Design of Triband High-Q Metasurfaces with Tunability of Dominant Multipole Moments

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In this paper, we propose a design of triband high-Q metasurface for tuning contributions of multipole moments. The proposed unit-cell structure is composed of two square loops placed side by side, and the loops are separated into four strips with two central and two lateral gaps. The roles of these gaps are to create the asymmetricity for each loop as well as the entire unit cell in both vertical and horizontal planes. This asymmetric structure allows for multiple resonances with different contributions of various multipole moments, as shows in Fig. 1. In detail, the resonance at the highest frequency is achieved by the interaction between two antiparallel magnetic dipoles, which results in the dominance of toroidal moment. On the other hand, the magnetic moment becomes more significant at the middle resonance where two parallel magnetic dipoles constructively interference. Especially, the contribution of two antiparallel toroidal dipole moments, which excites a sub-radiative electric quadrupole, produces the lowest resonance with the highest Q-factor. Note that these extraordinary phenomena cannot be observed in structures that only have a single asymmetric loop, which is usually used in Fano resonators (V. A. Fedotov, M. Rose, S. L. Prosvirnin, N. Papasimakis, and N. I. Zheludev "Sharp Trapped-Mode Resonances in Planar Metamaterials with a Broken Structural Symmetry," *Phys. Rev. Lett.*, vol. 99, pp. 147401, Oct. 2007).

To interpret operating principles of the triband resonances, the contribution of each multipole moment is calculated based on the multipole expansion. We also observe electric current density and near fields induced on each unit cell. Then, the existence of these resonances is verified in microwave region by fabricating the structure on a dielectric sheet with a size of 15 cm × 15 cm ($5\lambda_0 \times 5\lambda_0$ at 10 GHz). The frequency response of the fabricated metasurface is measured using scattering parameters obtained from two X-band horn antennas connected to a vector network analyzer (PNA-X, model: N5242A, Agilent). The results support that the proposed asymmetric structure is capable of achieving three distinctive resonances with different contributions of various multipole moments.

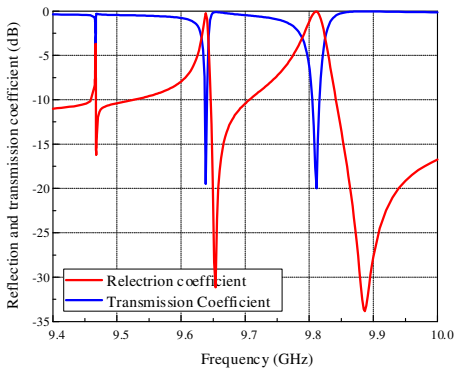

Figure 1. Frequency response of the proposed high-Q metasurface.

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