

Cloaking of Rectangular Patch Antenna Arrays with Coated Metasurfaces

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Abstract—The concept of electromagnetic cloaking is applied to eliminate the adverse effects of mutual coupling between the tightly spaced, interleaved rectangular patch arrays operating at C-band frequencies. We demonstrate that by coating the top surfaces of each patch antenna element with a suitably patterned metasurface, the elements appear to become electromagnetically invisible to each other. Particularly, the cloaking and decoupling effect is evaluated to enhance the functionality of the coupled arrays in terms of their realized gain and total efficiencies. Subsequently, the interleaved patch antenna arrays, even though placed in close proximity, can radiate independently as if they were isolated. The fact that these specifically designed metasurfaces achieve cloaking of an electrically large surface, makes our design unique in itself. The decoupling and cloaking action of the metasurfaces are demonstrated by various full-wave numerical simulation results.

I. INTRODUCTION

Antenna arrays mounted on the base stations or on vehicles, aircrafts, and satellites are anticipated to play a major role in fulfilling the ever-increasing demand for channel requirement in numerous wireless communications services. This may lead to incorporation of densely packed antenna arrays in a compact system. However, the performance of such a system may deteriorate due to the cross-coupling between closely packed antennas. As a possible solution to this challenge, in recent years, considerable research efforts have been dedicated to the aspect of electromagnetic invisibility. Various techniques that have been reported include transformation optics, transmission-line networks, plasmonic cloaking, among others. These techniques utilize bulk volumetric metamaterials and so they might prove inconvenient for antenna systems with limited space availability. As such, the concept of mantle cloaking was put forth, which utilizes an ultra-thin metasurface to create anti-phase surface currents that causes suppression of the dominant scattering mode of the object to be cloaked [1]. The mantle cloaking method has been shown to repress the electromagnetic interaction between neighboring antennas [2]. Recently, this approach has been utilized to achieve cloaking of printed monopole antennas and arrays [3]–[4]. Very recently, a novel cloaking technique for bow-tie antenna and its array configurations was put forth, wherein the surface of the bow-tie antennas are coated with specifically engineered metasurfaces to make the coupling robust within closely arranged neighboring antennas [5].

In this paper, we put forth a cloaking structure for the rectangular patch antenna arrays, motivated by the cloaking

design outlined in [5]. We have established the cloaking and decoupling effects for the interleaved array of two patches—Patch I and Patch II, placed in close vicinity (C-band frequencies have been targeted in this paper for 5G applications). It is shown that when the top surface of individual patch antenna element is coated by the appropriately designed metasurface (Fig. 1), not only are the arrays decoupled from each other, but their radiation characteristics are also restored in such a way that it emulates the independent operation of an isolated array. The novelty of our cloak design lies in the fact that it facilitates cloaking of an electrically large antenna surface (length of each patch antenna is approximately equal to half of the wavelength at the resonance frequency, within dielectric medium). As such, the coated metasurfaces act as filters, making the elements of the individual arrays poor radiators at the operating frequencies of one another. Accordingly, a fixed array size, which is traditionally allocated for only one array, can now accommodate two distinct interleaved arrays, potentially leading to cost reduction and practical applications with compact space utilization. The design procedure and all the numerical full-wave simulations presented in this paper are obtained with the CST Microwave Studio.

II. DESIGN OF DECOUPLED PATCH ANTENNA ARRAYS

In this paper, we examine the case of linear array of patch antennas, consisting of four elements each for Patch I and Patch II. Simple, coaxially fed patch antennas are considered with Patch I and II operating at frequencies $f_1 = 4.9$ GHz and $f_2 = 5.2$ GHz, respectively. The schematic design for the uncloaked and cloaked interleaved arrays is shown in Fig. 1.

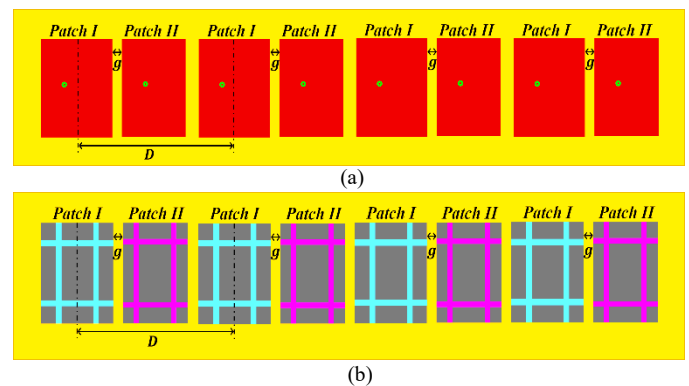


Figure 1. Schematic configurations of (a) uncloaked and (b) cloaked patch antenna arrays.

All the geometrical dimensions presented in Fig. 1 are in mm. Each element of Array I (comprising of all Patch I elements) is

spatially separated by a distance of $D = 40$ and the elements of Array II (consisting of Patch II elements) are positioned right next to the elements of Array I at a sub-wavelength distance of $g = 2$ ($\approx 0.048 \lambda_1$, where λ_1 is the wavelength corresponding to frequency f_1 within the dielectric medium). These arrays are embedded on a dielectric with height $h = 1.8$ and dielectric permittivity $\epsilon_r = 2.2$, backed by a ground plane. Now, to gain a better insight into the cloak design and the parameters involved, we present the uncloaked and cloaked configurations of a single unit of the array configuration in Fig. 2.

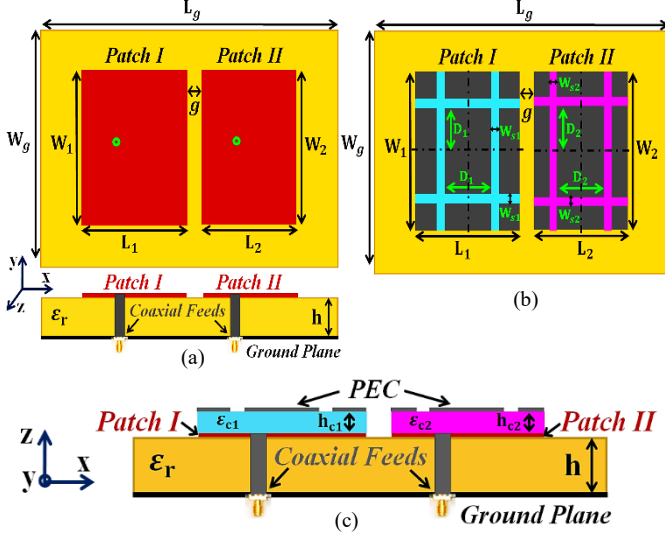


Figure 2. A single unit of the interleaved array showing (a) top-view and side-view of uncloaked patches, (b) top-view and (c) side-view of cloaked patches.

The parameters characterizing the uncloaked patch antennas are: $L_g = 57.55$, $W_g = 43$, $L_1 = 18$, $W_1 = 23$, $L_2 = 17.55$, and $W_2 = 23$. We begin our assessment by evaluating the radiation characteristics of each array in the isolated scenario (in the absence of the other array). Then, we analyze the case of uncloaked interleaved arrays, wherein both the arrays are tightly packed together. Typically, the close proximity of all these patch elements causes a strong mutual interference, thus leading to a decline in the matching and radiation aspects of both the arrays. In an attempt to minimize these destructive effects of mutual coupling, we implement the specific metasurface structures. For this purpose, the top surface of each patch element is first coated with a supporting dielectric material (permittivity $\epsilon_{c1} = 15.15$ and $\epsilon_{c2} = 16.71$, with heights $h_{c1} = 1$ and $h_{c2} = 0.9$, for Patch I and II elements, respectively). On these dielectric substrates, PEC patches are then placed with thin slots cut on its surface (slot widths are $w_{s1} = w_{s2} = 0.75$ and spacing between the slots are $D_1 = 8.55$ and $D_2 = 8.25$, see Fig. 2-(b) and (c)). The optimum values for each of the parameters was decided through parametric analysis (varying one parameter within the ranges while keeping the other parameters constant). It is evident from the plots of total efficiencies (Fig. 3) and the polar plots (Fig. 4) that coating the specific metasurfaces onto the patches, brings about a substantial reduction in the mutual coupling, thereby greatly improving the total efficiencies and the radiation properties of each array. The patterned metasurfaces do not disturb the radiation aspects of the patch antenna on which it is

coated; rather its effect is apparent at the frequency of the neighboring element.

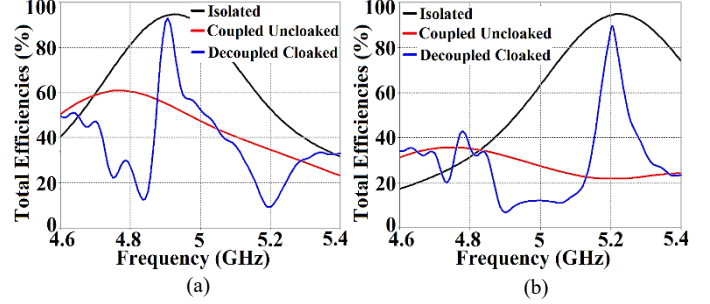


Figure 3. Total Efficiencies plots for (a) Array I ($f_1 = 4.9$ GHz) active and (b) Array II ($f_1 = 5.2$ GHz) active.

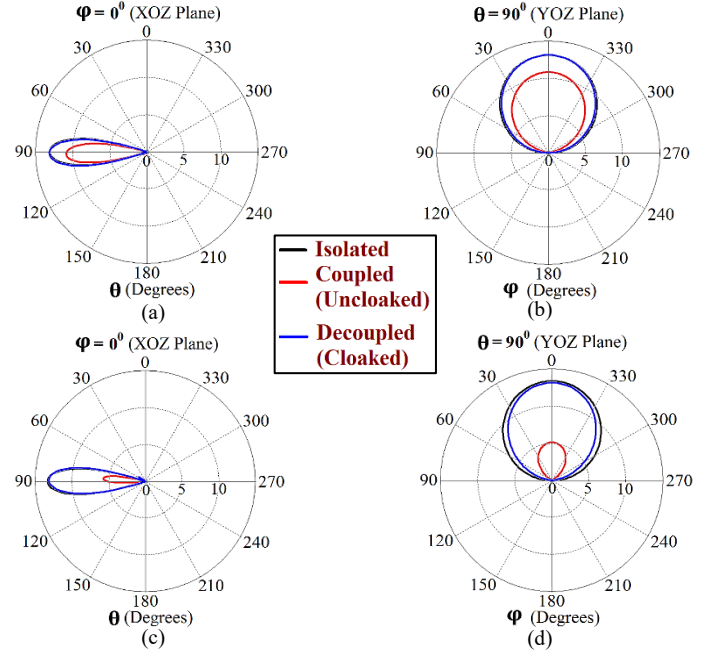


Figure 4. Polar plots at (a) $\phi = 0^\circ$, (b) $\theta = 90^\circ$ for Array I ($f_1 = 4.9$ GHz) and at (c) $\phi = 0^\circ$, (d) $\theta = 90^\circ$ for Array II ($f_2 = 5.2$ GHz).

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