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It is certified that the work contained in the thesis titled **"Design and Simulation Investigations of Millimeter Wave Gyrotron Travelling Wave Tube Amplifiers"** by **"Akash"** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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I, Akash, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of Dr. M. Thottappan from "21/07/2015" to “15/10/2020”, 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: **(Akash)**

Dedicated

To

My Family

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
BWO	Backward Wave Oscillator
BeO-SiC	Beryllium Oxide-Silicon Carbide
CRM	Cyclotron Resonance Maser
TWT	Travelling Wave Tube
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
TM	Transverse Magnetic
TE	Transverse Electric
ESR	Electron Spin Resonance
NMR	Nuclear Magnetic Resonance
PIC	Particle-In-Cell
PDL	Periodic Dielectric Loading
UDL	Uniform Dielectric Loading
MIG	Magnetron Injection gun
OFHC	Oxygen Free High Conductivity
VEDs	Vacuum Electron Devices
CST	Computer Simulation Technologies

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 of gyro-TWT amplifier
η_0	Efficiency of gyro-TWT with RF losses
η_{col}	Collector efficiency
η_{Total}	Total efficiency of gyro-TWT 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
$J_m\left(\chi'_{mn}\right)$	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
m_B	Number of folds
k_B	Bragg's periodicity vector
r_1	Corrugation amplitude
d	Corrugation period

PREFACE

The gyrotron traveling wave tube (gyro-TWT) amplifiers offers a unique opportunity to fill a long-standing gap in the generation of high-power coherent millimeter and sub millimeter wave radiation with its promise of broadband amplification. The gyro-TWT amplifier has emerged out as an efficient and stable high power, wide band amplifier which develops CW as well as pulse power that could not be done by the conventional microwave tubes or quantum mechanical devices. In recent years, there is renewed interest toward research and development of the gyro-TWT amplifier due to its requirement in the systems for the applications, such as high-resolution radar, high information density communication, satellite communication, material processing, weaponry, remote sensing, industrial heating, hyperthermia, linear accelerators, waste remediation, *etc*. Another major area of development is the possibility of exploiting the world leading gyro-TWT amplifier to be used in Electron Paramagnetic Resonance (EPR) and Dynamic Nuclear Polarization (DNP) spectroscopy which is currently hampered by the lack of high-power sources and especially broadband amplifiers of terahertz radiation.

Author is fascinated by various applications of high-frequency high-power gyrotron amplifiers. However, the inherent instability problem of gyro-TWT due to various source of oscillations limits the output power gain and efficiency. The existing single mode analysis fails to give the mutual effect of operating and oscillating modes on the performance of the device. These issues have motivated the author to investigate the multimode nonlinear beam-wave interaction of lossy dielectric loaded gyro-TWT using nonlinear analytical equation and numerical simulation tool by considering more than one mode in the operation. The lossy dielectric loading effectively suppresses the potential oscillations by providing them attenuation.

The other issues such as sensitivity to beam velocity spread, high-magnetic field requirement are also limiting the performance of the gyro-TWT to meet the practical application requirement. The author has also studied the design and simulation of low velocity spread diode and triode magnetron injection gun to improve the electronic efficiency. The design and simulation study of other subassemblies of gyro-TWT such as input coupler, output window and beam collector has been described. The author has investigated the second harmonic higher order mode operation to reduce the requirement of high magnetic field by a factor of 2.

The author has reported the present work in different parts at national and international conferences as well as in referred journals, namely, IEEE Transaction on Electronic Devices and IEEE transaction on Plasma Science.

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