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Negative Refraction from Metamaterial Unit Cells Predicted from the Standpoint of Array Theory

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Negative refraction from periodic structures has been observed in both physical experiments and numerical computations. For example, it has been shown that a composite medium of wires and split metal loops would presents an effective negative index of refraction to waves of the appropriate polarization [1, 2]. The original experiment demonstrating negative refraction was performed in the year 2000 where the measured refracted beam from a triangular prism constructed of unit cells arranged into a staircased prism was indeed in the negative direction.

Many researchers compute effective medium properties from the induced average polarization and magnetization responses of the unit cells. Such an analysis of a dipolar-effective medium treatment predicts negative indices of refraction that are consistent with full-wave electromagnetic computations.

In contrast to these approaches, we develop a predictive model for negative refraction in triangular prisms based on finite array theory independent of an appropriate effective medium description. The model emphasizes the importance of a single property of the underlying unit cell of the periodic medium: the excess phase delay imparted by the unit cell on a wave during transmission across the cell, compared to the phase delay across an equal distance of free space. It is then possible to develop an equivalent linear array of aperture radiators. The main transmitted beam of the projected equivalent aperture array is shown to be equivalent to the main beam transmitted through the prism using simulations.

Using our model, the agreement is excellent over the range of frequencies where the prism allows for beam transmission without appreciable reflections. The success of this model in predicting the occurrence of negative refraction suggests that, in fact, one need only select a unit cell with the correct phase delay to produce negative refraction.

1. R. A. Shelby, D. R. Smith and S. Schultz, "Experimental Verification of a Negative Index of Refraction, : Science, vol. 292, pp. 77-79, April 2001.

2. D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser and S. Schultz, "Composite Medium with Simultaneously Negative Permeability and Permittivity," Physical Review Letters, vol. 84. No. 18, pp. 4184-4187, 2000.