Dispersion Properties of Volumetric Optical Nanotransmission-Line Metamaterials with Negative Refraction

Andrea Alù[1,2], and Nader Engheta[1]*
[1]Dept. of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, PA, USA, engheta@ee.upenn.edu
[2]Dept. of Applied Electronics, University of Roma Tre, Rome, Italy, alu@uniroma3.it

The interest in extending the metamaterial concepts into the visible regime is currently of great interest in the physics and engineering communities. In particular, the exciting properties that left-handed or double-negative (DNG) metamaterials have shown at microwave frequencies, and in particular the possibility of resolving the sub-wavelength details of an image or of guiding the information beyond the limits of diffraction, are attracting a great deal of attention in the technical literature. Two different approaches have been generally employed by various groups to build a DNG at microwaves: on the one hand, embedding resonant sub-wavelength inclusions in a dielectric lattice, providing in this way the separate electric and magnetic resonances at the same frequency that ensure the desired double-negative behavior; and on the other hand, the transmission-line (TL) approach of loading striplines, microstrips or other guiding structures with proper inductances and capacitances to provide the backward propagation and left-handed behavior for the resulting TL. This second approach ensures larger bandwidth and robustness to the presence of losses and imperfection, since instead of relying on isolated resonances of sub-wavelength inclusions, which are necessarily related to high Q factors, it rather works through the broad-band resonance of a whole cascade of TL-like unit cells.

1-D and 2-D realization of TL left-handed metamaterials at microwave frequencies is well established in the literature, and extension to 3-D setups has been recently proposed by Eleftheriades and his group as a novel way of building bulk left-handed metamaterials at microwave frequencies (A. Grbic, and G. V. Eleftheriades, *J. Appl. Phys*., 98, 043106, 2005).

In a different context, our group has recently shown how the use of plasmonic particles may help to extend the circuit concepts of lumped inductors and capacitors into the high frequencies (infrared and visible regime) where such elements are not readily available, due to the lack of conducting materials (N. Engheta, A. Salandrino, A. Alù, *Phys. Rev. Lett.* 95, 095504, 2005). Applying these concepts to the TL metamaterials may provide a novel route to synthesize 1-D, 2-D and 3-D right- and left-handed TL metamaterials at optical frequencies, translating the established concepts of sub-wavelength imaging and sub-diffraction waveguiding into these high frequencies (A. Alù and N. Engheta, "Optical Nanotransmission Lines: Synthesis of Planar Left-Handed Metamaterials in the Infrared and Visible Regimes," *J. Opt. Soc. Am. B*, March 2006, in press). In this talk, we theoretically analyze in particular how a regular lattice of properly arranged and tightly packed plasmonic and/or non-plasmonic nano-particles may support forward or backward propagation in three dimensions, effectively extending the TL metamaterial concepts to the infrared and optical frequencies where noble metals or polar dielectrics may naturally provide the required electromagnetic properties for synthesizing such nano-TL networks. Dispersion properties of such volumetric structures are also studied and are discussed in detail.