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It is certified that the work contained in the thesis titled **"Investigation of Design and Analysis of Partially Dielectric Filled Coaxial Disc Loaded Magnetically Insulated Line Oscillator (MILO)"** by **"Nisheeth Upadhyay"** has been carried out under our 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 for the award of Ph. D. Degree.

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19.07.22

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I, Nisheeth Upadhyay, 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 from July 2017 to July 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 wilfully copied any other's work, paragraphs, text, data, results, *etc.*, reported in journals, books, magazines, reports, dissertations, thesis, *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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It is certified that the above statement made by the student is correct to the best of my knowledge.

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Date: 19/07/22 ***(Nisheeth Upadhyay)***

Dedicated
To
My Supervisor
&
My Family

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LIST OF ABBREVIATIONS

Abbreviation	Full form
HPM	High power microwaves
RF	Radio Frequency
PRF	pulse repetition frequency
DEW	Direct energy weaponry
EM	Electromagnetic
TWT	Traveling wave tube
RBWO	Relativistic backward wave oscillator
MILO	Magnetically insulated line oscillator
GHz	Giga-hertz
MHz	Mega-hertz
GW	Giga-watt
MW	Mega-watt
Ns	Nano-second
RKO	Relativistic klystron oscillator
RKA	Relativistic klystron amplifier
VIRCATOR	Virtual Cathode Oscillator
PASOTRON	Plasma Assisted Slow- Wave Oscillator
TTO	Transit-Time Oscillator
SCO	Split Cavity Oscillator
CRM	Cyclotron resonance masers
FEL	Free Electron Laser
SWS	Slow-wave structure

TM	Transverse Magnetic
TE	Transverse Electric
EEE	Explosive electron emission
CTL	Coaxial transmission line
UHF	Ultrahigh frequency
RBF	Relativistic Brillouin flow
VCO	Virtual cathode oscillator
PIC	Particle-in-cell
HEM	Hybrid electromagnetic
HE	Hybrid electric
FFT	Fast Fourier Transform
AC	Alternating Current
DC	Direct Current
TTO	Transit time oscillator
DFMILO	Dielectric filled magnetically insulated line oscillator
TGR	Temporal growth rate
SCW	Space charge wave
cm	Centimeter
mm	Millimeter
kV	Kilo-volt
kA	Kilo-ampere
TEM	Transverse Electromagnetic

LIST OF SYMBOLS

Symbol	Details
v_e	Electron velocity
v_p	phase velocity
L	Equivalent inductance for single cavity resonator
C	Equivalent capacitance for single cavity resonator
$C_{i,z}$	Coupling capacitance
C_{eq}	Equivalent capacitance of parallel resonator circuit
r_c	Cathode radius
r_d	Disc inner radius
r_w	Outer wall radius
L	Periodicity
T	Thickness
R_{ai}	Disc inner radius with different depth
g	The gap between disc inner radius and cathode
E	Electric field
H	Magnetic field
β_n	Axial propagation constant
ω	Angular frequency
γ_n	Radial propagation constant
k	Free space propagation constant
J_0	Bessel functions of 1st kind with zero order
Y_0	Bessel functions of 2nd kind with zero order
c	Speed of light
F	Frequency

A_z	Vector potential
μ	Permeability
ε	Permittivity
I_θ	Azimuthal current
Z_0	Charatecteristic impedance
ς_n	velocity shifted frequency
Γ_n^*	Radial beam parameter in presence of beam
ω_p	Plasma frequency
P	Total transmitted RF power
K	Interaction Impedance
l_{stub}	Length of stub
λ	Wavelength
λ_g	Guided wavelength
l_T	Length of tapered cathode
$\hat{v}_z$	Axial drift velocity
γ	Relativistic factor
P_z	Axial momentum
n_e	Charge number density
r_e	Electron beam radius
η	Normalized factor
$\delta(r-r_e)$	Delta function
I_A	Alfven current
γ_n^*	Radial propagation constant in presence of electron beam
v_{slow_sc}	Slow space charge velocity
f_i	Imaginary value of frequency
f_r	Real value of frequency
I_a	Anode current
I_{cr}	Critical current

B_c	Cut-off magnetic field
V_H	Hull cut-off voltage
V_{BH}	Buneman-Hartee voltage
E	Electron charge
m_0	Electron mass
χ_{np}	Modal root of the nth order Bessel–Neumann combination
dB	Decibel
MW	Mega-watt

PREFACE

Due to its numerous commercial and military uses, high-power microwave (HPM) has gained immense popularity in the microwave world. Researchers and academics from all over the world are interested in R&D in this field due to the creation of RF in millimeter-wave ranges and the dual-frequency generation using a single HPM device. A HPM source is a device that has a frequency range of 1–300 GHz and can generate RF power more than 100 MW. The major application fields for HPM include indirect energy weapons, communication, radar, UWB, power beaming, linear colliders, and (DEW). Different sub-systems are utilised throughout the whole process of HPM generation and application, starting with the prime power supply and following on through pulsed DC power formation, a microwave source, a mode converter, and an antenna. Each of these several HPM subsystems has a distinct function in the generation and application of RF energy. The primary component of the entire microwave generation process is the microwave or HPM source. A relativistic magnetron, a relativistic klystron, a relativistic backward wave oscillator, a relativistic gyrotron device, a vircator, a reltron, and a magnetically insulated line oscillator are examples of HPM sources that can produce RF power (MILO). Cherenkov radiation, transition radiation, and Bremsstrahlung radiation are the three basic categories used to describe the various radiation processes used by these HPM sources. The HPM source MILO, which employs the Cherenkov radiation process, is the basic foundation of this research. When compared to other HPM sources, the MILO requires no external magnetic field, which makes it compact, lightweight, and suitable for usage on many mobile platforms.

Similar in operation and theory to a linear magnetron, MILO is a crossed-field high power microwave device. Slow-wave tubes and magnetically insulated electron flow technology are

combined to make it operate. Two DC power sources are used in a microwave oscillator, which needs an external DC magnetic field, in order to demonstrate magnetic insulation and cause electrical breakdown when higher voltages are approached. Because of their extremely high inherent impedance, these oscillators can only function at very low power levels. Therefore, an oscillator that can function at the lower impedance and solve the voltage matching issue would be appropriate for effective operation at greater power levels. In order to solve the aforementioned issues, MILO has been employed, where the necessary magnetic field is generated by the electron-beam current itself, rather than by a separate magnet, making the device more compact and lightweight. The design of MILO must be improved in order to prevent some serious problems, such as the issue of pulse shortening, asymmetric mode generation and mode competition, shot-to-shot reproducibility, the requirement of high pulse rate frequency, and long cathode life, which are still observed as challenges for device development. The Electromagnetic analysis of partially dielectric filled in SWS of MILO by the use of field matching approach in beam absent case, and also the effect of dielectric material on device parameter are the prime concern for this thesis. Further the electromagnetic analysis of beam wave interaction in partially dielectric filled MILO has been done in this research. The partially dielectric filled MILO was simulated by the CST studio suite and cathode misalignment effect was also analyzed in this thesis.

The author has periodically published parts of the current work in reputed publications, including IEEE Transaction on Plasma Science.

If it proves helpful in the design of partially dielectric filled MILO, the author will consider his little effort a success.