Theoretical and Experimental Characterization of Focusing in Periodically Loaded Transmission Line Negative Refractive Index Metamaterials

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We have previously shown that a new class of Negative Refractive Index Metamaterials (NRIMs) can be constructed by periodically loading a host transmission line medium with inductors and capacitors in a dual (high-pass) configuration. A 55mm×30mm planar NRIM lens interfaced with a parallel-plate waveguide recently succeeded in experimentally demonstrating focusing of cylindrical waves[1].

In this paper, we present theoretical, simulation, and experimental data describing the focusing and dispersion characteristics of a larger device consisting of a 105mm×200mm NRIM lens interfaced with a 105mm×100mm Positive-Refractive-Index Medium (PRIM), the latter of which is constructed using an unloaded microstrip grid. This new prototype offers significant improvements over the smaller structure originally used to verify focusing; specifically, the edge effects are minimized to more clearly observe the attributes of the focal region; the increased size of the NRIM region permits a closer observation of the spatial evolution of phase and therefore the extraction of more precise dispersion information; and the use of a microstrip grid instead of a parallel-plate waveguide enables the direct measurement of the transmission from the source to the focal region through proximity coupling.

In order to compare the new experimental results with theory, we employ a technique based on the plane wave expansion of cylindrical waves to examine a homogeneous PRIM/NRIM interface excited by an infinitesimal line source oriented vertically to the device plane; this is equivalent to determining the corresponding Green's function. This theory is verified by full-wave electromagnetic simulations conducted on a microstrip implementation of the same structure excited by a shorted vertical dipole source. Supporting experimental data is then presented, revealing vertical electric field distributions consistent with the focusing of cylindrical waves. In particular, the fields at the focal plane exhibit a transmission of nearly unity with respect to the source at 1.8GHz, the frequency at which the theory predicts a relative refractive index of –1. The dispersion characteristic of the NRIM is obtained from the experimental data using the average phase shift incurred per unit cell (βd), and depicts an extremely broadband region spanning approximately 1.5GHz over which the refractive index remains negative. These results are in excellent correspondence with the dispersion characteristics predicted by standard periodic analysis.

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[1] G. V. Eleftheriades, A. K. Iyer, P. C. Kremer, "Planar negative refractive index media using periodically L-C loaded transmission lines," *IEEE Trans. on Microwave Theory and Tech.*, vol. 50, no. 12, pp. 2702-2712, Dec. 2002.