URSI EM Theory Symposium, EMTS 2019, San Diego, CA, 27– 31 May 2019

Metasurface Cloaks for Decoupling Closely Spaced Phased Antenna Arrays

Hossein Mehrpour Bernety(1), Alexander B. Yakovlev*(2), Harry G. Skinner(3), and Seong-Youp Suh(3)
(1) Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, Utah, USA
(2) Center for Applied Electromagnetic Systems Research (CAESR)
Department of Electrical Engineering, University of Mississippi, University, MS 38677-1848, USA
(3) Intel Corporation, Hillsboro, OR 97124, USA

Abstract

Here, we propose to apply the concept of electromagnetic invisibility/cloaking for decoupling two closely spaced antenna arrays operating at neighboring frequencies. Array elements used here are strip monopole antennas covered by previously designed conformal and confocal elliptical metasurface cloaks. We demonstrate that by cloaking two closely spaced antenna elements in strongly coupled antenna arrays enables to decouple the entire arrays in the near-field and in the far-field. The simulation results of two overlapping linear arrays operating at $f_1 = 2.95$ GHz and $f_2 = 3.35$ GHz are provided as examples.

1. Introduction

Electromagnetic invisibility has been an interesting application of engineered metamaterials and metasurfaces in recent years. To realize this concept, various methods have been proposed such as transformation optics [1], transmission-line networks [2], and plasmonic cloaking [3], among others. These techniques require bulky volumetric metamaterials, and thus, may not be suitable for antenna applications that rely on low-profile and thin metasurfaces.

To surmount the aforementioned issue and meet the requirements of antenna applications, the concept of mantle cloaking has been proposed to reduce the scattering width of various objects [4]–[10] at microwave and low-terahertz (THz) frequencies. In this approach, to make a given object with subwavelength dimensions cloaked for an impinging electromagnetic field, the object is wrapped by an ultrathin metasurface, which provides anti-phase surface currents resulting in the cancellation of the dominant scattering mode from the object.

Mutual coupling between closely spaced antennas has been an issue which hinders antenna performance. To overcome this undesired effect, it has been proposed to utilize metamaterials to decouple antennas [11]. As a realization of this concept, the mantle cloaking method has been used for reduction of the mutual coupling between free-standing cylindrical dipole antennas [12]. The metasurface cloaks not only make it possible to reduce mutual coupling drastically but also restore the original radiation patterns of the isolated antennas [13]–[17], in such a way that the neighboring antennas do not sense the presence of each other. Very recently, this concept has been applied to wideband microstrip monopoles at microwave frequencies [18].

In this paper, we introduce the concept of decoupling two closely spaced phased antenna arrays operating at neighboring frequencies, based on the idea of reducing the mutual coupling between two closely spaced antennas. The literally closely spaced arrays enable to use the same array size or aperture for two different arrays, which is traditionally used for only one array, and leads to a significant size and cost reduction in practical applications, and at the same time, helps to improve frequency diverse radar systems. To introduce this novel aspect, here we consider two strip monopole antenna arrays operating at $f_1 = 3.02$ GHz and $f_2 = 3.33$ GHz, with $\lambda_1/10$ spacing (λ_1 is the wavelength at f_1) between the elements of the two arrays.

2. Decoupling Phased Antenna Arrays

Elliptically shaped metasurface cloaks have shown potential for the efficient reduction of mutual coupling between two closely spaced strip dipole antennas in such a way that the antennas operate almost independently from each other, and are decoupled both in the near-field and in the far-field [15]. Considering the previously designed elliptical metasurface cloaks for these antennas with the design parameters given in [15], here we take into account the case of two closely spaced (overlapping) linear phased arrays made of 11 strip monopole antennas on an infinite ground plane shown in Fig. 1 (as the equivalents of the previously designed strip dipole antennas [15]) resonating at $f_1 = 2.95$ GHz (Array I) and $f_2 = 3.35$ GHz (Array II). The element spacing for each array is $d = 50$ mm (which is $0.5\lambda_1$ or $0.56\,\lambda_2$), and the inter-element deeply subwavelength spacing between the two arrays is 10 mm (which is $\lambda_1/10.2$ or $\lambda_2/9$).

We consider two scenarios: (a) Array I is ON and Array II is OFF, (b) Array I is OFF and Array II is ON. The simulations are performed using CST MWS [19]. For the former scenario, we have chosen two different scan angles of $\theta_0 = 30°$ and $\theta_0 = 60°$ and their respective realized gains are shown in Fig. 2. The elliptical metasurface cloaks provide restoration of the patterns of Array I in the presence of Array II even with such small spacing. Also, Fig. 3 shows the total efficiency of Array I for $\theta_0 = 60°$. It can be seen that the metasurfaces wrapped around the elements of Array II make it possible to retrieve the total efficiency of Array I at $f_1 = 2.95$ GHz, and at the same time, the metasurfaces covering the elements of Array I make this array a poor radiator at the resonance frequency of Array II, and thus, decouple the entire arrays.

For the latter scenario, we have chosen $\theta_0 = 25°$. Its respective realized gain at $f_2 = 3.35$ GHz and the total efficiency are shown in Fig. 4. Similar to the previous scenario, it can be seen that the metasurfaces recover the radiation characteristics of Array II although its elements are positioned with the deeply subwavelength distance from the elements of Array I.

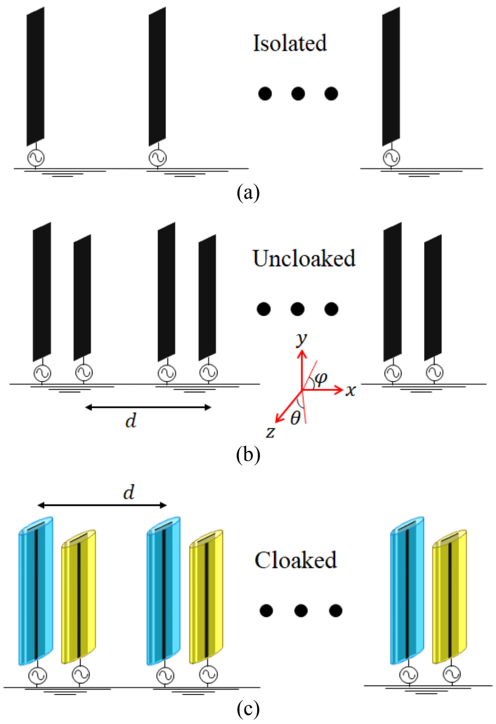
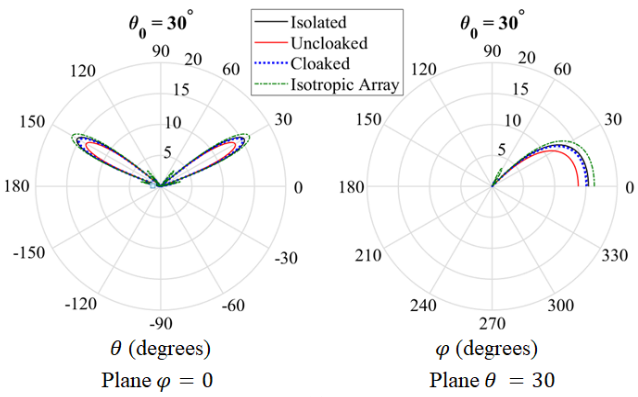
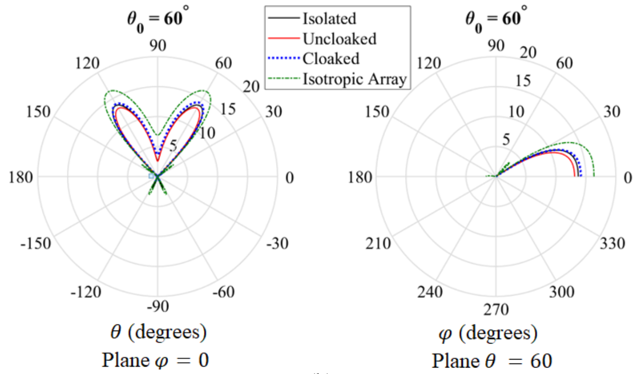


Fig. 1. Schematics of (a) isolated Array I, (b) uncloaked, and (c) cloaked linear phased arrays made of strip monopole antennas.



(a)



(b)

Fig. 2. (a) Realized gain of Array I for (a) $\theta_0 = 30°$ and (b) $\theta_0 = 60°$, at $f_1 = 2.95$ GHz.

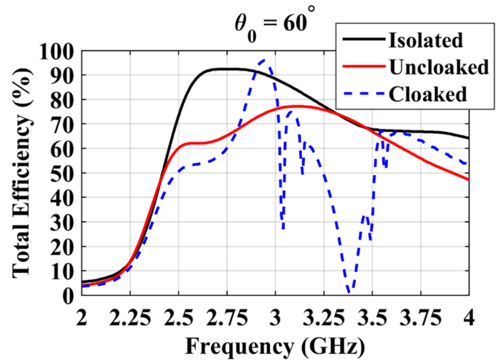
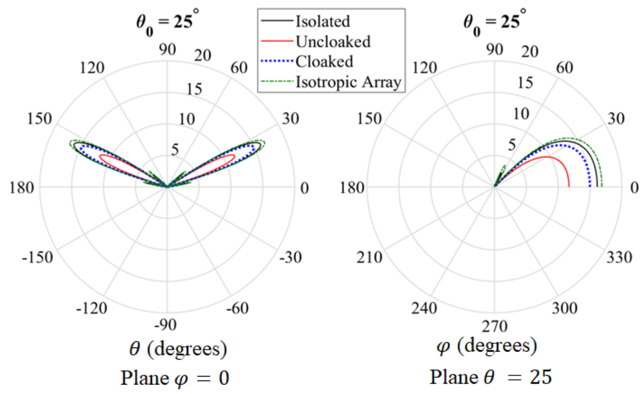
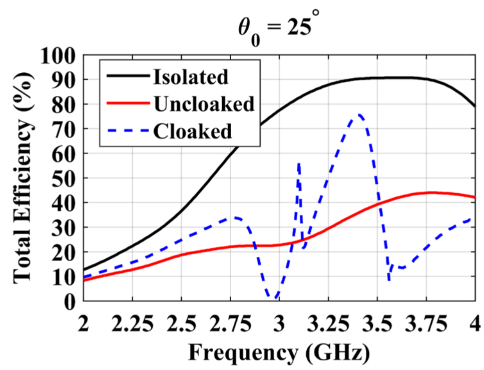


Fig. 3 The total efficiency of Array I for $\theta_0 = 60°$.



(a)



(b)

Fig. 4. (a) Realized gain of Array II at $f_2 = 3.35$ GHz and (b) the total efficiency for (a) $\theta_0 = 25°$.

3. Conclusions

In this paper, we have proposed the concept of mantle cloaking for decoupling two closely spaced linear phased antenna arrays operating at adjacent frequencies. The simulation results verify that by wrapping the engineered elliptical metasurfaces around the elements of Array I, makes it possible to recover the radiation properties of Array II, and vice versa, in such a way that the arrays operate independently and are almost isolated from each other. This design will lead to densely packed arrays occupying much less space compared to the conventional designs, and also, provide frequency diversity.

4. Acknowledgements

This work has been supported by the NSF I/UCRC Grant 1539990 and by the Intel Corporation.

5. References

1. J. B. Pendry, D. Schurig, and D. R. Smith, "Controlling electromagnetic fields," *Science*, vol. 312, no. 5781, pp. 1780–1782, 2006.

2. P. Alitalo, O. Lukkkonen, L. Jylha, J. Venermo, and S. A. Tretyakov, "Transmission-line networks cloaking objects from electromagnetic fields," *IEEE Trans. Antennas and Propag.*, vol. 56, no. 2, pp. 416–424, 2008.

3. A. Alù and N. Engheta, "Achieving transparency with plasmonic and metamaterial coatings," *Phys. Rev. E*, vol. 72, p. 016623, 2005.

4. A. Alù, "Mantle cloak: Invisibility induced by a surface," *Phys. Rev. B*, vol. 80, p. 245115, 2009.

5. P. Y. Chen and A. Alù, "Mantle cloaking using thin patterned metasurfaces," *Phys. Rev. B.*, vol. 84, p. 205110, 2011.

6. Y. R. Padooru, A. B. Yakovlev, P. Y. Chen, and A. Alù, "Analytical modeling of conformal mantle cloaks for cylindrical objects using sub-wavelength printed and slotted arrays," *J. Appl. Phys.*, vol. 112, p. 0349075, 2012.

7. Z. H. Jiang and D. H. Werner, "Exploiting metasurface anisotropy for achieving near-perfect low-profile cloaks beyond the quasi-static limit," *J. Phys. D: Appl. Phys.*, vol. 46, p. 505306, 2013.

8. P. Y. Chen and A. Alù, "Atomically-thin surface cloak using graphene monolayers," *ACS Nano*, vol. 5, pp. 5855–5863, 2011.

9. P. Y. Chen, J. Soric, Y. R. Padooru, H. M. Bernety, A. B. Yakovlev, and A. Alù, "Nanostructured graphene metasurface for tunable terahertz cloaking," *New. J. Phys.*, vol. 15, pp. 123029, 2013.

10. H. M. Bernety and A. B. Yakovlev, "Cloaking of single and multiple elliptical cylinders and strips with confocal elliptical nanostructured graphene metasurface," *J. Phys.: Condens. Matter*, vol. 18, p. 185304, 2015.

11. D. H. Kwon and D. H. Werner, "Restoration of antenna parameters in scattering environments using electromagnetic cloaking," *Appl. Phys. Lett.*, vol. 92, no. 11, p. 113507, 2008.

12. A. Monti, J. Soric, A. Alù, F. Bilotti, A. Toscano, and L. Vegni, "Overcoming mutual blockage between neighboring dipole antennas using a low-profile patterned metasurface," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1414–1417, 2012.

13. Z. H. Jiang and D. H. Werner, "Dispersion engineering of metasurfaces for dual-frequency quasi-three-dimensional cloaking of microwave radiators," *Opt. Exp.*, vol. 24, no. 9, pp. 9629–9644, Apr. 2016.

14. A. Monti et al., "Mantle cloaking for co-site radio-frequency antennas," *Appl. Phys. Lett.*, vol. 108, no. 11, p. 113502, 2016.

15. H. M. Bernety and A. B. Yakovlev, "Reduction of mutual coupling between neighboring strip dipole antennas using confocal elliptical metasurface cloaks," *IEEE Trans. Antennas Propag.*, vol. 63, no. 4, pp. 1554–1563, Apr. 2015.

16. H. M. Bernety and A. B. Yakovlev, "Decoupling antennas in printed technology using elliptical metasurface cloaks," *J. Appl. Phys.*, vol. 119, no. 1, pp. 014904-1–014904-11, Apr. 2016.

17. G. Moreno, H. M. Bernety, and A. B. Yakovlev, "Reduction of mutual coupling between strip dipole antennas at terahertz frequencies with an elliptically shaped graphene monolayer," *IEEE Ant. Wireless Propag. Lett.*, vol. 15, pp. 1533–1536, Dec. 2015.

18. G. Moreno , A. B. Yakovlev , H. M. Bernety, D. H. Werner, H. Xin, A. Monti, F. Bilotti, and A. Alu, "Wideband elliptical metasurface cloaks in printed antenna technology", *IEEE Trans. Antennas Propag.*, vol. 66, no. 7, pp. 3512-3525, July 2018.

19. CST Microwave Studio 2015: www.cst.com