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Non-linear Mantle Cloaks for Self-Configurable Power-Dependent Phased Arrays

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Abstract

The use of non-linear electronic components is proposed in this contribution to further expand the potentialities of mantle cloaking for antennas. In particular, the possibility to design phased arrays featuring a radiation pattern that can be made self-sensitive to the level of received/transmitted power by the system will be demonstrated. Towards this end, a phased array exhibiting a directive pattern when operating for high-power signals while presenting an omnidirectional pattern for low-power ones will be designed and numerically validated. This solution can be of particular interest for designing radar systems able to seamlessly/transparently switch between selectively scanning the environment when transmitting high power pulses, and omnidirectionally sensing the environment when handling low power scattered signals.

1 Introduction

Arguably, one of the most catching applications of metamaterials and metasurface is invisibility cloaking, i.e., the possibility of coating an object so that its total scattering cross section is minimized either by using bulk metamaterials [1] or thin and conformal metasurfaces [2]. In the latter case, the cloaking approach is often referred to as *mantle cloaking*, and invisibility is achieved through the use of suitably patterned metallic surfaces usually deposited on a dielectric substrate. Owing to such realization concept, the arising cloaking strategy has become very popular because of its inherent fabrication simplicity and inexpensive implementation. Moreover, the resulting mantle cloak does not electromagnetically isolate the object from the surrounding environment and, for this reason, such an approach is particularly suited for coating sensing/communicating devices such as antennas.

Thanks to these advantages, mantle cloaking has been successfully used in the literature for a plethora of different antenna applications, such as high efficiency sensors [3], camouflaging [4], ultra-compact nano-satellite systems [5, 6] and intelligent invisible antenna systems [7]. Among them, one of the most promising application relies on the use of mantle cloaks for the reduction of interferences between close/co-located antennas [8, 9]. This approach has been validated experimentally for the case of monopole antennas in [10, 11], and have been also demonstrated for different antenna typologies [12, 13].

Within this framework, the aim of this contribution is to illustrate that the concept of mantle cloaking in antenna systems can be further extended and generalized through the introduction of non-linear elements. Towards this end, an array of half-wavelength dipoles with power-dependent radiation patterns will be designed exploiting non-linear electronic elements applied onto the metasurface and following the approach proposed in [14] for the design of power-dependent absorbing metasurfaces. Although non-linear elements for cloaking devices in antenna scenarios have been introduced previously [15]-[16], here the design of the cloaking metasurfaces is more refined and the overall performances are improved.

2 Design of Non-linear Cloaking Metasurface

Let us consider the problem of designing a cloaking device able to suppress the scattering signature of a dipole antenna at its own resonant frequency f_0. From the mantle cloaking theory, it is known that an inductive metasurface, implemented through vertical metallic strips, is an effective solution for concealing resonant wire antennas [3]. Details of the adopted geometry are reported in Figure 1(a). The cloaking metasurface consists of 4 full vertical metallic strips, interleaved by groups of 3 connected strips separated by a horizontal gap. The metasurface is engraved onto a low loss dielectric cylinder with ε_r = 7.2. As shown in Figure 1(b), this configuration allows suppressing the scattering signature of a half-wavelength dipole at its own resonant frequency (f_0 = 3GHz) in the unloaded scenario.
By loading the gap between the strips with a non-linear element such as a diode pair [shown as a black-box in the inset of Figure 1 (a)], it is possible to introduce a “self-switching” functionality to the device, i.e., to turn ON/OFF the cloaking effect depending on the power level of the impinging wave. In fact, the impedance of the diodes is very large for low-power (LP) signals (the diodes are operating approximately as open-circuits [14]), while their impedance is very small and the diodes act as a short-circuit element for high-power (HP) signals [14].

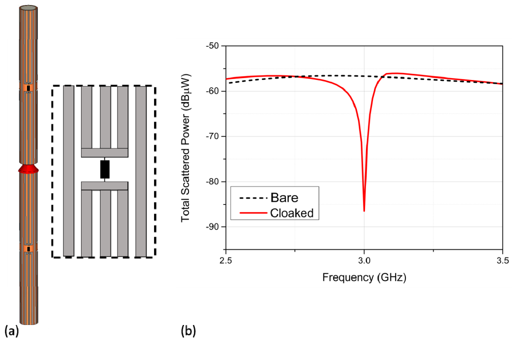

Figure 1. (a) Half-wavelegth dipole antenna coated by the non-linear mantle cloak. In the inset, detail of the loaded cloaking metasurface. (b) Total scattered power of the antenna in the uncoated case (bare) and when coated by the unloaed metasurface (cloaked).

According to such an operation principle, the cloaking resonance shifts to lower frequencies compared to the unloaded case when HP signals are at hand (Fig. 2). Indeed, in the HP scenario the diodes short circuit the interleaved strips, resulting in a change of the equivalent surface impedance of the metasurface with respect to its nominal cloaking value therefore effectively turning OFF the cloaking effect. On the contrary, the cloaking resonance remains at f_0 for LP signals, since the diodes are open circuited, and the metasurface geometric configuration resemble the unloaded one.

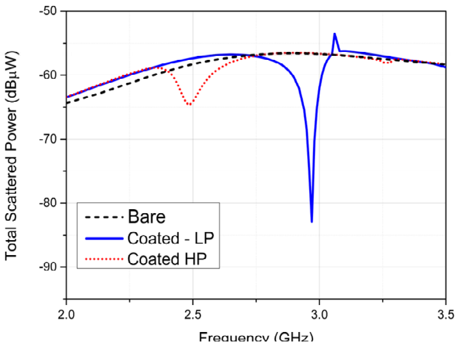

Figure 2. Total scattered power of the half-wavelegth dipole antenna in the uncoated case (bare); in the coated case for low-power signals (LP);in the coated case for high-power signals (HP).

3 Non-Linear Cloaked Phased Arrays

The possibility to achieve wide scan angles is of great interest in modern phased arrays. Unfortunately, due to the blockage effects between the single radiating elements, an omnidirectional embedded element pattern is very challenging to be achieved with standard antenna configurations, thus preventing wide scan angles to be achieved. A solution to overcome this limitation is proposed hereinafter based on the use of the designed non-linear mantle cloak.

For illustrative purposes, a benchmark setup consisting of a 3x3 phased array of half-wavelength dipoles resonating at f_0 = 3GHz is assumed. By properly setting the excitation phases of the array elements, a user-defined scan direction can be easily achieved [e.g., (θ, φ) = (90°, 45°) – Fig. 3(a)]. However, the embedded element factor of the central element is significantly deteriorated with respect to the free-space omnidirectional radiation pattern because of the blockage effects induced by the presence of the surrounding elements [Fig. 3(b)].

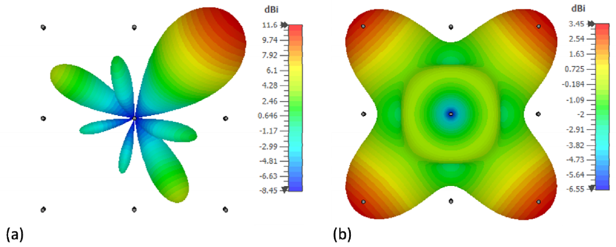

Figure 3. Top-view of (a) the radiation diagrams of the phased array with the antennas excitations set to have the array steering in a specific direction; (b) the embedded element factor of the central antenna.

By coating the peripheral elements of the array with the designed non-linear cloak (able to suppress the scattering of the dipoles at f_0), the omnidirectional pattern of the central element can be actually restored (Fig. 4). More specifically, for HP signals the array behaves as a conventional arrangement, since the cloaking effect is OFF and the external elements work properly (Fig. 4). On the other hand, in receiving mode, i.e., for LP signals, the array can receive from all direction of space, since the external elements are made invisible due to the cloaking effect (Fig. 4). Thus, thanks to the non-linear nature of the designed mantle cloak, the cloaked phased arrays achieves self-reconfigurability, since it can synthesize both a high directive beam and an omnidirectional pattern depending on the power level of the impinging signals.

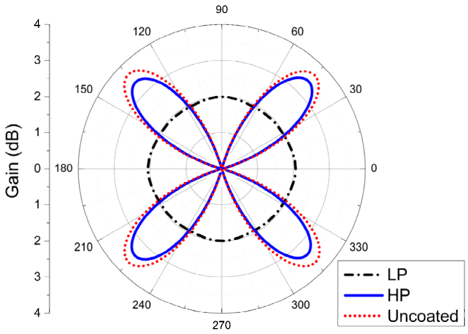

Figure 4. Polar plots of the array gain in different scenarios: phased array w/o the cloaking devices (uncoated case); phased array w/ the cloaking devices in the low-power case (LP); phased array w/ the cloaking devices in the high-power case (HP).

4 Conclusions

The potentialities of non-linear mantle cloaks for phased array applications have been presented. Through full-wave simulations it has been shown that a cloaked phased array can be designed to show power-dependent radiation patterns, which can be shaped according to a reduction/increment of the input power of the radiating elements. This unusual behavior is achieved exploiting a mantle cloak loaded by non-linear electronic elements which enable the introduction of a dynamic transformation of the effective geometry of the cloaking metasurface depending on the power-level of the impinging field. The proposed configuration introduces new degrees of freedom for the design of reconfigurable phased arrays.

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