CHAPTER 7

SUMMARY, CONCLUSION AND FUTURE SCOPE

7.1. Summary and Conclusion

7.2. Limitations of the Present Work and Future Scope

7.1. Summary and Conclusion

The modern advanced machinery, technology and simulation tools have been pushing the design and development of high-power vacuum electron devices (VEDs) from the low frequency region to high frequency region *i.e.,* millimeter and sub-millimeter frequency band. Since the conventional VEDs have their own limitations at high frequencies like narrow circuit dimensions, the fast wave gyrotron devices are being considered as an alternative at higher frequencies. The fast wave gyrotrons are being considered as the potential candidates for variety of applications in millimeter and sub-millimeter wave regime including the high-resolution radar and high information density communication, satellite communication, material processing, weaponry, remote sensing, industrial heating, hyperthermia, linear accelerators, waste remediation, plasma heating, etc. The gyrotron amplifiers operating at high frequency regime offers a unique opportunity to bridge the long-standing gap (THz gap) in the generation of high-power millimeter wave electromagnetic radiation that could not be possible through the conventional VEDs and Lasers.

The gyro-TWT is an amplifier variant of gyrotron devices, which uses a non-resonant beam-wave interaction circuit. The use of non-resonant interaction circuit in gyro-TWT offers the highest bandwidth among all gyrotron amplifiers. Despite of high-power and wideband characteristics, the performance of the gyro-TWT is limited by the unwanted spurious oscillations that causes the instability in operation. To suppress these unwanted oscillations, the lossy dielectric loading scheme has been proposed in the present thesis work. The lossy dielectric loading on the inner surface of the metal waveguide provides the attenuation to the oscillating modes and suppressed their growth during the beam-wave interaction process. In the present work, two types of lossy dielectric model have been analysed *i.e.,* uniform dielectric loaded (UDL) and periodically dielectric loaded (PDL) structures. The fundamental theory and dispersion diagram for the lossy dielectric loaded interaction waveguide have been revisited and studied. The periodic dielectric loaded structure avoids the dielectric charging problem that occurs with the uniform dielectric waveguide by draining the charge through the metal rings.

In order to investigate the mutual effect of the operating and other oscillating modes during the beam-wave interaction, a steady state multimode nonlinear analysis has been carried out on the fundamental W-band gyro-TWT with a uniform dielectric loaded RF interaction circuit. The analytical nonlinear multimode results have been validated through the numerical simulation using "CST Particle Studio". The CST simulation of the uniform dielectric loaded gyro-TWT has predicted an RF output power of ~138kW when driven by a DC electron beam of 100 kV and 5 A with 5% axial velocity spread. The electronic efficiency and bandwidth were calculated as ~28% and 5%, respectively. The other subassemblies of gyro-TWT such as electron gun, input coupler, beam collector, and output window have also been designed and simulated. The design and simulation studies of single and double anode magnetron injection gun have been carried out by using 2D electron optics (EGUN) for their beam trajectories and 3D simulation by using "CST Tracking Solver". A Y-shaped power divider TE_{01} mode input coupler has been designed and simulated to feed the fundamental harmonic W-band Gyro-TWT. To collect the spent beam, both type of collectors; undepressed and depressed collectors have been designed and simulated. The heat wall loading of the undepressed collector has been optimized by using 2D electron optics (EGUN) to get a value well below the threshold limit *i.e.*, 1.0 kW/cm^2 for copper. The CST simulation of PDL gyro-TWT has predicted an RF output power of ~207 kW in the operating TE_{01} mode with ~29% electronic efficiency for an electronic beam of 70kV and 10A. In order to recover the spent beam energy, a three-stage depressed collector has been designed and simulated using a 3D PIC simulation tool "MAGIC". The collector efficiency of the 3-stage depressed collector has been achieved ~74 % and the total efficiency has been improved to ~61%. To extract the amplified RF output power, single and triple disk window has been explored to achieve the wideband transmission of the RF output signal with minimum reflections.

Since, the high frequency operation of gyro-TWT requires high DC magnetic field in order to synchronize the cyclotron frequency with the RF frequency. For the fundamental mode and fundamental harmonic operation, this magnetic field requirement becomes high (3-4 Tesla for W-band operation), which further requires a superconducting magnet and become bulkier and power consuming unit of the whole device. Therefore, one of the effective methods to overcome this issue is higher harmonic operation with higher order mode. The study of second harmonic operation of W-band gyro-TWT with TE_{02} mode has been carried out, which reduces the requirement of high magnetic field by a factor of 2 and also increases the power handling capabilities by increasing the cross-sectional dimensions. To feed the operating TE_{02} mode, a novel TE_{02} mode input coupler has been designed and simulated. This input coupler first converts the fundamental TE_{10} mode of rectangular waveguide into a circular TE_{01} mode and then into TE_{02} mode by using a gradually tapered slotted waveguide section. The design and simulation studies of other sub-assemblies for the second harmonic gyro-TWT has also been carried out. The PIC simulation of the second harmonic gyro-TWT has predicted an RF output power of ~500 kW at 91.4 GHz with ~20 % efficiency and 30dB gain.

The second harmonic operation of W-band gyro-TWT with 3-folded helically corrugated interaction waveguide has been discussed. The helically corrugated waveguide provides the most favourable dispersion characteristic for gyro-TWT *i.e.*, constant group velocity over the large frequency band. The other advantages of helically corrugated interaction structure are the low sensitivity to beam velocity spread and stability in the operation without any absorber or lossy medium. The dispersion analysis of 3-folded helically corrugated structure has been presented by using the analytical method based on coupled mode theory and numerical simulation using “CST Eigenmode Solver”. A circularly polarized TE_{11} mode input coupler has been designed and simulated to feed the RF input signal. This input coupler consists of two section one is rectangular to circular waveguide side-wall coupler to convert the rectangular TE_{10} mode into linearly polarized TE_{11} mode. The second section is the polarizer section that converts the linearly polarized TE_{11} mode into a left circularly polarized TE_{11} mode. A 3D electrodynamic model for the low power wide band gyro-TWT with helically corrugated interaction waveguide has been modeled and simulated using “CST Particle Studio”. The electrodynamic model consists of an input coupler, a circular to helical uptaper, regular helical corrugated section, helical to circular down taper and linear output tapered section. The PIC simulation of the present helically corrugated waveguide gyro-TWT amplifier has predicted an RF output power of 3.75kW at 94GHz, 3-dB bandwidth of more than 8GHz and maximum gain of 38.5 dB.

7.2. Limitations of the Present Work and Further Scope

This work presents the nonlinear multimode analysis of W-band gyro-TWTs, which employs a lossy dielectric section in the linear interaction region to stabilize the spurious oscillations. The present work also includes the design and simulation studies of electron guns, RF input couplers, RF interaction circuits, beam collectors and RF output windows. It is hoped that the present studies of dielectric loaded waveguide design analyses and simulation investigations of various sub-assemblies would be useful in designing of zero-drive stable gyro-TWT. However, the author is aware of the limitations of the present work and scope of further research work for its improvements.

While designing an MIG, the other factors affecting the beam quality such as non-uniform emissions due to the cathode surface roughness and temperature can be incorporated, which may provide a more realistic scenario of beam velocity spread in it. An axis encircling electron gun can also be designed for the second harmonic operation of gyro-TWT. The input couplers can be fabricated using highly precise 5-axis CNC machine for S-parameters measurement studies and their validation. In the present analysis, one of the practical aspects of gyro-TWT like the thermal analysis has not been considered. The thermal analysis of electron gun, interaction region, beam collector and output window can also be done. The effect of secondary electron emission from the depressed collector can also be studied.