t$	Transverse velocity spread
X	Bunching Parameter
η_{ele}	Electronic efficiency
P_{in}	Drive Power at the input cavity
r_1, r_2, r_3	Radius of waveguide region, collector, window
d	Disc thickness
$\eta_\perp$	Transverse efficiency
Q	Quality factor

Q_{cpl}	Coupling quality factor
$k_{\perp}$	Transverse propagation constant
$k_{\parallel}$	Axial propagation constant
BW_{Δ}	Stagger tuned bandwidth
BW	Synchronous tuned bandwidth
V_d	Voltage depression
I_i	Limiting Current
G	Gain
Δ	Normalized Stagger tuned parameter
δ	Normalized frequency detuning factor
Φ	Normalized bandwidth product

PREFACE

The desire to bridge the millimeter-wave and submillimeter-wave technology gap in the high-power regime, where numerous civilian and military applications exist, has led to significant research and development in fast-wave gyro sources and amplifiers. Although one such gyro-source, the gyrotron, is now commercially available for applications such as plasma heating and material processing, gyro-amplifiers such as the gyro-klystron and the gyro-TWT have emerged as successful amplifiers for millimetre radar systems, they each have their own set of drawbacks. To mitigate the issues and combine the advantages of both devices, a hybrid device known as a gyro-twystron is introduced.

The gyro-twystron amplifier is created from the gyroklystron and gyrotron travelling wave tube (gyro-TWT) amplifier. This hybrid amplifier integrates the merits of both amplifiers, resulting in a high power-bandwidth product and a gain-bandwidth product. Despite these aspects, the gyro-twystron is the gyrotron family's most undiscovered device. These benefits and uses have sparked the curiosity of research to improve the potential capabilities of a gyro-twystron for applications such as high-resolution radar and high-information-density communication systems in the millimeter-wave frequency band.

The author, in the present thesis, has investigated the different configurations of millimeter wave gyro-twystron, using various techniques to improve the performance of gyro-twystron for various radar applications. For the high power 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 analysis has been used to investigate the growth of operating as well as competing modes in RF interaction structure of *Ka*-band gyro-twystron and predicted the unwanted spurious oscillating modes cause instability in operation. To suppress spurious oscillating modes, a short periodic dielectric loading in the output waveguide section was made, and multimode analysis was carried out to investigate the behaviour of multiple modes in PDL gyro-twystron, which predicted that spurious oscillating modes was well suppressed. Further, a stability analysis of the PDL gyro-twystron was performed. An intermediate cavity was introduced to single cavity PDL gyro-twystron to improve the performance metrics of the hybrid gyro amplifier. Furthermore a three-cavity *Ka*-band stagger-tuned gyro-twystron was designed to improve the bandwidth, and its beam-wave interaction behaviour was explored. The author has also studied the design and simulation of low-velocity spread diode and triode magnetron injection guns to improve electronic efficiency. The design and simulation study of other subassemblies of gyro-twystron, such as input coupler, output window, undepressed, and depressed collector, has been described.

The author, from time to time, has reported the present work part-wise at national and international conferences as well as in professional journals, namely, IEEE Transaction on Electron Devices, Journal of Electromagnetic Waves and Applications.

The author will consider his modest effort as a success if it would be useful to the community of microwave tube designers and researchers.