Modeling of the interaction of a volumetric metallic metamaterial structure with a relativistic electron beam

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We present the design of a volumetric metamaterial (MTM) structure and its interaction with a relativistic electron beam. This novel structure has promising applications in particle beam diagnostics, acceleration, and microwave generation. The volumetric MTM has a cubic unit cell allowing structures of arbitrary size to be configured as an array of identical cells. This structure allows the exploration of the properties of a metamaterial structure without having to consider substrates or other supporting elements. The dispersion characteristics of the unit cell are obtained using eigenmode simulations in the HFSS code and also using an effective medium theory with spatial dispersion. Good agreement is obtained between these two approaches. The lowest-order mode of the MTM structure is found to have a negative group velocity in all directions of propagation. The frequency spectrum of the radiation from a relativistic electron beam passing through the MTM structure is calculated analytically and also calculated with the CST code, with very good agreement. The radiation pattern from the relativistic electron beam is found to be backward Cherenkov radiation, which is a promising tool for particle diagnostics. Calculations are also presented for the application of a MTM-based wakefield accelerator as a possible all-metal replacement for the conventional dielectric wakefield structure. The proposed structure may also be useful for MTM-based vacuum electron devices for microwave generation and amplification.