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Metasurface Cloaks for Reduction of Mutual Coupling in Slot Antennas at C-Band Frequencies

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***Abstract*—With the intention of reducing the detrimental effect of mutual coupling between two slot antennas placed in very close proximity, designed to operate at C-band frequencies, we make use of the specifically designed metasurface cloaks, which employs the concept of mantle cloaking. In this paper, it is demonstrated that by encasing each edge of the individual slot antenna with the elliptical metasurface cloaks, we are able to achieve a significant reduction in the mutual coupling. This decoupling effect is evident in the plots for S-parameters of the slot antennas. Along with this, restoration of the far-field radiation patterns is also observed. Thus, these explicitly tailored cloaks enable each slot antenna to radiate independently, as if the antennas were functioning in an isolated environment.**

I. Introduction

The design of a slot antenna can be discerned from the Babinet's principle, which illuminates the fact that a vertical slot cut in a flat metallic plate is the dual of a horizontal dipole in free space, i.e., their electric field and magnetic field directions are interchanged. Slot antennas have gained popularity due to numerous advantages like their smaller size, design simplicity and convenient adaptation to mass production using either waveguide or PC board technology. Now, to accommodate for the escalating demand in the wireless communication system, it is crucial to have a densely packed antenna system in a very compact space. The task of designing such antenna systems is not only formidable, but placing the antenna elements in such close proximity also brings about undesirable effects of mutual coupling, such as, deterioration of radiation patterns, reduction in total efficiencies, etc. To take care of this peculiarity, considerable research efforts have been dedicated towards the phenomenon of electromagnetic invisibility.

Over the past decade, tremendous advancement has been observed in achievement of electromagnetic invisibility and numerous approaches have been recorded. One of the most successful approaches include the coordinate transformation (CT) cloaking method, based on the principle of bending the electromagnetic waves around an object [1]. Owing to its immense significance in the potential applications involving non-invasive probing, camouflaging, etc., much attention has been directed towards electromagnetic cloaks employing the use of metamaterials, like plasmonic cloaking, cylindrical transmission-line cloaking, to name a few. The most notable disadvantage of these methods is in the use of bulk volumetric metamaterials that renders them inconvenient for antenna applications with a limited space availability. Consequently, a different cloaking technique was put forth. Based on the concept of mantle cloaking, this particular methodology focuses on the cancellation of the dominant scattering mode through the use of ultra-thin conformal metasurfaces [2]. This mechanism has also proven effective in eliminating the electromagnetic interference between neighboring antennas [3]. Recently, mantle cloaking method has been applied to obtain cloaking of strip dipole antennas [4] and printed monopole antennas [5].

Adopting the mantle cloaking approach, in this paper, we focus on decoupling the two closely placed slot antennas, so as to remove the unwanted effects of mutual coupling in the near-field as well as the far-field, thereby achieving the cloaking effect. The slot antennas are designed to operate in the C-band (sub-6 GHz) frequencies for 5G wireless applications. By enveloping each radiating edge of the individual slots with the explicitly designed metasurface cloaks, we aspire to accomplish decoupling and cloaking of the slot antennas such that each antenna radiates freely, without facing any interference from the neighboring antenna, even though they are placed very close to each other. CST-MWS software [6] was used for simulation and to demonstrate the decoupling and cloaking of the slot antennas.

II. Metasurface Cloaks for Slot Antennas

We begin with the design of two slot antennas–Slot I and Slot II, resonating at the frequencies f_1=4.5 GHz and f_2=5.5 GHz, respectively. All the geometrical dimensions mentioned henceforth in this paper are measured in mm. The slot antennas are cut in a flat metallic sheet (L=180 and W=180); refer to Fig. 1 for the uncloaked and cloaked slot antenna configurations.

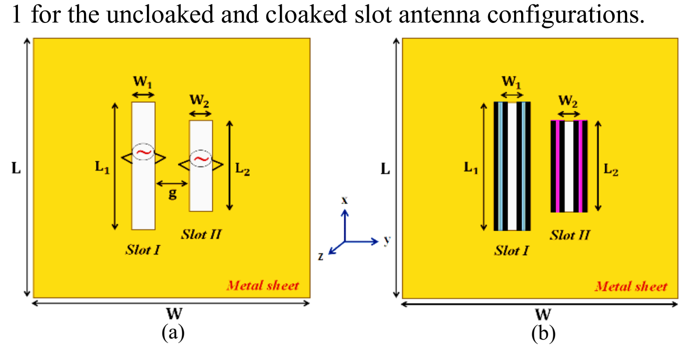

Figure 1. Configurations of (a) uncloaked coupled and (b) cloaked decoupled slot antennas.

The dimensions given in Fig. 1 are as follows: L_1=34.8, W_1 =1.5, L_2=28.5, W_2=1.5, g=3. To get a better insight into the layout of the metasurfaces, a side view of the cloaked configuration, with a detailed design for the elliptical cloaks is shown in Fig. 2.

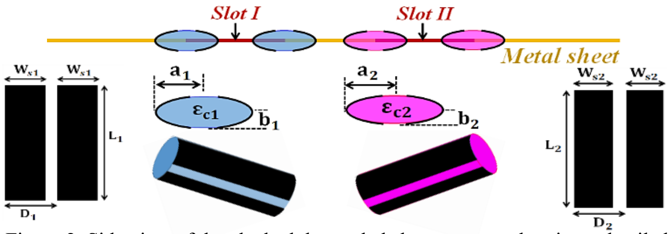

Figure 2. Side view of the cloaked decoupled slot antennas, showing a detailed construct of the elliptical metasurface cloaks.

The dimensions and dielectric constants illustrated in Fig. 2 are: W_{s1}=0.35, D_1=0.585, W_{s2}=0.325, D_2=0.572, a_1=0.5, b_1=0.218, a_2=0.5, b_2=0.196, ε_{c1}=3.67, ε_{c2}=2, L_1=34.8, L_2=28.5. To manifest the decoupling and cloaking of our slot antenna designs, we initiate by analyzing the radiation characteristics of each uncloaked slot separately (i.e., in the absence of the other slot); this is referred to as the 'isolated uncloaked' case. We then place the uncloaked slot antennas very close to each other, which is referred to as the 'uncloaked coupled' case and as expected, the performance of both the slots degrade substantially. Consequently, to improve their radiation aspects, each radiating edge of slots I and II is enclosed by the specially engineered elliptical metasurface cloaks; we allude to this case as 'cloaked decoupled'. The metasurface cloaks bring about a considerable reduction in the mutual coupling (validated by S_{12} & S_{21} plots in Fig. 3(b)), thereby decoupling the slot antennas at the desired frequencies. A comparison of the total efficiencies plots for the aforementioned cases is presented in Fig. 3(c), for Slot I (f_1=4.5 GHz) and in Fig. 3(d) for Slot II (f_2=5.5 GHz). Evidently, the total efficiency of one slot reduces significantly at the resonance frequency of the other, whereas it may be improved at its own resonating frequency. It is important to note that the metasurface cloaks do not perturb the radiation characteristics of the slot antenna which it envelops; rather its effect is emulated at the frequency of the other slot placed in its vicinity (The 2D polar plots in Fig. 4 further substantiate this claim).

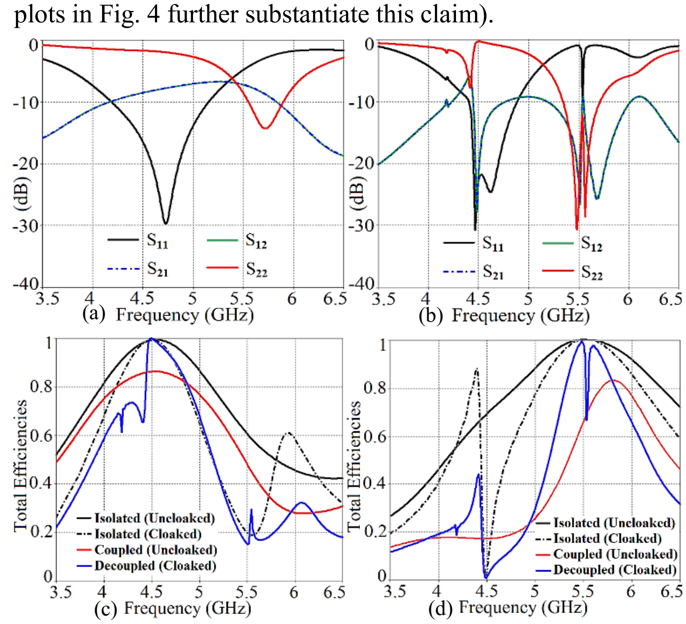

Figure 3. S-parameter plots for (a) uncloaked coupled, (b) cloaked decoupled slot antennas and Total Efficiency plots for (c) Slot I, (d) Slot II.

We also present the 2D polar plots (see Fig. 4) at $\varphi=0^0$ and $\theta=0^0$ planes of reference for both Slot I and Slot II. It serves to exemplify the fact that when the two slots are placed very close to each other, a distinct deterioration in their individual radiation patterns is noticed, which is almost completely restored when each slot is encased by their specific elliptical metasurfaces.

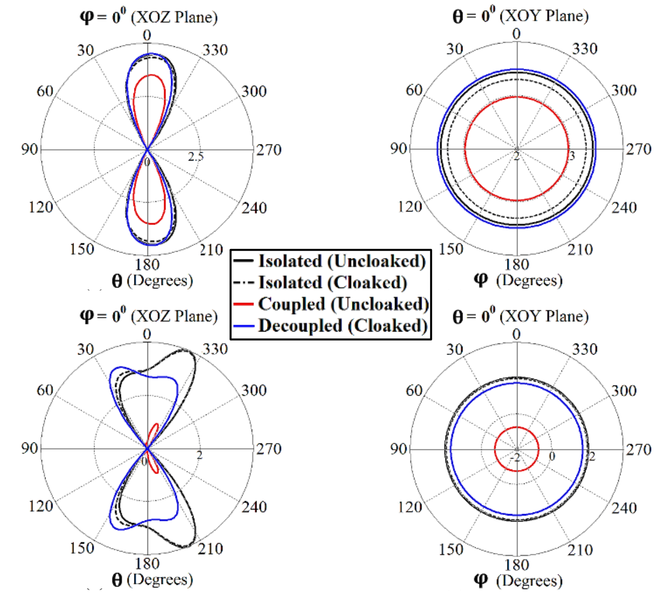

Figure 4. 2D polar plots at (a) $\varphi=0^0$, (b) $\theta=0^0$ for Slot I (f_1=4.5 GHz) and at (c) $\varphi=0^0$, (d) $\theta=0^0$ for Slot II (f_2=5.5 GHz).

III. Conclusion

Cloaking and decoupling of closely placed slot antennas using the mantle cloaking approach is proposed in this paper. The usage of the uniquely devised elliptical metasurface cloaks facilitates the reduction of mutual coupling between the two slot antennas, thereby leading to the improvement in their overall radiation attributes. This fact is corroborated by the simulation results presented in this paper. Thus, our design aids in the unobstructed radiation of the slot antennas, even though they are crammed together in a compact space.

Acknowledgment

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