Ultrasonic Hologram for Bi-directional Diffusion by Phase Controlling the Scattering Coefficients

E. Ballestero[1], J. Rodríguez-Sendra[2], J.-P. Groby[1], N. Jiménez[2] and V. Romero-García[3*]

[1]Laboratoire d'Acoustique de l'Université du Mans, LAUM - UMR 6613 CNRS, Le Mans Université, France
[2]Instituto de Instrumentación para Imagen Molecular, Consejo Superior de Investigaciones Científicas (CSIC), Universitat Politècnica de València, València, Spain.
[3]Instituto Universitario de Matemática Pura y Aplicada (IUMPA), Departamento de Matemática Aplicada, Universitat Politècnica de València, València, Spain.
[*]corresponding author: virogar1@mat.upv.es

Abstract: We report an ultrasonic hologram based on Quadratic Residue sequences encoded with resonant building blocks behaving as an ideal Lambertian scatterer from both sides, with spatial autocorrelation coefficients $\delta \approx 0.7$ each one, therefore diffusing waves in both transmission and reflection.

In this work, we present a bi-directional asymmetric ultrasonic hologram that can simultaneously control both the reflected and transmitted wave-fields. To do that we design a surface made of a discrete spatial distribution of monolithic elements with different properties than the surrounding medium. This allows to compress two identical or different wavefield scattering patterns (for transmission and reflection) into a single monolithic object. Depending on the applications, such hologram could be useful in situations where transmitted and reflected wavefields need to be controlled at the same time, such as a bi-directional diffusing system emitting and receiving equally in and from all directions (equivalent of perfect optical diffusers in optics [1]) or as a bi-directional beam directivity selector, e.g., focusing/collimating/decollimating beam switch. Such hologram could also be used directly in reflection situations for minimizing unwanted specular reflections, e.g., reflections from surgical instruments during ultrasound-guided medical procedures [2].

We consider the building block is made of a monolithic polymer block of length l surrounded by two water blocks of length d_1 and d_2 respectively (see Fig. 1(a)). The sound pressures, p, and normal particle velocities, v_z, at $z = 0$ and at $z = L$ can be modelled by means of the Transfer Matrix Method (TMM). We consider each building block is independent from each other in the structure and considered as an equivalent fluid. Such approximation can be made due to the low difference in impedance between the water and polymer media, with a polymer-to-water impedance ratio, coupled with the fact that shear waves can also be neglected due to the system being considered under normal incidence. Therefore, the scattering coefficients of each building block can be calculated

In order to design a lens that can behave as an ideal scatterer in both reflection and transmission directions, the latter must display a phase distribution coefficient at the surface, $\xi(x, y)$, such that the spatial Fourier transform of said distribution approximates a flat distribution. There are many number theoretic sequences that can help de- sign such phase distribution, such as the maximum length or quadratic residue sequences [3]. Here, the quadratic residue (QR) sequence will be used. In order to determine the phase distribution coefficient at the surface, $\xi(x, y)$, we perform a data base of properties of the monolithic polymer block to produce the desired phase of the reflection and transmission coefficients.

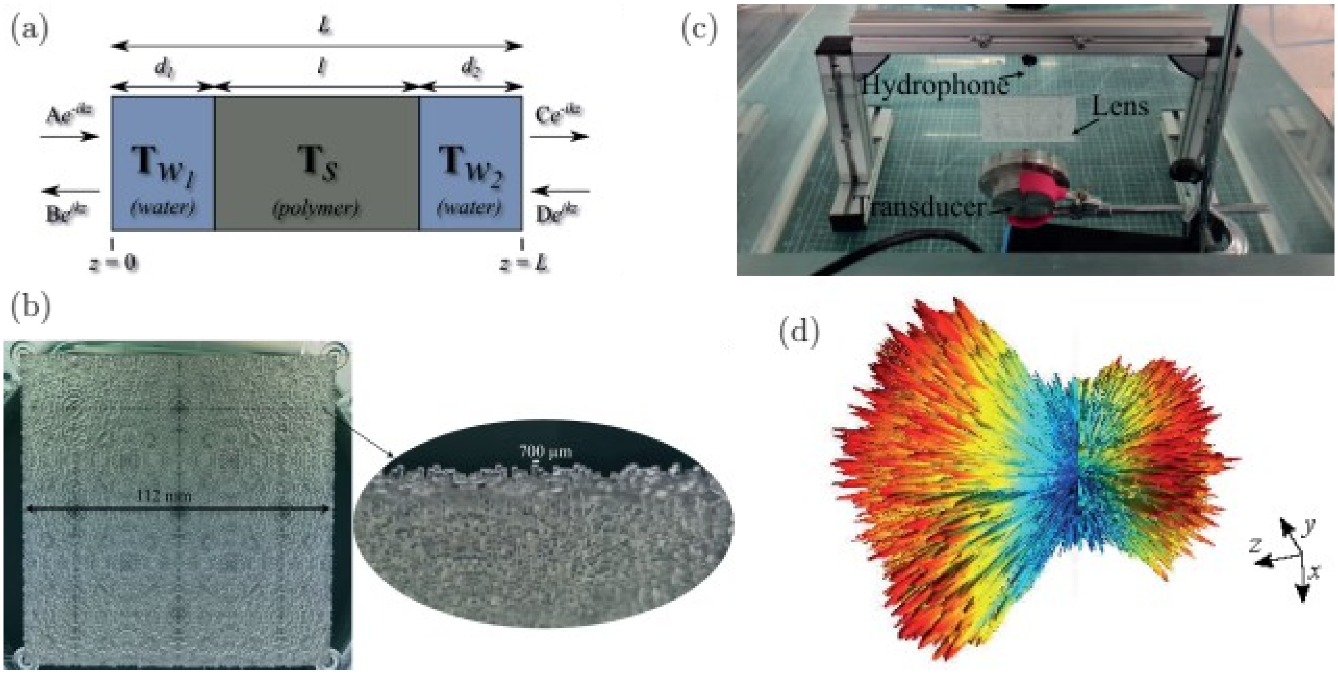

Figure 1. (a) Representative 1D Scattering Matrix diagram of a block of total length L composed of a polymer element and an exterior water medium. (b) Picture and detail of the fabricated sample. (c) Experimental setup. (d) 3D measured acoustic field at 1.1 MHz from both sides of the diffusing hologram.

A picture of the fabricated sample can be seen in Fig. 1(b). It has been experimentally tested for underwater acoustics in the water tank shown in Fig. 1(c). In this talk we will show the excellent agreement between the theoretical predictions and the experimental results, and we will discuss in details the main features of the system with a Physical insight of interest for the audience of the META conference.

The collaboration between the authors of this article was made possible thanks to Institut d'Acoustique -- Graduate School (IAGS) project (ANR-17-EURE-0014) from the Laboratoire d'Acoustique du l'Université du Mans (LAUM) for the support and mobility. The authors gratefully acknowledge the ANR-RGC METARoom (ANR-18-CE08-0021) Project. N. J. and V.R.-G. acknowledge financial support from Conselleria de Innovación, Universidades, Ciencia y Sociedad Digital de la Generalitat Valenciana through project CIAICO/2022/052 of the Programa para la promoción de la investigación científica, el desarrollo tecnológico y la innovación en la Comunitat Valenciana.

References

1. D. Arslan, A. Rahimzadegan, S. Fasold, M. Falkner, W. Zhou, M. Kroychuk, C. Rockstuhl, T. Pertsch, and I. Staude, Advanced Materials 34, 2105868 (2022),

2. J. Huang, P. Dupont, A. Undurti, J. Triedman, and R. Cleveland, Ultrasound in medicine & biology 32, 721 (2006).
3. T. Cox and P. D'Antonio, "Schroeder diffusers: A re- view," *Building Acoustics*, vol. 10, no. 1, pp. 1–32, 2003.