Single Negative Metamaterials take on Negative Indices owing to Multiple Scattering: Demonstration with an Acoustic Super-lens

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Abstract— We evidence that single negative metamaterials can turn into double negative ones, hence leading to a negative band solely by breaking the symmetry. We explain this phenomenon from multiple scattering effects and give an analogy with the phonon optical branch. We experimentally demonstrate a negative index acoustic super-lens using a soda can hexagonal array with a focal spot 15 times smaller than the wavelength.

Media presenting negative indices of refraction were first considered theoretically by Veselago in the 60’s [1]. They have recently become a very attractive field of research since they theoretically offer the compelling possibility of designing flat super-lenses that can beat the diffraction limit, as suggested by Pendry [2]. This negative refraction can be achieved using metamaterials presenting simultaneously two negative effective properties (permittivity and permeability in electromagnetics or modulus and mass density in acoustics). From a practical point of view, this requires to combine two single negative locally resonant meta-atoms, each bringing one of the negative properties. On the other hand, it was highlighted that the negative refraction may also occur from the superposition of a monopolar and a dipolar resonance of a single acoustic Mie scatterer [3]. In this work, we show analytically and numerically, that, contrarily to previous ideas, double negative media can be created from a single negative metamaterial, that is a metamaterial having a single resonant atom. We chose to work with an acoustic metamaterial made out of soda cans as Helmholtz resonators. We start from a periodic one dimensional medium, for which the elementary cell, of deeply subwavelength dimension, is composed of a single acoustic resonator and whose dispersion relation is polaritonic (Fig.1a). By slightly breaking this medium’s symmetry, thus creating a bi-periodic medium (Fig.1b), we evidence the creation of a negative band in the bandgap of the original medium. We prove that this can be explained only by considering the multiple scattering within the unit cell, which allows the rise of a dipolar mode otherwise inexistent. An analogy with the phonon optical branch will be provided. We then experimentally demonstrate a negative index acoustic super-lens for a frequency within the negative band of an hexagonal array of soda cans, that focus sound on a $\lambda_0/15$ focal spot behind the lens, in the vicinity of the output surface.

Figure 1: (a-b) Simulated dispersion relation of a periodic triangular (resp. biperiodic hexagonal) array of soda cans in the $\Gamma - M$ direction and schematic of the simulated medium. (c-e) Experimental results of super-lensing.
This new approach of a double negative medium from symmetry broken metamaterials stresses the importance of multiple scattering at subwavelength scales that is generally considered unimportant, as metamaterials are considered as effective media. We believe this work simplifies the design of negative index materials and paves the way to the design of new and exotic metamaterials.

REFERENCES