Epsilon-and-mu-near-zero (EMNZ) Structures

Ahmed M. Mahmoud*, Nader Engheta
Department of Electrical and System Engineering, University of Pennsylvania, Philadelphia, PA, 19104

Throughout the last decade, there has been extensive research in the field of metamaterials that are artificial structures exhibiting unusual electromagnetic properties in wave-matter interaction not readily available in nature (Y. Liu and X. Zhang, Chem. Soc. Rev. 40, 2494; N.I. Zheludev, and Y.S. Kivshar, Nat. Mater. 11, 917–924). More recently there has been a great interest in materials with the near-zero parameters. This is the category of metamaterials whose relative permittivity, and (or) permeability are designed to be near zero (M. Silveirinha and N. Engheta, Phys. Rev. Lett., 97 (15), 157403; N. Engheta, Science, 340(6130), 286-287). The uniqueness of such media basically lies in having a low wave number as a consequence of the near zero refractive index, which leads to a relatively small phase variation over physically large volume of such media. In the present work, we investigate some of the unprecedented features that are exhibited within epsilon-and-mu near-zero (EMNZ) media, i.e., structures with both the relative permittivity and permeability near zero. In particular, we show that using an EMNZ medium one might in principle “open up” and “stretch” the space, and have regions behaving as “single electromagnetic point” despite conventionally being electrically large. This offers a platform in which some interesting physical concepts can be explored and investigated. We demonstrate analytically and numerically that we can achieve electromagnetic invisibility of arbitrarily-shaped, electrically large, perfectly electric conducting objects when embedded in an EMNZ medium owing to the unusual scattering properties within an EMNZ medium. Moreover, we investigate some of the unusual effects that accompany placing classically radiating elements within an EMNZ region due to the unique phenomenon of uniform phase distribution within an EMNZ region. This will open doors to manipulating and engineering the radiation performance of more complicated systems like quantum emitters offering environments within which quantum effects including (among others) super-radiance and coherence might be taken beyond conventionally known limits (R. Fleury and A. Alu, Phys. Rev. B., 87(20), 201101). We suggest two possible implementations of structures that would exhibit an EMNZ behavior and demonstrate the possibility of having arbitrarily shaped electrically large regions to behave as EMNZ media, by having a host medium with ENZ behavior (a dielectric medium near its plasma frequency in the optical regime or a large parallel-plate metallic waveguide section near its cut-off) and loading it by properly designed dielectric inclusions. We finally verify the ability of those structures to exhibit some of the aforementioned phenomena that takes place in a hypothetical EMNZ medium.