

Spatial Sound Modulation: From Acoustic Vortices and Levitation to Quantal Metasurfaces.

Currently, if an acoustic field is required for a given application, then either a purpose-built acoustic lens or an array of phase controllable sources is required. Lenses are bulky, perform a fixed operation and cause high insertion losses, and so they have not seen much use in practice. Phased arrays are a collection of elements that emit or receive with specific phases or time delays. They are in widespread use in radar, sonar, and ultrasonic imaging since they can dynamically change the direction or shape of the beam. At present, the phase delays are programmable and achieved using bespoke electronics, but when these systems were first developed the delays were static and introduced with passive elements. Inspired by these early passive delay lines, we developed sound modulating devices that can produce any acoustic field on-demand. Using a process of analogue-to-digital conversion and wavelet decomposition, we introduce the notion of quantal meta-surfaces. The quanta here are small, pre-manufactured 3D units – which we call metamaterial bricks – each encoding a specific phase delay. We apply this methodology to show experimental examples of acoustic focusing, steering and, after stacking single meta-surfaces into layers, the more complex field of an acoustic tractor beam. We demonstrate single-sided air-borne acoustic levitation using meta-layers at various bit-rates: from a 4-bit uniform to 3-bit non-uniform quantization in phase. We also show devices where the phase-shifting unit cells are not limited to the size of the wavelength, review a method for trapping Mie particles using acoustic virtual vortices with tuneable orbital angular momentum, and give an outlook for promising future directions and potential practical applications.