High-Q Factor Dual-Layer Anapole Metamaterial for sub-THz range

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Simulation results and experimental study are presented for a dual-layer metamaterial displaying a resonance with a Q-factor of 4000 in the sub-THz frequency range, achieved by combining resonances from two complementary planar metamaterials. The initial layer, constituting the original metamaterial, is comprised of metallic unit-cells shaped like epsilon letters and is based on a high Q-factor planar toroidal metamaterial [1]. This metamaterial exhibits significant localization of electromagnetic energy in the near field region rather than in the radiation zone due to the interference of toroidal and electric dipole moments with identical radiation patterns in the far zone. The second layer, which complements the first one, is composed of a metallic layer with cutouts in the epsilon letter shape [2]. Individually, the original metamaterial depicts a high Q-factor resonance and confines the electric field of the incident wave. Conversely, the inverted structure does not respond to the incident wave but is instead stimulated by near-field interaction with the original metamaterial. The observed low losses can be ascribed to the interaction between the two most significant multipoles excited within the metamaterials [3]. In the case of the original metamaterial, this interaction entails interference between toroidal and electric dipole moments, resulting in an anapole formation. Conversely, the properties of the inverted metamaterial arise from the interaction between toroidal dipole and magnetic quadrupole moments. Both metamaterials are manufactured as free-standing to evade dielectric losses from the substrate, which could considerably reduce the Q-factor of the resonance. The simulated metamaterial (Fig.1a) is stimulated with the wave polarized along the wires of the metamolecules of the original type, enabling the support of dual loops of currents along the voids, leading to toroidal excitation. The inverted structure, rotated to complement the original one, does not exhibit excited currents with the wave's set polarization; instead, it is activated by near-field interaction with the original metamaterial. Transmission spectra of the metamaterials at varying distances are depicted in Fig. 1b, with optimal outcomes attained at a distance of 0.8 mm. The metamaterials were created using a xTool laser cutter on a 50nm brass film, with the original and inverted structures comprising 10x10 metamolecules of 1.3 mm radius and periods of 2.60 mm and 2.55 mm, respectively. Experimental transmission spectra (Fig.1c) were gauged utilizing a Keysight PNA Network Analyzer with VNA Extenders WR-12. The layers were contained in 3D-printed holders separated by spacers ranging from 0.6 to 2 mm in thickness. The most prominent resonance, with a Q-factor close to 4000, was noted at a distance of 0.8 mm, similar to the simulation.

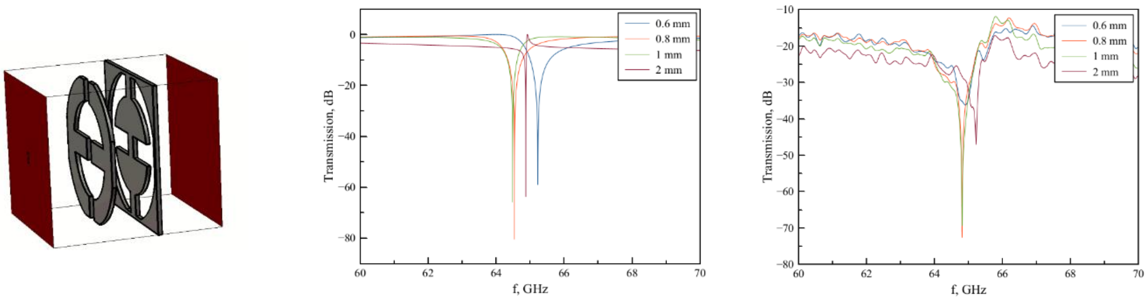

Figure 1.: a) metamaterial model, b) simulated and c) experimental metamaterial transmission spectra for different distances between the layers.

In conclusion, a new dual-layer metamaterial configuration with a high Q-factor resonance in the sub-THz frequency range has been introduced. Through simulations and experiments, the efficacy of this configuration combining responses from two complementary planar metamaterials has been illustrated.

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