Space-Time Engineered Metamaterials: Computational Electromagnetic Analysis and Design using Time-varying Transmission Lines

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Space-time engineered metamaterials (STEMs) are structures whose constitutive parameters modulate in space and time. Usually, the notion of time-invariant media properties leads to numerous fundamental boundaries, which can be overcome by temporal and spatial variation of bulk constituent parameters (e.g., permittivity (ε), permeability (μ), or conductivity (σ)) [1-3]. STEMs hold a plethora of unexplored physical phenomena. Instances of physics discovered recently include generalized space-time crystallography, space-time mirroring and focusing, chromatic birefringence, and inverse prism transformation. The study of metamaterials, and STEMs, require modelling space and time-dependent material properties, but popular EM solvers like CST Microwave Studio, COMSOL Multiphysics, Keysight ADS and Ansys HFSS offer no flexibility in modelling negative/time-varying media properties, anisotropy and time-varying circuit elements. Practical metamaterial systems involve objects with complex shapes and material properties (ε, μ, σ) with frequency dispersion, where the time modulation can be arbitrarily regulated. Therefore, there is a need to develop techniques to model STEMs. We have attempted to address the above limitations by employing analytical formulations and computational methods and creatively using existing CAD tools. We analyzed the effects on the EM waves propagating in a dielectric slab undergoing temporal variation of the permittivity (μ) using 1D-FDTD and analytical formulation. A frequency translation of sine-modulated Gaussian pulse is exhibited for different source frequencies [4]. The realization of STEMs proposes a significant challenge. A circuit-based approach to model STEMs can help realize them with existing fabrication technology. We have proposed the use of time-varying transmission lines (TVTLs) to realize STEMs as TVTLs offer time-varying capacitance, i.e., the time-varying permittivity of the media, and this concept can be extended to include spatial variation to realize STEMs. We modelled a transmission line loaded with time-varying capacitors in shunt [5] and in series [6] to test the concept using the FDTD technique. The capacitance is varied as a function of time, switching between two states achieving modulation of the signal propagating in the transmission line with the switching signal, acting as a mixer [5]. In addition, a new alternative approach using the new RF Blockset Library of Simulink to model STEMs is introduced in [6]. The future work includes the fabrication and testing of STEM-based mixers proposed in [5-6] using TVTLs on either printed circuit board (PCB) or monolithic microwave integrated circuit (MMIC) technology.

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