A Multilayer Metasurface Cloak Coating for Monopole Antennas

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Abstract- A multilayer metasurface cloak coating is introduced for monopole antennas. It retains the input impedance and radiation parameters of the antenna for its original operational band. At the same time, it also reduces the monopole’s scattering signature and the received power for the operational band of another system located in close proximity. The coating, consisting of two layers of concentric anisotropic metasurfaces, is designed by tailoring their dispersive electromagnetic properties.

Invisibility cloaking of objects has been a topic of great research interest over the last decade. Various methods have been proposed by scientists and engineers around the world to achieve this physical effect, including transformation optics [1], scattering cancellation [2], transmission lines [3], and so on. Efforts have also been made to investigate and develop practical applications for cloaks, which includes improving the performance of existing microwave as well as optical devices and systems. For example, plasmonic cloaks that hide a receiving sensor while retaining its sensing functionality have been numerically verified and experimentally demonstrated [4, 5]. Transmission line cloaks have been experimentally proved to be useful for reducing the blockage of waves caused by obstacles positioned in front of microwave antennas [6]. Transformation optics and single layer metasurfaces have also been theoretically proposed to restore the properties of electromagnetic radiators or reduce mutual blockage in a multi-radiator environment, respectively [7, 8]. Here, we propose a practical integrated metasurface coating, with a compact form factor and light weight, for achieving simultaneous suppression of mutual coupling and blockage. Full-wave numerical simulations will be presented to validate the concept.

Fig. 1. (a) Configuration of the double layer integrated cloak coating surrounding a monopole. (b) Simulated $S_{11}$ and radiation patterns (insets) at 2.4 GHz for the monopole w/wo the coating. Electric field distributions in the x-y plane for an incident plane wave propagating in the +y direction for the monopole w/wo the coating.

As a proof-of-concept example, we designed an integrated multilayer coating for a 2.4 GHz monopole, which reduces its scattering at 5.2 GHz. The configuration is illustrated in Figure 1(a). The coating is comprised of two concentric layers of anisotropic metasurfaces surrounding a monopole antenna. The inner and outer metasurface layers have a radius of only 0.03$\lambda_0$ and 0.06$\lambda_0$, respectively. Since the metasurfaces are printed on a 0.1 mm thick Rogers substrate with a relative permittivity of 2.9, their electromagnetic properties
can be described by surface electric and magnetic polarizability tensors. The inner layer is made by a miniaturized meandered slot array, which has a z-component of the surface electric polarizability that is near-zero around 2.4 GHz and strongly capacitive at 5.2 GHz. Consequently, this metasurface layer greatly reduces the induced current on the inner monopole, thus minimizing the mutual coupling due to another nearby antenna operating at around 5.2 GHz. However, the monopole together with the single layer metasurface possess stronger scattering. In order to suppress the overall scattering, a second metasurface comprised by a short dipole and spiral resonator composite array is added at the outermost layer. Both its in-plane electric and out-of-plane magnetic response are tailored to reduce the scattering at around 5.2 GHz.

Figure 1(b) shows the simulated $S_{11}$ of the monopole with and without the integrated metasurface coating. It can be seen that the impedance matching is improved with the coating due to the tuned near-field coupling. At 5.2 GHz, the $S_{11}$ of the monopole alone is below -5 dB, hence it will pick up a significant amount of signal when there is a 5.2 GHz radiator nearby. In contrast, with the cloak coating, the $S_{11}$ is nearly 0 dB, indicating that the mutual coupling between the coated monopole with a nearby 5.2 GHz radiator will be significantly suppressed.

The inset of Figure 1(b) displays the radiation patterns for the monopole with and without the coating on an infinite ground plane. It is clear that the added coating does not affect both the radiation pattern and gain of the monopole within its own operational bands. Figure 1(c) shows the electric field distributions when a z-polarized plane wave is incident along the $+y$ direction at 5.2 GHz. While the monopole alone scatters the wave, the coated monopole is invisible to the plane wave whose wavefront is well maintained after passing through the structure. Moreover, the electric field in the region close to the monopole is much stronger for the monopole alone case than that for the coated monopole case, which provides further evidence that the monopole is well isolated from outside influences at 5.2 GHz.

In conclusion, we have proposed and numerically validated an approach for using integrated cloak coatings comprised of multi-layer metasurfaces to simultaneously suppress the mutual coupling and blockage between neighboring antennas. This concept has potential applications ranging from microwaves and millimeter waves to possibly even optical wavelengths.

REFERENCES