Nonlinear Analysis of Beam-Wave Interaction in THz Planar TWTs

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Compact vacuum microelectronic devices (VMDs) are being investigated for efficient high power generation and amplification of terahertz (THz) frequencies (0.1THz - 3THz) for many new emerging applications including ultra broadband communication, security and medical imaging. These devices are extremely complex and their operations are based on the efficient interaction of the relativistic electron beam with the radiofrequency (RF) circuit field in such a manner that maximum energy from the electron beam can be transferred to the RF circuit field. Among various vacuum microelectronic devices, travelling wave tubes (TWTs) are most preferred for communication and radar because of their wide instantaneous bandwidth and high gain. Planar structure of RF circuit with rectangular/elliptical shape electron beam is used for a THz TWT because of small size of RF structure at THz frequencies.

SUNRAY-1D and SUNRAY-2.5D codes are developed for one- and 2.5-dimensional large signal (nonlinear) analysis of beam-wave interaction in TWTs with cylindrical electron beam and axi-symmetric RF structure. The basic approach used in a large-signal analysis is to represent one RF wavelength of the electron beam by representative charged particles and to track these particles in small steps of forward integration along the tube under the influence of the RF circuit field, the space charge field and the magnetic field. The mutual beam-wave coupling variables, namely the RF current induced on the electron beam by the RF circuit field and the RF voltage induced onto the RF circuit by the modulated electron beam, are calculated at each step of forward integration along the tube. Both the Predictor-Corrector method and the Runga-Kutta Method of forward integration are used for numerical solving of the relativistic Lorentz Force equations of the representative particles. Also, both the time-step and the distance-step methods are explored for tracking of representative particles along the tube accurately and efficiently. Efficient use of look-up table is developed for fast calculation of space charge force on each representative particle during its tracking along the tube. At each step of forward integration of representative particles, energy balance calculation is made to check numerical accuracy of the code. The energy balance factor is achieved (1.0±0.01) under different operating conditions signifying high numerical accuracy of the code. The codes are very fast to provide detailed information about the interaction of the electron beam with the RF circuit field, and can interactively be used to design an efficient TWT of desired RF performance. Algorithm for parallel-processing is also being developed for fast analysis of beam-wave interaction in a TWT under multi-signal operation.

Indigenously developed SUNRAY codes are improved for fast and accurate simulation of planar TWTs with sheet electron beam for their operation at THz frequencies. The results simulated by SUNRAY codes on output power and gain of different THz TWTs are compared with the commercially available 3D e.m. simulator code (CST-PS), and good agreements between these results are obtained.

Index Terms— Large-Signal (nonlinear) Analysis, Beam-wave interaction, THz vacuum Amplifier, THz Sheet-beam TWT, Vacuum Microelectronic Devices.