Design strategies for amplitude and phase acoustic holograms in biomedical ultrasound

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Abstract: We present several topologies for phase-and-amplitude acoustic holograms based on metamaterial and phononic crystals. These approaches go beyond traditional phase holograms and produce sharper acoustic images for non-invasive and localized preclinical and clinical therapeutical applications like neuromodulation, drug delivery or surgery, or biomedical ultrasound imaging. Several application examples are provided.

Passive acoustic structures like metamaterials can be used to engineer wavefronts in many practical applications. By tuning its topology, the local refraction, scattering or inner resonances can be tailored for a particular functionality. Among them, acoustic holograms are emerging as a low-cost technology to focus therapeutic ultrasound beams [1-8]. These high-performance lenses can produce therapeutic acoustic images of arbitrary shape into biological tissues. In addition, by exploiting time-reversal symmetry of the wave equation acoustic holograms can encode complex wavefronts compensating the aberrations of stiff layers, enabling the focusing of ultrasound into the human brain. However, usually acoustic holograms are only designed to encode the phase of the beam, neglecting the amplitude information of the time-reversed wavefront. In addition, most of the design strategies for sound waves in air are not suitable for biomedical ultrasound applications, which are generally water-coupled.

In this work, we propose metasurfaces with internal resonances to encode the full-wave information in a 3D-printed structured material. In particular, we report the use of metasurfaces to synthesize wavefronts by tuning subwavelength 3D-printed elastic resonators for ultrasonic frequencies, as shown in Fig. 1. These structures are shown to be remarkably flexible for spatially-coding arbitrary phase-conjugated fields corresponding to the ones used for selected biomedical ultrasound applications.

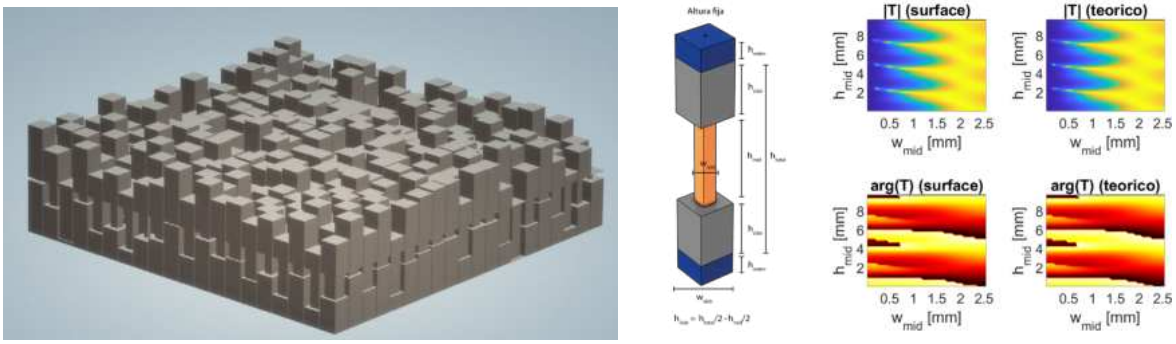


Figure 1. Topology of an acoustic hologram using a metamaterial as a building block. Phase and magnitude can be controlled locally to generate accurate acoustic images.

Then, by mimicking phase-and-amplitude information, these lenses can synthesize complex and arbitrary acoustic images with great accuracy. In this way, by tuning the hologram inner structure, we can synthesize

high-intensity acoustic images with unprecedent resolution, which are currently being applied to focus therapeutic ultrasound beams and treat several diseases in a non-invasive, non-ionizing, localized and low-cost manner. This approach improves the targeting of ultrasound and paves the road for low-cost biomedical ultrasound applications.

We acknowledge financial support from Ministerio Español de Ciencia e Innovación and the Ministerio de Universidades Grants “Ramón y Cajal” RYC2021-034920-I, and FPU19/00601, Agencia Estatal de Investigación PID2022-142719OB-C21 and CNS2023-145707 funded by MCIN/AEI/10.13039/501100011033 and to the Agencia Valenciana de la Innovació through grants INNVA1/2022/37, INNVA2/2022/11 and METASMART project INNEST/2022/345, and by Generalitat Valenciana through the programs Programa de Garantía Juvenil I+D EDGJID/2021/189, CIAICO/2023/052, and the program Equipamiento e Infraestructuras FEDER 2021-22 IDIFEDER/2021/004.

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