Acoustic Metamaterial Lens And Simulation-Based "Meta-Library"

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Abstract

Metamaterials are composites of subwavelength structures that can be engineered to affect the propagation of a wave in specific ways as it travels through the material. While metamaterials can be used with any type of wave, they are most commonly found in electromagnetic waves. However, acoustic wave behavior in many ways mimics and resembles that of electromagnetic waves. This project takes the concepts used in the design of electromagnetic metamaterials and applies it to the less explored field of acoustics. Acoustics metamaterials offer a greater range of structural variation as they are not limited by a set geometry or material. This feature makes them ideal for applications where cosmetic appearances matter, such as soundproofing windows, walls, or cars. Specifically, this project focuses on creating a metamaterial lens, which focuses acoustic waves using a uniform thickness metamaterial. This lens has been explored for use in a variety of applications, including as a focuser of ultrasonic waves for non-contact and low-contamination medical debridement.

For this lens to function, the wave should accrue a sufficient phase shift to produce a spherical wavefront. We accomplish this by using subwavelength meta-cell inclusions that each provide a different phase shift, designed to accumulate the necessary phase versus position to replicate a convex/concave lens (Fig 1). By taking an optical approach to the lens design process, existing methods of metamaterial design can be used while also incorporating necessary modifications for acoustics. Meta-cells are designed by simulating an array of rectangular pillars using the COMSOL® Acoustics Module with the Acoustics-Structure Interaction interface with varying width and height (1 [mm] - 19 [mm]), while recording the transmitted acoustic power and the change in phase caused by the structure (Fig 2). The maximum dimensions of each meta-cell are 20 [mm] by 20 [mm]. This forms a "meta-library" (Fig 3), which is gathered at the design frequency of 1715 [Hz] (for a wavelength of 20 [cm].) These values are selected for ease of testing, and can be modified. From this meta-library, a relatively flat phase profile achieving shifts ranging from 0.15 - 1.55 [rad] with transmission between 16 - 100 [%]has been recovered. The flatness of the profile (i.e. non-resonant structures) allows for broadband operation of the acoustic metamaterial, but limits the overall phase shifts achievable. By exploiting natural resonant points in the meta-cell structure, an even wider range of phase shifts can be achieved. From this meta-library the individual phase shifts required to realize the design focal length of 1 [m] can be selected, and the final lens design simulated. The final lens will be 3D printed using PLA plastic.

Ultimately, the results verify the validity of using an optics approach to design an acoustic metamaterial. Acoustic metamaterials which can be flat, thin, light weight, and transparent can dramatically improve acoustic engineering where it is necessary to stack multiple acoustic elements. Furthermore, acoustic metamaterials do not need to be made from specific materials, and can instead be engineered with aesthetics in mind, allowing them to blend in with or enhance their operating environment.

Figures used in the abstract

Figure 1 : Fig 1: An ideal metamaterial lens focusing at a length of 1 [m]

Figure 2 : Fig 2: An example of meta-cell structure and wave interactions, where the width and height are varied

Figure 3 : Fig 3: The meta-cell’s phase shift [rad] based on inclusion width or height [cm]