Design Methodologies for Digitally Coded Metasurfaces Producing Anomalous Reflection: A Comparative Study

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In an era of ever-evolving wireless communication and connectivity, reconfigurable intelligent surfaces (RISs) are emerging as groundbreaking technology. These reconfigurable surfaces, composed of programmable elements, hold immense promise for their capability of shaping electromagnetic waves by manipulating phase shifts and employing digital coding strategies, leading to intelligent [1]. However, the capability of RIS beam steering range, and accuracy depends on the design methodologies adapted for reflection phase modulation. In this study, we analyze two different digitally coded metasurfaces (DCM) based reflection phase estimation methodologies demonstrated in [1] and [2], for anomalously reflecting an incident beam to a desired direction.

Initially, we performed a study on the beam steering accuracy by considering the DCM aperture size $10\lambda_0 \times 10\lambda_0$ for the following inputs such as frequency of operation (f = 26 GHz), number of coding bits (n = 2), size of the square unit cell element ($a = \lambda_0/6$), and reflection direction ($\theta_r = 45^o, \phi_r = 0^o$). It is observed that the systematic design method presented in [1] produces a phase profile with a uniform cluster size of 2 elements, whereas the design method in [2] produces a phase profile with a non-uniform cluster size of 2 and 3 elements. Further, the DCM prototypes are synthesized according to the above estimated phase profiles using 2-bit digitally coded unit cell elements and finally, the far-field scattering patterns are observed for a plane wave incident in CST EM solver. It is observed that the DCM-based RIS design based on [1], produces a main lobe in the direction of ($\theta_r = 49^o, \phi_r = 0^o$) having a side lobe level (SLL) of -9.15 dB (see Fig. 1(a)), which shows a beam steering deviation error of 4^o from the desired direction. In contrast, the DCM-based RIS design based on [2], produces a main lobe in the desired direction of ($\theta_r = 45^o, \phi_r = 0^o$) having a SLL of -7.86 dB (see Fig. 1(b)). Note that, both the designs have a similar half-power beamwidth of 5^o.

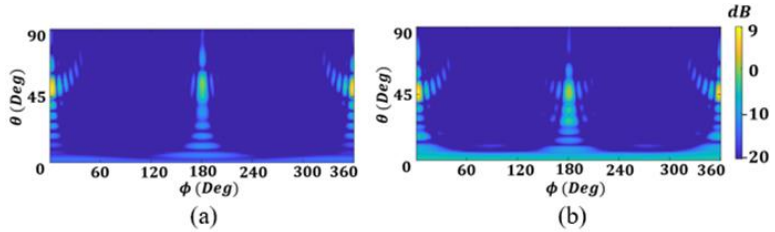

Figure 1. Far-field scattering pattern of the DCM designed at 26 GHz using (a) method in [1], (b) method in [2].

In addition, we conducted an analytical study on the beam steering range for the design methodologies in [1] and [2] using MATLAB. For 2-bit coding, the method in [1] achieves zero steering error up to a range of 30°, while the method in [2] maintains zero steering error up to 70°. Thus, the method in [2] demonstrates superior performance in beam steering range and accuracy, despite potentially increasing hardware complexity due to non-uniform cluster sizes. Conversely, the method in [1] offers better side lobe reduction.

1. R. Malleboina, J. C. Dash and D. Sarkar, "Design of Anomalous Reflectors by Phase Gradient Unit Cell-Based Digitally Coded Metasurface", *IEEE Antennas and Wireless Propagation Letters*, vol. 22, no. 9, pp. 2305-2309, Sept. 2023.
2. H. Taghvaee et al., "Scalability analysis of programmable metasurfaces for beam steering," *IEEE Access*, vol. 8, pp. 105320–105334, 2020.