Design of a Metamaterial-Based Backward-Wave Oscillator

Jason Samuel Hummelt, *Student Member, IEEE*, Samantha M. Lewis, Michael A. Shapiro, *Member, IEEE*, and Richard J. Temkin, *Fellow, IEEE*

***Abstract*— In this paper, we present the design of a microwave generator using metamaterials (MTMs) in a negative index waveguide interacting with a high-power electron beam. The microwave structure is formed by inserting two MTM plates loaded with complementary split-ring-resonators (CSRRs) into a rectangular waveguide. Electromagnetic simulations using the high-frequency structure simulator code confirm the presence of a negative index TM-like mode suitable for use in a backward-wave oscillator (BWO). Particle-in-cell (PIC) simulations using the computer simulation technology (CST) Particle Studio code are performed to evaluate the efficiency of an S-Band MTM-based BWO (MTMBWO) excited by a 500 keV, 80-A electron beam. After about 250 ns, the MTMBWO reaches a saturated output power of 5.75 MW with an efficiency of 14% at a frequency near 2.6 GHz. The MTMBWO is also modeled by representing the MTM plates, which consist of CSRRs, as dielectric slabs whose effective permittivity is given by a Lorentzian model. The dielectric slab model is also simulated with the CST PIC code and shows good qualitative agreement with the simulations including the CSRR loaded plates. A cold test structure was fabricated from brass to test the theoretical predictions of the microwave transmission versus frequency of the negative index waveguide. Test results using a vector network analyzer showed very good agreement with the simulations for the excitation of the negative index TM-like mode near 2.6 GHz. The proposed structure appears to be promising for use in a MTMBWO high-power microwave generator.**

***Index Terms*— Backward-wave oscillator (BWO), metamaterial (MTM), plasma waves, vacuum electronics.**