Analysis and Design of Metasurface Antennas

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by

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Abstract

The modern wireless systems demand a more efficient and sophisticated antenna with polarization reconfigurability, gain enhancement, beam shaping, and low side-lobe levels. The conventional antenna arrays require a complex feed network to meet the desired pattern requirements, which makes the system costly and complex. The metasurface antennas offer a more simple and cost-effective solution to meet the present demands of modern communication systems. The metasurface is an engineered surface designed to manipulate the incident wave to realize a low profile, light-weight polarizer, and lenses. A comprehensive approach to design and analyze the metasurface placed in the antenna's near-field and far-field region for manipulating the electromagnetic wave is critical to achieve the desired antenna characteristics. The overall goal of the present work is to design metasurface antennas to realize the desired radiation characteristics such as circular polarization, gain enhancement, beam shaping, and SLL reduction, which are considered as four different objectives. The first objective is to analyze the polarization reconfigurable metasurface antennas for different near-field configurations. The second objective is to explore the metasurface placed in the far-field region for dual-band gain enhancement. The third objective is to design the metasurface for dual-band flat-top radiation pattern, and further, extended to realize circularly polarized flat-top radiation pattern. Finally, the reduction in side-lobe levels of

MTS antenna is considered as the fourth objective.

A detailed analysis of polarization conversion metasurface (MTS) placed in the near field of an antenna is carried out using the characteristic mode (CM) analysis. CM analysis is used to optimize three different MTS, i.e., diagonal slot square patch MTS, cross slots square patch MTS, and dual-layer truncated square patch MTS, for polarization conversion near 2.45 GHz. The analysis demonstrates the advantages and efficiency of CM analysis for optimization of polarization reconfigurable MTS.

Next, a dual-band polarization dependent phase gradient metasurface (PGMS) lens is proposed based on the phase compensation method. A multi-layered elliptical structure is used as a unitcell, which generates independently controllable phase characteristics for two orthogonally polarized incident waves at two different frequencies in X-band. The primary focus of the work is to enhance the gain in board-side direction at 10 and 12 GHz for x- and y-polarized wave incidence. Also, the beam steering mechanism is demonstrated at both operating frequencies by steering the antenna in focal and lateral planes for both frequencies. Owing to the asymmetric shape of unitcell, the work is further extended to enhance the antenna gain in two different directions, i.e., broadside and end-fire directions for x- and y-polarized incident waves. Both the simulation and measured results are presented.

As part of the third objective, a flat-top radiation pattern is synthesized by dividing the metasurface (MTS) into multiple regions. Each sub-region generates a beam in a particular direction, and multiple beams with different directions form a flat-top pattern in the far-field. A flat-top pattern in a single and 3D plane is realized by dividing the

MTS into two and four regions, respectively. Using the polarization dependency of the unitcell, a dual-band flat-top pattern is realized. Further, the same concept is applied to realize a circularly polarized flat-top radiation pattern. All the simulated results are verified by measurement results.

Finally, we carried out a study on side-lobe level (SLL) reduction of an antenna with metasurface to address the maximum achievable SLL based on the feed selection, feed position, and amplitude tapering on the MTS at 10 GHz. Initially, the reduction in SLL is studied and analyzed for different feed antenna and feed position. Subsequently, the reduction in SLL is studied using non-uniform antenna theory. The required phase and amplitude distributions are realized by simultaneous control of amplitude and phase of MTS transmission coefficient. Several amplitude tapering functions, such as, Kaiser, Hamming, Hanning, Blackman, and Gaussian functions, are analyzed, and maximum achievable SLL is found out. Some of the MTS prototypes are fabricated, and the simulation results are verified through measurement results.