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Acoustic Rainbows
Passive Shaping of Free Space Sound Emission

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Abstract

The optical rainbow is a well understood phenomenon which is easily reproducible on a macroscopic scale by guiding sunlight through a prism. The underlying mechanism of the rainbow is the dispersive nature of visible light as it is reflected and refracted through different media, such as water and glass. Sound-waves in the audible spectrum are however not subject to significant dispersion in most homogeneous media. Thus acoustic rainbows are not readily observable in nature. This work, meanwhile, demonstrates that it is possible to design devices, yielding a spectral separation of sound analogous to that of light seen in the optical rainbow.

This work presents a passive, single material device, tailored for controlling the free space emission pattern of an acoustic point source by angularly separating its frequency content across a $\pm 25\%$ frequency band around a central frequency, f_c. In addition other devices tailored to exhibit different emission patterns are presented demonstrating the versatility of the underlying design methodology. The characteristic dimensions of the presented devices are on the order of the wavelength, a region which is problematic when using traditional methods, such as ray tracing. Both numerical and experimental results are presented, demonstrating the real world feasibility of the proposed devices.

The device design has been carried out using the topology optimization based approach detailed in [1]. Here a 2D model problem is formulated in the frequency domain with the acoustics modelled using the Helmholtz equation. The design goal is to identify a distribution of solid material in a bounded region of space which creates a desired emission pattern into free space for a targeted frequency band. The design problem is formulated as an optimization problem where the objective function depends on the difference between a prescribed desired sound field and the solution to the model problem for a given material distribution. The Globally Convergent Method of Moving Asymptotes is used to perform the optimization [2].

References

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