Roles of Epsilon-Near-Zero (ENZ) and Mu-Near-Zero (MNZ) Materials in Optical Metatronic Circuit Networks

Fereshteh Abbasi* and Nader Engheta
Department of Electrical and Systems Engineering, University of Pennsylvania,
Philadelphia, PA, 19104

The notion of circuits is a very powerful tool in analysis and design of networks in microelectronics. This notion is based on defining individual circuit elements, deeply subwavelength isolated entities that may be described by their voltage-current characteristics that depends only on geometry and materials used in these elements. Consequently, in conventional electronic circuits the voltage-current characteristics of an ensemble of these elements can be written as a combination of individual elements. As a result of such modularity, huge flexibility is offered in design of electronic circuits. Developing a similar notion of circuitry in optical frequencies also extends such flexibility to those frequency regimes. In (N. Engheta et al., Phys. Rev. Lett., 95, 095504; N. Engheta, Science, 317, 1698-1702) the concept of metamaterial inspired nanocircuits, dubbed "metatronics", was introduced. It was suggested how optical lumped elements (nanoelements) can be made using subwavelength plasmonic or non-plasmonic particles. As a result, the optical metatronic equivalence of a number of electronic circuits, such as frequency mixers and filters, was suggested (U. Chettiar and N. Engheta, Phys. Rev. B, 86, 075405; A. Alu et al., Phys. Rev. B, 77, 144107). In this work we further expand the concept of electronic filters into optical metatronic circuit two-port networks and suggest a conceptual model for fundamental metatronic configurations in such two-port structures, as well as employing them in various metatronic filters networks. In particular, we differentiate between the series and parallel networks using epsilon-near-zero(ENZ) and mu-near-zero(MNZ) materials. We employ layered structures with subwavelength thicknesses for the nanoelements as the building blocks of metatronic networks. Furthermore, we explore how by choosing the non-zero constitutive parameters of the materials with specific dispersions, either Drude or Lorentzian dispersion with suitable parameters, the series or parallel configurations in the layered stacked two-port networks can be modeled. Next we proceed with the one-to-one analogy between electronic circuits and optical metatronic filter layered networks and justify our analogies by comparing the frequency response of the two paradigms. In order to analytically predict the response of more complex metatronic filter networks, we show that methods commonly used in microwave networks can provide a good approximation. To further improve these approximations, we embed extra "insulating" layers between the nanoelements. Finally, we take into consideration the material dispersion of near-zero relative permittivity and permeability as well as other physically important material considerations such as losses.