Cloaked half-wave dipole antennas using the mantle-cloaking approach

A. Monti[1], A. Alù[2], and F. Bilotti[1]

[1]Department of Applied Electronics
"Roma Tre" University
Via della Vasca Navale 84, Rome 00146, Italy
Fax: + 39–0657337026; email: amonti@uniroma3.it
[2]Department of Electrical and Computer Engineering
University of Texas at Austin
Austin, Texas 78712, United States

Abstract

In this paper, we show how it is possible to realistically cloak half-wave dipole antennas in transmitting and receiving regimes by using the mantle-cloaking approach. In particular, we first propose the design of a cloaked half-wave receiving dipole and investigate the improvement in terms of absorption efficiency. In agreement with the theoretical limitations, we demonstrate that it is possible to cloak the dipole and still receive, under TM plane-wave illumination, an amount of power that is four times higher compared to the case of a short dipole with same scattering cross-section. Next, we apply the mantle-cloaking approach to a multiple-antenna scenario, in order to reduce the mutual blockage effect between two resonant dipoles placed in close electrical proximity. The cloak designs proposed in the paper can be realistically and easily fabricated and its employment may open the door to new co-siting strategies of antennas in complex platforms, such as satellite payloads, ships, planes, etc.

1. Introduction

Electromagnetic cloaking techniques developed in the last years have shown their potentials in different application fields. Basically, an electromagnetic cloak is a device that allows to sensibly reduce the scattering cross-section (SCS) of an object in a given range of frequencies, making it invisible to an observer. Different approaches have so far been proposed to achieve this purpose. Some of them [1]-[3] inhibit any electromagnetic interaction between the object and the external electromagnetic field, but are difficult to realize, due to the involvement of inhomogeneous materials. Conversely, the scattering cancellation approach [4] requires only homogenous and isotropic materials and, furthermore, does not inhibit the interaction between the external electromagnetic field and the cloaked object. Recently, a new cloaking approach has been proposed [5]-[7], which requires the use of patterned metallic surfaces conformal to the object to cloak. This latter approach, known as "mantle-cloaking", is particularly useful at microwave frequencies and suitable for practical cloak realization.

In this paper, we show our recent results on applying the mantle-cloaking approach to some typical antenna problems. In particular, we first show that the use of a suitably designed mantle-cloak can increase by 80% the absorption efficiency of a half-wave receiving dipole. Then, we show that the same approach can be successfully applied also to reduce the mutual blockage effect between two electrically close dipole antennas. This result allows considerable space-saving and enables new co-siting strategies in modern multiple-antenna complex platforms. All the numerical results presented in the paper have been the result of full-wave simulations performed through the frequency-domain solver of CST Studio Suite 2011.

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2. Cloaked half-wave receiving dipole

As a first application of the mantle-cloaking approach, we consider a half-wave receiving dipole. The antenna is closed on a 75 Ω load resistance and resonates at 3 *GHz*. We assume the dipole illuminated by a TM plane-wave and we are interested to its SCS and absorption cross section (ACS). These two physical quantities are related with the portions of the impinging electromagnetic power scattered and received by the antenna, respectively. For a conventional resonating dipole, these quantities are approximately the same, resulting in an absorption efficiency η of *0.5* [8]. Although it is not theoretically allowed to obtain a scattering reduction of the antenna without affecting the received power [8]-[9], it is however possible to increase η, approaching indefinitely its upper limit (equal to one) [8]. In other words, a SCS reduction necessarily involves an ACS reduction, but with a proper design it is possible to make this reduction low compared to the SCS one, obtaining, thus, a low-scattering antenna with a reasonable level of received power.

For this purpose, we have covered the antenna with a suitable mantle-cloak able to minimize the SCS at its resonance frequency. Different metasurface geometries have been considered. Some of the best solutions identified are shown in the insets of Fig. 1. The cover is a thin ($a_c = 1.2a$, a is the dipole radius) flexible support constituted by a commercial dielectric substrate (Rogers TMM 6, $\varepsilon_r = 6$, $tan\delta = 0.0023$) with a printed pattern of *10* vertical metallic strips. This metasurface leads to a SCS reduction at the design frequency (*3 GHz*) of about *15 dB*. The corresponding η parameter is shown in Fig. 1 (dashed line) and compared to the efficiency of the uncloaked dipole (continuous line). At the design frequency, the absorption efficiency approaches *0.9*, with an *80%* increase compared to the uncloaked dipole, but decreases rapidly after *3 GHz*. Wider bandwidths can be obtained using covers with bigger radius. For example, the result for a cover with $a_c = 1.68a$ is shown in Figure (dotted line).

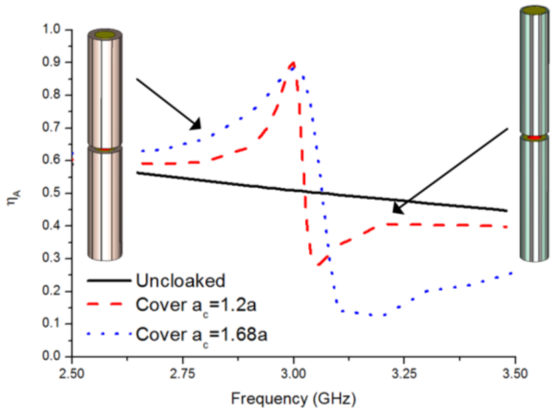

Figure 1: Absorption efficiency of an uncloaked dipole (continuous line) and of two cloaked ones.

For comparison, we have also computed the ACS of a short dipole with the same radius and SCS of the proposed half-wave one resonating at *3 GHz*. In this case, the ACS value is *6 dB* less than the one of our cloaked antenna.

3. Reduction of the blockage effect between two electrically close antennas

As a second antenna application of mantle cloaks, we consider the reduction of the blockage effect between two electrically close antennas. It is well known that the presence of an antenna in the near field of another one dramatically deteriorates its radiative and electrical proprieties. The problem has been considered to some extent also in [10], where an ideal inhomogeneous transformation-based cloak has been proposed for a similar purpose. The approach used in the previous section can be successfully applied also to obtain a realistic cloak design to reduce blockage effects. As an example, we consider a typical situation, in which two dipoles, resonating at different frequencies, are placed very close to each other. The first antenna is designed to resonate at $f_{01} = 3.3$ *GHz*, while the second one at $f_{02} = 3$ *GHz* and their separation distance is $d = 10$ *mm* ($\lambda_0 / 10$ at *3 GHz*). Due to the mutual coupling

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between the antennas, it is possible to notice a dramatic degradation of the radiation pattern and of the impedance matching of the two antennas. In order to restore the antenna properties in correspondence of their resonant frequencies, we have cloaked the two dipoles with proper mantle-cloaks. In particular, the first antenna is cloaked with a cloak working at f_{02} while the second one is cloaked at f_{01}. Please note that both cloaks are realized with commercial dielectric substrates and non-critical size of the vertical metallizations, being suitable for fabrication with conventional printed circuit board facilities. The comparison between the uncloaked and cloaked scenarios is shown in Fig. 2, where the 3D gain patterns at the two working frequencies of the two antennas are shown. The cloaks are tailored to be effectively transparent at the operating frequency of the transmitting dipoles they are covering, but they suppress the scattering at the other frequency.

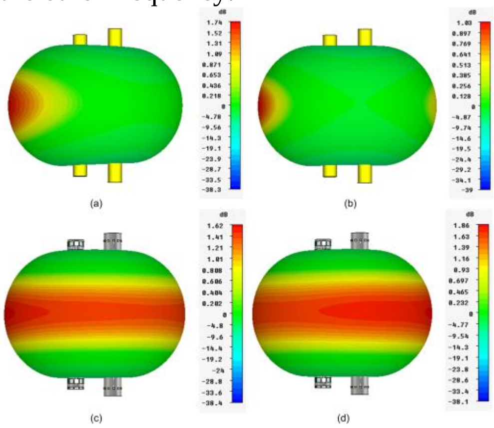

Figure 1: 3D realized gain pattern of the first antenna at f_{01} (a) and of the second antenna at f_{02} (b) in the uncloaked scenario. (c)-(d) Same quantities in the cloaked scenario.

4. Conclusion

In this contribution, we have presented two realistic mantle-cloaking antenna applications: for a single receiving dipole, it is has been shown that is possible to sensibly reduce the SCS at its resonance frequency, increasing the received power level with respect to other typical solutions (*6 dB* better than a short dipole). Next, we have shown that is possible to dramatically reduce the mutual blockage effect between two electrically close dipoles, with many consequences in the design of complex platforms.

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