Inhomogeneous metasurface to enlarge cloaking bandwidth

1st Barbara Cappello
Department of Electronics and Telecommunications
Politecnico di Torino
Torino, Italy
barbara.cappello@polito.it

2nd Ladisalu Matekovits
Department of Electronics and Telecommunications
Politecnico di Torino
Torino, Italy
ladislau.matekovits@polito.it

***Abstract*—The main issues of cloaking problems are to increase the bandwidth of operation and to efficiently cloak electrically large objects. In order to overcome these problems, in this paper a inhomogeneous metasurface is proposed. The metasurface unit cell is composed of two metallic square patches with different lengths. Two arrangements of the single patches are analysed in terms of scattering field reduction and compared with an homogeneous structure.**

***Index Terms*—cloaking, metasurfaces, scattering reduction.**

I. Introduction

In last decades, the problem of electromagnetic cloaking has been widely studied [1] – [3], especially thanks to the advent and the deep investigations of metamaterials [4], [5]. The aim of cloaking is to make a target object transparent for an incoming wave, so that an incident field is not perturbed by the object presence.

Different cloaking techniques have been developed in last years [6], [7]. Among the others, Mantle Cloaking exploits a thin 2D metasurface to cover the target object, with the aim of reducing its scattered field [8].

The principal limitations of cloaking problems are the difficulty in the enlargement of the operational bandwidth and the cloaking of objects with dimensions comparable to the wavelength of interest.

Since by using a homogeneous metasurface it is possible to cancel only one harmonic of the scattered field at one frequency [8], a possible solution could be the use of an inhomogeneous one. Also multilayered structures could be used, but they present the drawback of an increasing of the size of the cloaking coat.

In this framework, here, the proposed metasurface is based on an unit cell composed of two square metallic patches with different lengths printed on a dielectric substrate. Moreover, different arrangements of the singles patches are examined.

In the paper, the scattering reduction achieved with the use of the inhomogeneous metasurface is evaluated and compared to an homogeneous configuration. Moreover, the effects of different arrangement of the single square patches in the double cell configuration are investigated, showing how this can effectively realise a lower scattering and an increasing of the cloaking bandwidth.

II. Analytical formulation

The main goal in cloaking problems is to reduce the field scattered from a target object when it is illuminated by an incoming wave. In particular, in Mantle Cloaking technique, the scattered field is formulated as an infinite sum of harmonics, each associated to a scattering coefficient c_n, where n represents the harmonic number. Considering as target object an infinitely long metallic cylinder, illuminated by a TM polarised planewave, its scattered field E_s can be conveniently described in cylindrical coordinates (ρ, φ) as:

$$E_s = \hat{z} \sum_{n=-\infty}^{\infty} j^{-n} c_n H_n(k_0 \rho) \exp(jn\varphi) \tag{1}$$

where $\hat{z}$ is the direction parallel to the cylinder axis and to the incoming electric field, and k_0 is the wavenumber in the background medium.

It is possible to demonstrate that, for electrically small objects, the harmonic with modal index n = 0 is the dominant one, while as the object dimension increases with respect to the operational wavelength, also the relevant number of harmonics increases [9].

Mantle Cloaking approach, proposes to reduce the scattering coefficients c_n by covering the object with an opportune metasurfaces. In particular, the metasurface is equivalently described by its values of surface impedance Z_s and therefore plays the role of an impedance boundary condition at the interface between the object and the background medium [7].

It is proven that a homogeneous Z_s can completely cancel one scattering coefficient, and therefore one harmonic of the scattered field, for a fixed frequency value. For this reason, if the target object is electrically small, its scattering can be strongly reduced by opportunely tuning the surface impedance Z_s which corresponds to the annulment of the coefficient c_0. However, beyond quasi-static regime, the harmonic content is richer, and therefore lower reductions of the scattering will be achieved by using a homogeneous metasurface.

For this reason, in the following section, a inhomogeneous metasurface, based on a two-square patches unit cell is proposed, comparing the results in terms of scattering reduction with the one achieved with a single square patch unit cell.

III. Inhomogeneous metasurface and results

The proposed structure is composed of a metallic cylinder of radius a = 2 cm, covered by a metasurface based on a metallic square patch unit cell printed on a dielectric substrate. The dielectric layer thickness is t = 3 mm and its permittivity is ε_r = 2. The dimension of the metasurface unit cell is D = 12.04 mm such that there are N = 12 cells in the azimuthal direction.

The structure is simulated with CST Microwave Studio. On the top and bottom of the cylinder periodic boundary conditions are imposed to emulate an infinite structure. The considered incident field is a TM polarised planewave.

The metasurface unit cell is composed of a two square metallic patches, with length g_1 = 10.04 mm and g_2 = 8.04 mm respectively. The two patches are periodically repeated in the azimuthal direction with two different periods. In particular, in the first configuration the two patches are alternated (Fig. 1a), while in the second one, a single patch is repeated three times (Fig. 1b).

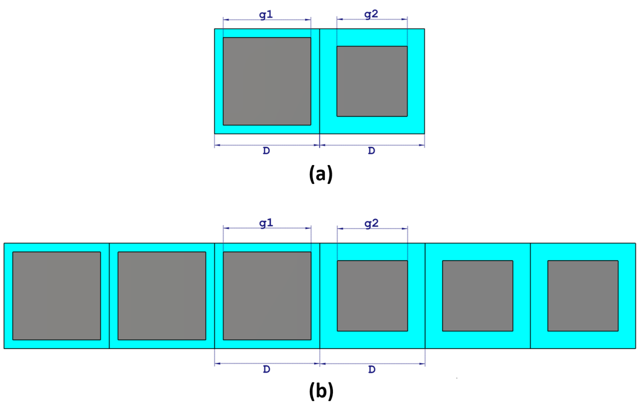

Fig. 1. Unit cells of the proposed inhomogeneous metasurfaces.

The scattering reduction obtained with the two inhomogeneous configurations are studied and compared with the one obtained for an homogeneous metasurface, i.e. realised by the repetition of a single square patch (with length g_1 or g_2). The cloaking performances are evaluated in terms of Scattering Width SW defined as:

$$SW = \lim_{\rho \to \infty} 2\pi\rho \frac{|E_s|^2}{|E_i|^2} \tag{2}$$

where E_i is the incident field.

As can be seen in Fig. 2 the cloaking frequencies of the homegeneous metasurfaces are f = 6 GHz, and f = 8.1 GHz, for g_1 and g_2 respectively. As expected, the latter configuration shows a higher SW due to the higher electrical dimensions of the object.

Considering the inhomogeneous configurations, while the arrangement with alternating cells presents a lower scattering reduction with respect to the homogeneous ones, interestingly, the double cell with period 3 produces a higher SW reduction. In fact, in this case the cloaking SW is 8.2 dB lower than the bare case at f = 6.4 GHz which correspond to a normalized cylinder radius a/λ_0 = 0.43. Moreover, also the cloaking 3 dB bandwidth is increased up to 16.4%.

It must be underlined, that in the case of a homogeneous metasurface the cloaking is independent of the incoming wave direction, while for the inhomogeneous metasurfaces the cloaking is directional. However, this is not a problem in many applications in which the direction of the incident field is known.

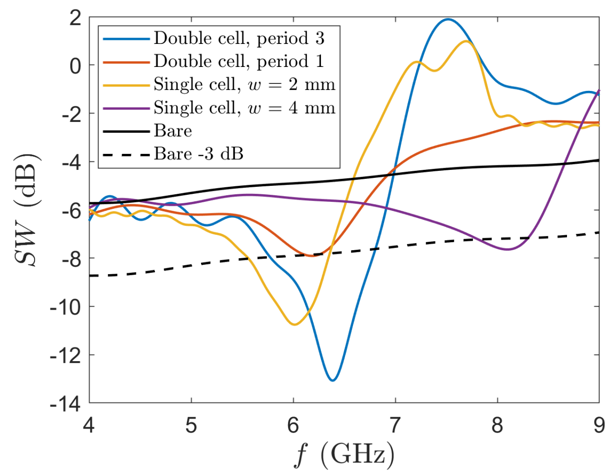

Fig. 2. Scattering width of the cloaked structures for different metasurface configurations, and the bare metallic cylinder.

IV. Conclusions

In this paper, a inhomogeneous metasurface for cloaking applications has been presented. The metasurface unit cell is composed of two metallic square patches with different length. It is shown that for a specific disposition of the single patches, it is possible to increase both the scattering reduction and the cloaking bandwidth with respect to a homogeneous metasurface configuration.

References

[1] D. Schurig, J. J. Mock, B. J. Justice, S. A. Cummer, J. B. Pendry, A. F. Starr and D. R. Smith, “Metamaterial electromagnetic cloak at microwave frequencies,” Science, Vol. 314, pp. 977-980, 2006.

[2] Y. R. Padooru, A. B. Yakovlev, P. Chen, A. Alù, “Analytical modeling of conformal mantle cloaks for cylindrical objects using subwavelength printed and slotted arrays,” Journal of Applied Physics, 112, 034907, 2012.

[3] G. Labate, S.K. Podilchak, L. Matekovits, “Closed-form harmonic contrast control with surface impedance coatings for conductive objects,” Applied Optics, vol. 56, Issue 36, pp. 10055–10059, 2017.

[4] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, “Composite medium with simultaneously negative permeability and permittivity,” Physical Review Letters, vol. 84, Issue 18, pp. 4184–4187, 2000.

[5] W. J. Padilla, D. N. Basov, and D. R. Smith,“Negative refractive index metamaterials”, Materials Today, vol. 9, Issue7-8, pp. 28–35, 2006.

[6] A. Alù, N. Engheta, “Achieving transparency with plasmonic and metamaterial coatings”, Phyisical Review E, vol. 72, 016623, 2005.

[7] P. J. Chen, A. Alù, “Mantle cloaking using thin patterned metasurfaces,” Phyisical Review B, vol. 84, 205110, 2011.

[8] A. Alù, “Mantle cloak: Invisibility induced by a surface,” Physical Review B, vol. 80, no. 24, 245115, 2009.

[9] B. Cappello, L. Matekovits, "Spectral Composition of the Scattered Field from a Large Metallic Cloaked Cylinder," Proc. of the 20^{th} International Conference on Electromagnetics in Advanced Applications (ICEAA18), pp. 240–243, 2018.