Squeezing and Tunneling of Waves through Sub-Wavelength Waveguide Bends and Discontinuities Using Epsilon-Near-Zero (ENZ) Metamaterials

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The advent of metamaterials opened many new possibilities in different fields of physics and engineering. These artificial materials may consist of electrically small inclusions embedded in a host matrix, and can be designed in such a way that their electromagnetic properties, such as effective permittivity or permeability, meet desired specifications. This possibility is obviously very exciting, because it means that new classes of materials with unusual properties (sometimes not directly available from nature), can be synthesized and used in several components. In recent years, it has been shown that metamaterials may allow for the miniaturization of some devices (e.g., N. Engheta, *IEEE Antennas and Wireless Propagation Letters*, Vol. 1, pp. 10-13, 2002) and also subwavelength focusing (J. Pendry, *Phys. Rev. Lett.*, Vol. 85, pp. 3966-3969, 2000), just to mention a few possibilities.

So far, most of the research on metamaterials has been focused in the design of double-negative (DNG) materials, which have both permittivity and permeability simultaneously negative. In this talk, we will discuss instead the properties and physics of non-magnetic metamaterials with relative effective epsilon-ε near zero (ENZ). It has been shown before that zero-index matched materials (R. W. Ziolkowski, *Phys. Rev. E*, 70, 046608 2004) can be used in delay lines and to make radiation elements very directive. Also, in a previous work (N. Engheta, M. Silveirinha, A. Alù and A. Salandrino, *ICEAA'05*, Torino, Italy, Sept. 12-16, 2005, pp. 101-104), we discussed the role of these materials in achieving low scattering and transparency and improving the transmission through waveguide bends.

In this talk, we will prove that electromagnetic waves can be "squeezed" and tunnel through very narrow sub-wavelength channels or bends filled with ENZ materials. We will show that the incoming wave front is replicated at the output interface, independently of the specific geometry of the sub-wavelength channel. It will be shown that in some configurations the isotropy of the ENZ metamaterial may not be an issue, and that anisotropic metamaterials can be used instead. Several design examples using an ENZ-"wire medium" will be presented.