

## Tailoring sub-THz Beams by Liquid Crystal Assisted Reconfigurable Intelligent Surfaces

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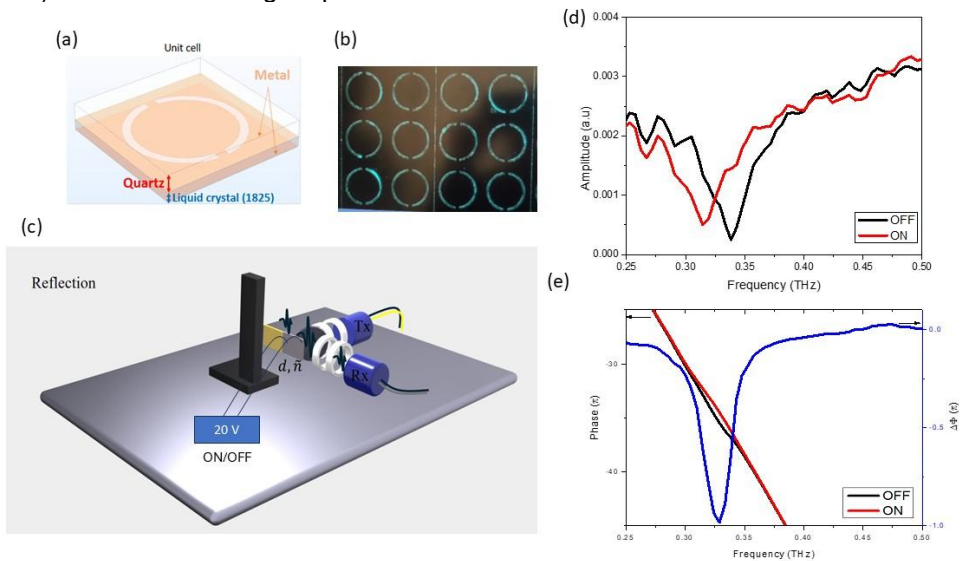
**Abstract:** Reconfigurable Intelligent Surfaces (RIS) are on the verge of revolutionizing wireless communications, due to their ability to manipulate the propagation environment and enhance the network coverage. Here, we present the design, the fabrication and preliminary experimental test of a liquid crystal (LC) assisted reflective RIS operating in the mm-wave/THz band.

A typical RIS architecture mainly consists of a planar surface and an external controller. The surface is covered by a periodic array of reflecting or transmitting elements (single cells or macrocells), each of which can independently impose, using the controller, the required phase shift on the incoming electromagnetic signal [1]. In the mm-wave/THz spectral range PIN diodes and varactors, which are currently employed for the electronic control of metasurfaces in the microwave region, can hardly be as tuning elements because of their inherent large size and low operational frequency [2]. Liquid crystals (LC), instead, address these limitations offering a low-loss and continuously tunable alternative that remains effective at very high frequencies. LC anisotropy permits electrically controlled phase modulation with minimal perturbation of the metasurface resonance. LC-based tuning, however, is inherently slower (on a time scale of milliseconds) than semiconductor technologies and requires precise LC alignment and electrode design. Nevertheless, LCs currently remain a compelling and practical choice for THz programmable metasurfaces due to their broadband tunability and compatibility with large-area fabrication, which can be leveraged by utilizing display technology.

The proposed RIS is composed of several layers, including an array of conducting "meta-atoms" on quartz, the intercalated LC, and a reflecting ground plane on quartz again. The meta-atom pattern is based on a complementary split ring resonator (CSRR) made of a 300 nm thick aluminum thin film, so that the overall array provides high reflectance and the single unit cell achieves the desired metasurface response. The LC has high birefringence ( $\Delta n \approx 0.38$ ) and low loss (absorption coefficient  $< 10 \text{ cm}^{-1}$  for both ordinary and extraordinary polarization) at the considered frequency range [3], and it fills the gap (25  $\mu\text{m}$  thick) in between the upper and lower quartz substrates. The design enables a phase difference close to  $\pi$  in correspondence with the working frequency nominally set at around 300 GHz, due to the LC molecules re-orientation. The designed RIS device is realized using UV lithography and LC filling/assembling techniques. To avoid accelerated aging and potential device damage caused by charge accumulation in the liquid crystal layer under DC bias conditions, a square wave operating at 20 V and 1 kHz is generated.

Defining the state having a different phase response as state 0 and state 1, a 1-bit programmable RIS is obtained. We present the amplitude and phase response of the device as a function of frequency at 0 and 1 state respectively, under a linearly polarized incident wave. RIS characterization is carried out using a THz time-domain spectrometer (TDS) equipped with photoconductive antennas for emission and detection and an optical setup with polymeric (TPX) lenses. Measurements are conducted in reflection mode with a variable detection angle  $\theta$  or with a normal configuration ( $\theta = 0$ ). The design and fabrication of the metasurface consisting of the CSRR array, the TDS characterization setup, and the first experimental results are briefly summarized in Fig. 1.

A complete RIS prototype, comprising 16 independently controlled channels, is currently under characterization enabling multi-channel beam steering and advanced dynamic reconfiguration. To verify the two-dimensional beam scanning capability, we will measure the far-field normalized scattering patterns in both  $x$ - $z$  and  $y$ - $z$  planes ( $z$  being the beam direction) for different coding sequences.



**Fig. 1** | (a) design of the “meta-atom”; (b) picture of the upper layer showing a detail of the CSRR array; (c) pictorial scheme of the TDS setup; (d), (e) measured response (amplitude and phase respectively) vs frequency at  $\theta = 0$  for a single coding sequence (000... or 111...).

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## References

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