Locally resonant acoustic metamaterials beyond homogenization: subwavelength control of waves, slow waves, negative index and other exotic phenomena

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Abstract
Starting from the very simple example of a soda can metamaterial (an acoustic medium made of Helmholtz resonators), we explain the propagation of waves in locally resonant media without claiming homogenized parameters. This allows to highlight the importance of multiple scattering even at this deep subwavelength scale where usually the quasi-static approximation is performed. This then permits to envisage exotic phenomena such as subwavelength control of waves, slow waves or even negative refraction with a single negative medium.

Keywords: acoustics, metamaterial, negative refraction, slow wave.

In this talk, we show how going beyond the homogenization paradigm usually introduced in the context of locally resonant metamaterials permits to enrich the physics associated with them in a drastic way. Starting from the very simple example of a soda can metamaterial in acoustics and the wire medium microwaves (Figure 1), we first underline that their physics can be entirely understood at the light of polaritons in solid state physics. We show, using a microscopic approach based on the transfer matrix that the metamaterials properties are strictly governed by interferences and propagation effects [1]. Namely, the physics of the system solely depend on Fano interferences between the scattered and the unscattered, and multiple scattering of waves between the unit cells of the metamaterial.

a)

b)

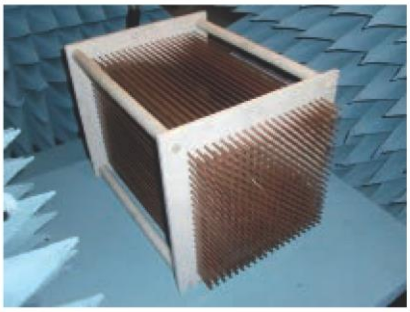

Figure 1 – Two examples of locally resonant metamaterials: (a) an acoustic example based on Helmholtz resonators (the soda cans), and (b) a microwave one based on half-wavelength-long copper wires.

We then demonstrate how this observation allows one to tailor this kind of composite media at the scale of the unit cell, hence going much further than the homogenization approximation. Specifically, we show how this allows one to design various components such as cavities, waveguides, filters, that present deep subwavelength dimensions, much smaller than that of their phononic crystal counterparts [1]. We discuss the possibility to slow down waves drastically using this kind of components, through a comparison with recent microwave experiments [2].

Starting again from our microscopic approach of locally resonant metamaterials, we show how it can underline new effects that are totally hidden by other ones. In particular, we explain how a single negative metamaterial can be turned on a double negative medium thanks to multiple scattering, provided that it is rightly structured [3].

Finally, to conclude, we present a few exotic ideas that are direct consequences of the previous results and of a relatively new understanding of the physics of locally resonant metamaterials. For instance, we show how a 2D soda can metamaterials can be turned into a sheet of "acoustic graphene" whose Dirac cone can be positioned at will within a given frequency range.

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