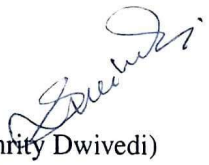
CERTIFICATE

It is certified that the work contained in the thesis titled "Design, Analysis, and Performance Improvement of the HPM Oscillator Reltron" by "Soumojit Shee" has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive, Candidacy and SOTA.



(Dr. Smrity Dwivedi)
Supervisor
Deptartment of Electronics Engineering
IIT (BHU), Varanasi

DECLARATION BY THE CANDIDATE

I, Soumojit Shee, certify that the work embodied in this thesis is my own bonafided work and carried out by me under the supervision of Dr. Smrity Dwivedi from "25/07/2017" to "27/08/2020", 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 will fully 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.

Soumojit Shee

Date: 31/08/2020
Place: IIT (BHU)

Signature of the Student

(Soumojit Shee)

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my knowledge.

(Dr. Smrity Dwivedi)
Supervisor
Department of Electronics Engineering
IIT (BHU), Varanasi

31.08.2020

Signature of Head of Department

"SEAL OF THE DEPARTMENT"

HEAD
इलेक्ट्रानिकी अभियान्त्रिकी विभाग/Department of Electronics Engineering
भारतीय प्रौद्योगिकी संस्थान (का हि वि)/Indian Institute of Technology (BHU)
वाराणसी/Varanasi-221005 (INDIA)

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis: **Design, Analysis, and Performance Improvement of the HPM Oscillator Reltron.**
Name of the Student: **Soumojit Shee**

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University), Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the **Doctor of Philosophy**.

Date: 31/08/2020
Place: IIT (BHU)

Soumojit Shee
Signature of the Student
(Soumojit Shee)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the Institute's copyright notice are indicated.

Acknowledgement

First of all, I wish to express my profound gratitude and deepest sense of regard to my supervisor Dr. Smrity Dwivedi for her guidance and motivation. The thesis is an outcome of her constant supervision and trust that always kept me engaged with my work. Her positive outlook never let my enthusiasm to diminish. I could not complete the thesis without her encouragement and dedicated time, even during the unexpected situation due to the outbreak of COVID-19.

Besides my supervisor, I would like to thank Prof. P. K. Jain for various technical discussions and suggestions. I acknowledge Prof. S. P Singh for making himself available at all times for technical discussions. I further acknowledge the members of my Research Progress Evaluation Committee (RPEC): Prof. R. Mahanty, and Dr. M. Thottappan for putting up questions and giving valuable suggestions. I thank the HOD, Electronics Engineering for extending administrative support. I wish to convey my special thanks to the Librarian and the Asst. Librarian, IIT(BHU) for providing the knowledge resources and other online research tools, and the staffs of various workshops for helping me in constructing the test cavity.

Next, I sincerely acknowledge the reviewers for their criticism, comments, and suggestions, which helped to improve my articles.

I want to express my sincere thanks to Dr. Somak Bhattacharyya for giving me the opportunity to join IEEE MTT-S SBC, IIT(BHU), which proved to be immensely helpful in knowledge and professional development. His encouragement and company, inside and outside the campus, made my stay memorable.

I wish to thank my seniors and colleagues: Dr. Vikram Kumar, Mr. Siva Rao, Dr. Manpuran Mahto, Dr. Rajan Agrahari, Mr. Prabhakar Tripathi, Mr. Akhilendra Pratap Singh, Mr. Anshu Sharan Singh, Mr. Mumtaz Ali Ansari, Mr. Rajnish Singh, Mr. Vineet Singh, Mr. Arjun Kumar, Mr. Akash, Mr. Shyam Gopal Yadav, Mr. Veerababu, Mr. Nilotpal, Mr. Sambit, Mr. Deeptiranjan, Mr. Gundu, Mr. Venkatta Reddy, Mrs. Kritika, Ms. Pratibha, Mr. Rahul, Mr. Arun, Mr. Sanjeev, Mr. Saurabh, and Mr. Manas Ranjan Tripathy for their company.

I wish to convey my special thanks to Prof. B. N. Basu, Dr. K. S. Bhat, Dr. S.U.M. Reddy, and Mr. Bikash Chandra Sahana for their motivation and encouragement.

I wish to thank the HOD Electronics and Communication Engineering, Dean Academics, and Dean Research of Institute of Technical Education and Research, Faculty of Engineering and Technology, and the Board of Management of Siksha 'O' Anusandhan University, Bhubaneswar, for granting me the study leave. I acknowledge Dr. D. B. Ramesh for his sincere and prompt help, and all my colleagues in Bhubaneswar for their encouragement. I want to convey my special thanks to Mr. Gyana Ranjan Patra for introducing me to LaTeX. I thank Prof. Gouranga Bose and Mrs. Mitali Bose for their unconditional love and blessings.

I wish to acknowledge my parents and in-lays for their blessing, my friends: Abhijit, Abhishek, Anupam, Asif, Chaitali, Debayan, Ranajoy, Santigopal, Sumit, and my loving son Nirmallya for giving me a close company, that helped me survive the stressful times. I have no words to acknowledge my wife Prathama, who sacrificed her career and stand beside me all the time.

I thank Shri Kashi Vishwanath, Maa Annapurna, and the holy city Varanasi for strengthening spirituality.

Date: 31/08/2020

Soumojit Shee

(Soumojit Shee)

Dedicated

to my wife

Prathama

Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Detais
1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
A	Ampere
AFRL	Air Force Research Laboratory
AK	Anode-Cathode
AR	Auto-Regressive
ARL	Army Research Laboratory
CNC	Computerized Numerical Control
CST	Computer Simulation Technology
DC	Direct Current
DEW	Directed Energy Weapon
DSC	Double Side-Cavity
EM	Electromagnetic
FD	Frequency Domain
FDTD	Finite Difference Time-domain
FEL	Free Electron Laser
FIT	Finite Integration Technique
FT	Fourier Transform
GHz	Giga Hertz
GPU	Graphics Processing Unit
HPEM	High Power Electromagnetic
HPM	High Power Microwave
HV	High Voltage
Hz	Hertz
IREB	Intense Relativistic Electron Beam
J	Joules
kA	Kilo Ampere
kV	Kilo Volt
LINAC	Linear Accelerator
MA	Mega Ampere
MHz	Mega Hertz
MILO	Magnetically Insulated Line Oscillator
MITL	Magnetically Insulated Transmission Line
MW	Megawatt

MWS	Microwave Studio
NRL	Naval Research Laboratory
nS	Nanosecond
PEC	Perfect Electric Conductor
PIC	Particle-In-Cell
PRF	Pulse Repetition frequency
RBWO	Relativistic Backward Wave Oscillator
RDG	Relativistic Diffraction Generator
RF	Radio Frequency
RM	Relativistic Magnetron
RR	Resonant Reflector
S	Second
SCO	Split Cavity Oscillator
SLAC	Stanford Linear Accelerator Center
SWS	Slow Wave Structure
TE	Transverse Electric
TFE	Tetra-fluoro-ethylene
TM	Transverse Magnetic
TTO	Transit Time Oscillator
VIRCATOR	Virtual Cathode Oscillator
VNA	Vector Network Analyzer
VOM	Volt-ohm Multi-meter
VSWR	Voltage Standing Wave Ratio
W	Watt

List of Symbols

Symbol	Detais
β	Propagation constant
$\boldsymbol{\beta}$	VSWR at resonant frequency
$\mathbf{B}$	Magnetic flux density
B	Susceptance
C	Capacitance
d	Coupling depth
d_{ak}	Anode cathode gap distance
e	Electronic charge
ϵ_0	Vacuum permittivity
$\mathbf{E}$	Electric field intensity
f_{res}	Resonant frequency
g	Grid spacing
g_{opt}	Optimum grid spacing
G	Conductance
Γ	Reflection coefficient
h_wg	Height of extraction waveguide
j	imaginary value ($\sqrt{-1}$)
J_n	Bessel function of first kind
J_z	Longitudinal current density
k	Coupling coefficient
k_c	Cutoff wave number
k_z	Axial wave number
l_mc	Length of main cavity
l_sc	Length of side cavity
l_idl	Length of idler disc
l_dt	Length of drift tube
l_pa	Length of post acceleration gap
λ	Wavelength
L	Inductance
m	Electronic mass
M	Mutual inductance
μ_0	Vacuum permeability
n	Integer
Ω	Normal mode frequency
π	Ratio of a circle's circumference to diameter

Φ	Magnetic flux density
P_{np}	Pth root of Bessel function
Q	Quality factor
q_l	Loaded quality factor
q_u	Unloaded quality factor
q_{ext}	External quality factor
r_mc	Radius of main cavity
r_sc	Radius of side cavity
r_idl	Radius of idler disc
R_{eq}	Equivalent resistance
$\mathtt{t}$	Grid thickness
T	Time period
v	Velocity of electron
ω	Angular frequency
ω_0	Uncoupled resonant frequency
ρ, ϕ, z	Cylindrical co-ordinate system