Theory and Simulation of The Interaction Between Periodic Multi-Transmission Lines with a Degenerate Band Edge and Electron Beams

Mohamed A. K. Othman, Mehdi Veysi, and Filippo Capolino*
Department of Electrical Engineering and Computer Science
University of California Irvine, Irvine, CA, 92697
*f.capolino@uci.edu

The interaction between a slow-wave structure (SWS) and an electron beam has been investigated by Pierce (J. R. Pierce, Bell System Technical Journal 29(3) 390-460, 1950) and several other contemporaries, leading to amplification regimes for traveling wave tubes. Slow-wave structures can be designed using homogenous or periodic waveguide structures to achieve synchronous phase velocity to the electron beam, and desirable interaction impedance. A multi-transmission line (MTL) model of homogenous SWSs has been investigated in (A. Tamma and F. Capolino, IEEE Trans. Plasma Sci. 2(4) 899-910, 2014), which accurately models wave propagating and amplification inside MTL-electron beam coupled system. Here we demonstrate a new regime of amplification for traveling wave tubes based on synchronizing the degenerate band edge in the dispersion diagram of periodic structures with the electron beam. A degenerate band edge (DBE) is a photonic band edge condition that is manifested in periodic waveguide structures supporting two modes or more, and results in a very dramatic reduction in group velocity (A. Figotin and I. Vitebskiy, Phys. Rev. E 72(3), 036619, 2005). We show that the interaction between an electron beam and SWS working at the DBE can produce simultaneous amplification in more than one propagating mode, unlike the case with uniform MTL-beam interaction where solely one mode can be amplified (M. Othman et al., arXiv:1411.1046, 2014). We develop a theoretical framework for such an unconventional interaction in both time and frequency domain, using a periodic MTL approach with the help of Floquet theorem. A MTL-electron beam finite-difference time-domain (FDTD) algorithm is also developed to show the advantages of utilizing a DBE in a traveling wave tube, where we demonstrate the required conditions for amplification and oscillation. Various considerations are taken into account, such as losses, space-charge effects in the electron beam, and loading effects. Theory developed here may have a major impact on the enhancement of the efficiency, gain, and overall performance of traveling wave tubes for high power microwave generation.