

Supplementary Material: Diffuse Field Cross-Correlation in a Programmable-Metasurface-Stirred Reverberation Chamber

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We provide supplementary material for the interested reader about

- (i) the programmable metasurface design, and
- (ii) the modified experimental setup for imaging.

I. PROGRAMMABLE METASURFACE DESIGN

In this section, we elaborate on the programmable metasurface design used for the experiments reported in the main text. Before diving into technical details, we highlight that the goal of our work is *not* to present a novel metasurface design but to use an existing prototype to demonstrate a new application that leverages programmable metasurfaces. Indeed, our work could be implemented with any alternative programmable metasurface design, too. The literature contains by now many different designs of 1-bit or multi-bit programmable metasurfaces for the microwave regime, and they are also known as “tunable impedance surface”, “spatial microwave modulator” or “reconfigurable intelligent surface”. Early works^{1,2} date back to the early 2000s; the concept gained considerable traction about ten years later^{3,4}. Providing a complete review of available programmable metasurface designs is beyond the scope of our contribution. We note, however, that design priorities differ depending on whether applications in free space or in scattering rich environments are targeted⁵. Our work inside a reverberation chamber clearly falls into the latter category.

The prototype used in our experiments is based on the design introduced in Ref.⁴. Each meta-atom has two digitalized states, “0” and “1”, and can be configured individually to be in either of these states. The fundamental working principle is that introduced in Ref.⁴. The meta-atom consists of two resonators that hybridize, and the resonance frequency of one of the two can be altered by controlling the bias voltage of a PIN diode. This results in a phase change of roughly π for the reflected wave.

Unlike the meta-atoms in Ref.⁴, our prototype offers independent control over the two orthogonal field polarizations. In short, this is achieved by fusing two single-polarization meta-atoms, one rotated by 90° with respect to the other, into a single one. As seen in the inset of Fig. S1(a), the two meta-atoms share the same fixed resonator but one PIN diode controls the tunable resonator for each of the two polarizations.

While a detailed characterization of the programmable meta-atoms would be crucial for a free space application, our application in a scattering rich environment does not require any specific characteristics other than that the electromagnetic response of the two states is clearly different. Thoroughly characterizing the exact response of the meta-atoms is chal-

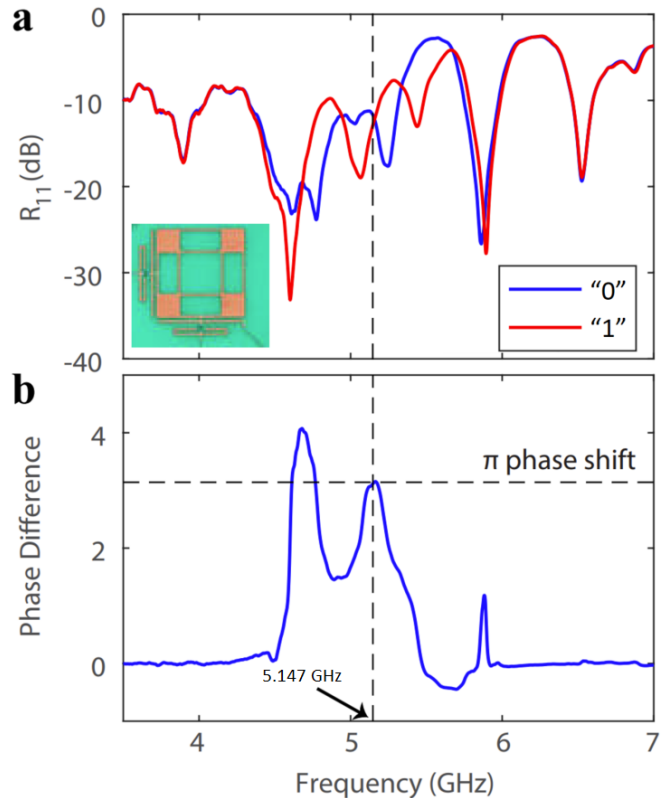


Figure S1. (a) Reflection coefficient $R_{11} = |S_{11}|^2$ measured with a horn antenna placed in front of the metasurface, for the two distinct states “0” and “1”. (b) Phase difference of the S_{11} parameter between the two states. At the optimal operating frequency of 5.147 GHz (indicated with a dashed vertical line), the metasurface response of the two states differs by a phase difference of π .

lenging since the characterization procedure inevitably impacts the results. Here, we illuminate the metasurface with a plane wave polarized along one of the two polarizations with a horn antenna. We synchronize the states of all meta-atoms for this measurement and measure the return loss of the horn antenna in close proximity to the metasurface for the two possible states, “0” and “1”. The resulting curves are displayed in Fig. S1. Recall that the absolute values of the return loss are modulated by the horn antenna’s transfer function. The

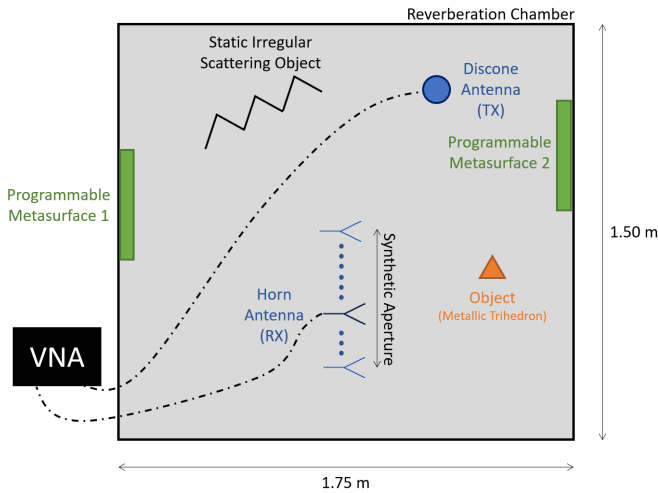


Figure S2. Sketch of the modified experimental setup, seen from above, used for the imaging experiments. Using a VNA, we measure the transmission from a discone antenna to a horn antenna. The horn antenna is mounted on a linear stage and can be displaced to create a synthetic aperture. The horn antenna faces the object to be imaged.

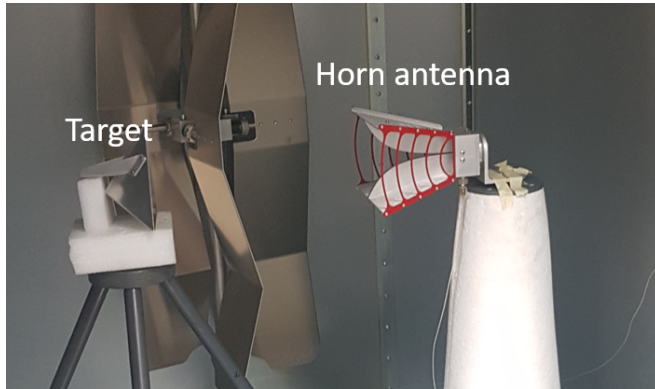


Figure S3. Photographic image of the receiving horn antenna and the target object (the metallic trihedron) within the reverberation chamber.

absolute value $R_{11} = |S_{11}|^2$ is therefore not an indicator of the amount of energy absorbed by the metasurface. The phase

difference of S_{11} for the two states, however, confirms that around the working frequency the metasurface does indeed offer a phase shift of roughly π . In other words, every meta-atom can be configured to mimic a Dirichlet or a Neumann boundary condition. Similar results are obtained for the other polarization.

II. MODIFIED EXPERIMENTAL SETUP FOR IMAGING

In this section, we detail and illustrate the modifications of the setup seen in Fig. 1 of the main text that were implemented in order to perform the imaging experiments on which Fig. 4 and Fig. 5 are based. As seen in the sketch in Fig. S2 which views the setup from above, a horn antenna faces the object to be imaged. This horn antenna is displaced using a motorized stage in order to create a synthetic aperture. For each position of the horn antenna, we measure (using a VNA) the transmission spectrum between the discone antenna acting as source (similar to Fig. 1) and the horn antenna acting as receiver for the same pre-defined series of random metasurface configurations. A photographic image of the horn antenna and the target is shown in Fig. S3.

Whereas in the first part of the main text we correlated the signals received by two distinct passive antennas, here we auto-correlate the signals received by a single passive antenna at each point of the synthetic array. The main text provides mathematical details about the signal processing.

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