Acoustic Metamaterial Lens and Simulation-Based “Meta-Library”

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INTRODUCTION: Metamaterials are materials which are engineered at the subwavelength scale to possess some desired affect on an incident wave. Acoustic metamaterials are more versatile than traditional structures as they are not limited by geometry. Acoustic focusing, absorption, and other desirable effects can be achieved without the usual geometric constraints. This makes metamaterials desirable for applications in venues where aesthetics are of importance. This project is an acoustic metamaterial lens.

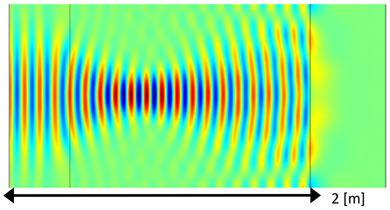

Figure 1. Ideal metamaterial focusing at approximately 1[m]

METHODS: The intensity pattern at the image plane of an acoustic lens is completely determined by the phase shift profile and transmissivity of the lens. The design approach is to simulate various meta-cells to see which geometries have desired phase shifts and high transmission. A hallway of air with a rectangular steel pillar is simulated to find resonant frequencies (Figure 2). Steel is chosen because its material properties are well documented.

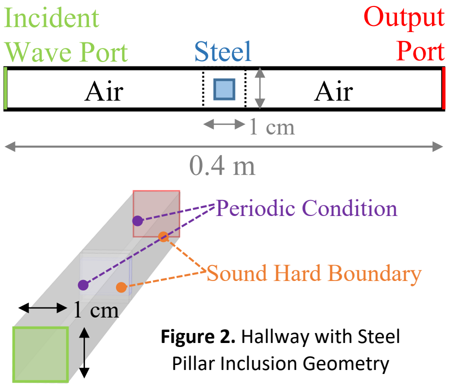

Figure 2. Hallway with Steel Pillar Inclusion Geometry

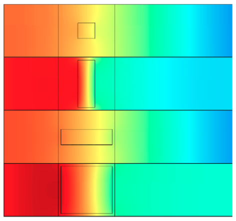

Figure 3. Example Cross Sections of Pillar Geometry

We then simulate permutations of the rectangular geometry and measure the output phase-shift and transmission (See Figure 3). These values are compiled into a table of amplitude and phase change (or “meta-library”), for the associated rectangle geometry. Meta-cells are selected from the meta-library to produce a calculated discretize phase profile, and final lens design. The assembled metamaterial lens is simulated in COMSOL by injecting a plane wave to observe focusing.

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RESULTS: For the 0.7 cm by 0.7 cm pillar, the reflection and transmission are graphed against frequency. Transmission is at its maximum and reflection is at its minimum at the resonance frequency (~10,000 Hz, see Figure 4). Using this frequency the transmission and phase shift of a range of rectangular structures is determined, whose lengths and widths range from 0.05 cm to 0.95 cm, with 0.05 cm step sizes. The phase shift for each rectangular structure simulated is tabulated in Figure 5.

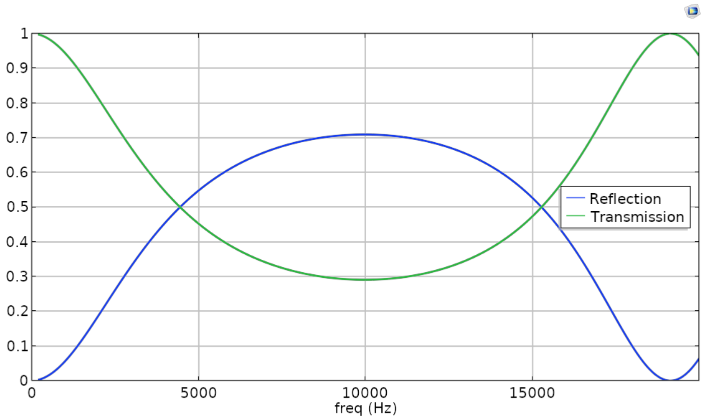

Figure 4. Reflection & Transmission vs Frequency for a 0.7 by 0.7 [cm] pillar

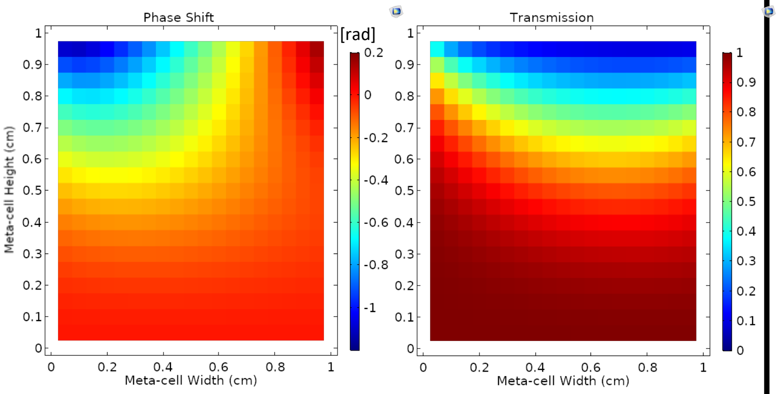

Figure 5. The Meta-cell’s Phase Shift [rad] and Transmission based on inclusion width or height [cm]

CONCLUSION: The results show a COMSOL-generated meta-library. We can select several meta-cells with different phase shifts that have the same transmission to construct our lens. For example, by choosing meta-cells along the yellow crescent in the Transmission graph, we can achieve roughly 1.4 radians of phase shift. Acoustic metamaterials can be constructed into a wide range of shapes, dimensions, and materials, making them useful for many potential applications. Acoustic metamaterials are specifically suited for applications where the cosmetics of the structure matter, such as concert halls or museums.

REFERENCES:

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2. V. M. Shalaev, et al., High-Efficiency All-Dielectric Metasurfaces for Ultracompact Beam Manipulation in Transmission Mode, Nano Letters, 15, 9, 6261–6266, 2015