CHAPTER 5

SUMMARY, CONCLUSION AND FUTURE SCOPE

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5.1. Summary and Conclusion

The conventional sources of radiation offer very little in terahertz range. The microwave sources such as relativistic klystron, magnetron, MILO and Vircator are operate below 60GHz, while lasers operate above and Gyrotrons are limited to range 30-200GHz. FEL amplifiers (FELA) is offer an alternative which overcomes many of the drawbacks of the other high power microwave (HPM) sources. The FEL amplifiers are operated with multiple wavelengths; however, its major advantage is the fact that it does not require a metallic structure for the interaction to take place. Consequently, it has the potential to generate very high power radiation signal contact with metallic walls which is created very serious problems. It is produces radiation at sub-millimetre wavelengths to X-ray. It is demonstrated for extremely high power, continuous tunable radiation and moderated efficiency of the source in sub-millimeter waves to optical ranges and the potential application in the field of communication system, nuclear fusion, radio astronomy, military applications, atmospheric studies, chemical and isotope separation, inertial confinement fusion, remote sensing and security identification, plasma accelerator diagnostics, medicine and molecular spectroscopy, biological imaging (general test, measurement and diagnosis), room temperature THz imaging, materials characterization (spectroscopy of solids and liquids), build computer chips and to clean up toxic waste, electronic material processing, nanotubes synthesis and many other curriculums. The devices, FELs is operated with multiple wavelengths and allow tuning of the wavelength continuously with some ranges, however, the major advantage of this device is that, it does not require a metallic structure for the interaction to take place.

Consequently, it has the potential to either radiation very high power with metallic walls or generation at millimetre to sub millimetre wavelengths, infrared, terahertz radiation, visible, UV, XUV or X-ray, where there are no any other sources achieved. The FEL amplifies has a magnetic field perpendicular to the beam velocity i.e., the main components, hence, therefore, the electrons have an oscillatory motion in transverse direction, which is suitable for interaction with either TE mode or TEM mode (TWT is always interacting with the TM mode whereas in gyrotron interaction is always interacting with the TE mode only). As fast-wave device, gyrotron is interacting with an electromagnetic wave (uniform or periodic magnetic field) by phase velocity equal or slightly larger to the light velocity, c whereas, in FELs, the electron oscillation is in transverse direction while its bunching process is in longitudinal direction as similar to the TWT. Hence the free electron lasers offered an alternative to generate the ranges of sub millimetre wavelengths to x-rays.

The dispersion relation of the FEL amplifiers is sensitive to the linear tapered strong axial magnetic fields, electron cyclotron frequency and plasma frequency of electrons. For the synchronism of the pumped frequency, it is closed to electron cyclotron frequency which is resonantly enhanced the wiggler wave number that produces the amplifier radiation for higher frequency from sub millimeter wave to optical ranges. The guiding of radiation signal into the waveguide and charge neutralization phenomenon, the beam density is greater than the background plasma density with tapered strong axial magnetic field. It is quite considerable that radiation signal slowed down at much higher background plasma density comparable to the density of beams and enhanced the instability growth rate also. In Raman Regime operation, the growth rate decreases as increases with operation frequency of the amplifier, however, the growth rate is larger in this regime. It is noted that as increases with background plasma density, the beat wave frequency of the ponderomotive waves is increases thus the mechanism of background plasma density is served for tenability of the higher frequencies. The tapering of the strong guided magnetic field is a crucial role to enhance the efficiency of the net transfer energy as well as reduction of interaction region along the axis. It is observed that, an efficiency of the transfer energy enhanced by 20% while the reduction along the interaction region of about 10% with the variation of tapering in a strong axial guided magnetic fields. The operating behavior and optimization in the TM_{01} mode of a free electron laser amplifier (FELA) has been discussed using the Eigen mode analysis and the simulation techniques and their results has been also analyzed with 3D particle-in-cell (PIC) codes “CST particle studio”. In the modeling of an FEL amplifier, the pattern of the magnetic and electric field in TM_{01} mode has been showed and performed their RF simulation results in the absent case of electron beams i.e., the cold simulation. The reading of the measurement values has been showed for the large radiation growth rate 2dB/cm approximately with 231 GHz instantaneous band width. The good agreement of the simulation results has been found as reported experimental values with predicted theory of operation in the Collective Raman Regime. Additionally, the result to extraction of the kinetic energy from the electron beams to beat-wave has been observed the power and efficiency largely increases with the linear tapering of the strong axial magnetic field that produces 20% efficiency in the FEL amplifiers. There are many applications in different areas, typically not all, the science of the free electron lasers studied in many areas as classical physics, engineering physics, applied mathematics, material science, biology, medicine, life science, nuclear physics and engineering, electrical engineering, electronics engineering, mechanical engineering and many other curriculums.

A detailed insight of the design, analysis and simulation of the FEL amplifiers Raman regime operation, as well as performance improvement of the amplifiers are presented. Finally, the work embodied in the present thesis is organized into six chapters, as follows.

In Chapter 1, the geometrical structure of FELs and its components as electron gun, RF interactions, wiggler/undulator, depressed collector, output window and applications are studies. Types of FELs as amplifier, oscillator, self-amplified spontaneous emission (SASE), storage ring FELs (SR-FELs) are also explained. A brief review of the FEL amplifiers, problem definition, plan and scope are discussed. The state of the art of the FEL amplifiers is presented with their scope and limitations.

In Chapter 2, we studied the fundamental analysis of FEL amplifiers and their behaviour into the interaction region. The working principal of FEL amplifier, frequency operations, mechanism of radiation, phase coherence and bunching, Madey's theorem for gain, stimulated emission by Madey's theorem, principles of energy conservation by Madey's theorem are discussed here. The Raman regime operation, nonlinear state of Raman regime and gain estimate of Raman regime in FEL amplifier has been presented to investigate the beam-wave interaction behaviour in an interaction chamber of the FEL amplifier. The study of the FEL amplifiers is used in the subsequent chapters for their design analysis and performance improvements.

In Chapter 3, the device has been explored the magnetic field tapering for gain and efficiency in collective Raman regime mode. The dispersion relation of the FEL amplifiers is sensitive to the linear tapered strong axial magnetic fields, electron cyclotron frequency and plasma frequency of electrons. For the synchronism of the pumped frequency, it is closed to electron cyclotron frequency which is resonantly enhanced the wiggler wave number that produces the amplifier radiation for higher frequency from sub-millimetre wave to optical ranges. In Raman Regime operation, the growth rate decreases as increases with operation frequency of the amplifier, however, the growth rate is larger in this regime. It is noted that as increases with background plasma density, the beat wave frequency of the Ponderomotive waves is increases thus the mechanism of background plasma density is served for tenability of the higher frequencies. It is observed that, an efficiency of the transfer energy enhanced with the variation of tapered magnetic fields.

In Chapter 4, a detailed design procedure, methodology and simulation study of the FEL amplifiers has been presented to the 231GHz operating frequency. The operating behaviour and optimization in the TM_{01} mode of FEL amplifiers has been discussed using the Eigen mode analysis and the simulation techniques and their results has been also analyzed with 3-D particle-in-cell (PIC) code CST particle studio. The detail description of FEL amplifiers has been explained using 3-D PIC simulation approach which is commercially available in "CST Studio Suite". The emission process in the FEL amplifiers interaction chamber is simulated through the commercially 3-D PIC simulation codes “CST Particle Studio”. To find out the excitation of electromagnetic modes, frequencies and EM field patterns inside the interaction region of an amplifier is carried out through the Eigen mode simulation (i.e., cold simulation or beams absent simulations). To observed the overall performance of an FEL amplifiers, such as frequency of operations, gain, power, efficiency, RF output and the beams present PIC simulation is carried out. The reading of the measurement values has been showed for the large radiation growth rate 2dB/cm approximately with 231 GHz instantaneous band width. The good agreement of the simulation results has been found as reported experimental values with predicted theory of operation in the Collective Raman Regime (CRR). Additionally, the result to extraction of the kinetic energy from the electron beams to beat-wave has been observed the power and efficiency largely increases experimentally with the linear tapering of the strong axial magnetic field that produces 20% experimental efficiency in the FEL amplifiers.

Finally, in Chapter 5, the works embodied in the present thesis are summarized. The conclusions of the work are drawn and highlighting the major findings with their significance. In addition to this, the limitations of the present study are also discussed and outlined the scope for future work.

5.2. Limitations of the Present Work and Scope for Further Studies

In the present thesis, increases the RF energy, growth rate, gain and efficiency of the FEL amplifiers are the main goals of this work. The dealing with the fundamental theory, analytical formalism, description of the device design methodology and PIC simulation was the prime state of art work towards the research. The limitations of excessive energy spread and excessive emittance have severely suppressed amplifiers gain. The disadvantage of FEL amplifiers is the cost and complexity. Since the particle accelerator has more complexity as well as higher cost association, due to this, mainly the FEL amplifiers are used as oriented, and the future scope and their extensions are as:

i. It is used for EM spectrum as the soft and hard X-ray or far infrared (FIR) region.

ii. It is used where atomic or molecular lasers are not available due to the tenability limited power.

iii. It is used for high-efficiency and large average power.

iv. The DC magnetic field positive and negative both end tapering may be affects the strengths of the FEL amplifiers through coupling with the pondermotive potential. The axial field makes possible an additional instability which is play an important role in the amplifiers.

v. Wiggler DC magnetic fields positive and negative both end tapering is gradually decreasing the amplitude of the wiggler field due to decreasing the electron wiggler velocity i.e., decrease the phase velocity of the pondermotive wave after the electrons are trapped by the spatially decreasing the wiggler wavelength. Hence it is make the possibilities to enhance the performance of the device.

vi. The efficiency of the FEL amplifiers operation is quite sensitive to spreads in the electron beams velocity. Therefore, spreads in the energy is obviously remove some of the electrons from the resonance. Using depressed collector its spreading is controlled for the performance improvement of the amplifiers.