A Metasurface for RCS Reduction in X Band

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Abstract— In this paper, we will introduce an ultrathin metasurface, which is based on destructive interference between the incident and reflected waves and therefore leads to dramatic decrease of backward RCS. The main lobe and some of the side lobes of the scattering pattern of the targets could be suppressed significantly. When the phase shifts of metallic patches of the metasurface are randomly distributed, the reflected energy from the random metasurface will be scattered in various directions, resulting in the RCS reduction. By comparing the scattering pattern of the designed metasurface and a pure metallic plate with the same dimensions, the backward RCS can be reduced by more than 10 dB within the whole X band.

1. INTRODUCTION

With many novel detection systems and precision-guided weapons developed, stealth technologies based on metamaterials [1–15] have attracted much attention in the military field. As radar is the mainstream technology for target detection, RCS reduction [16–19] plays an important role for military targets to survive.

In this paper, we have proposed an ultrathin metasurface [20] based on destructive interference between the incident and reflected waves to reduce the RCS of targets. By tuning the structural parameters of the composing elements, a phase range of 0°–360° can be realized. Through particular arrangement of these basic elements, the whole metasurface can reflect the incident waves in different directions, resulting in RCS reduction. Simulation results have shown that the backward RCS of this metasurface is reduced by over 10 dB in comparison to a pure metallic plate.

2. DESIGN AND SIMULATION

In our design, a single-layer metasurface, which is more compact in size, is designed to realize the backward RCS reduction instead of multilayer structures. And a multi-resonance structure has been chosen as the basic unit as shown in Fig. 1, which is composed by an inner quadrate ring and an outer ring with several branches on a grounded substrate. This structure can create two adjacent resonant frequency bands so as to broaden the frequency band of the basic unit, which can also be used as the unit of reflect-array antennas. In addition, the two-ring combination can also increase the total phase shift range by introducing a second resonant band.

F4B ($\varepsilon = 2.65$) is chosen as the substrate of the metasurface, and the thickness is 4 mm. The line width d is 0.35 mm, and the gap width g is 0.3 mm. The unit period b is 10 mm. The reflected phase varies with the change of the branch length. We have plotted the reflected phase curves with the branch length changing from 0.2 mm to 2.4 mm at 8 GHz, 9 GHz, 10 GHz, 11 GHz and 12 GHz in Fig. 2. The linearity of the reflected phase curves can meet the final design requirements as in Fig. 2.

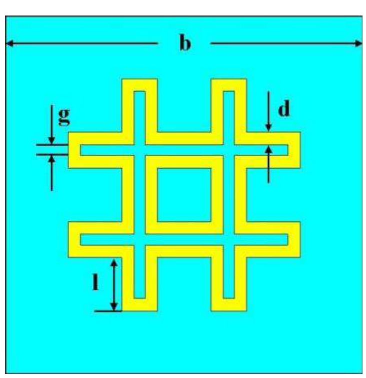


Figure 1: The front view of the basic unit.

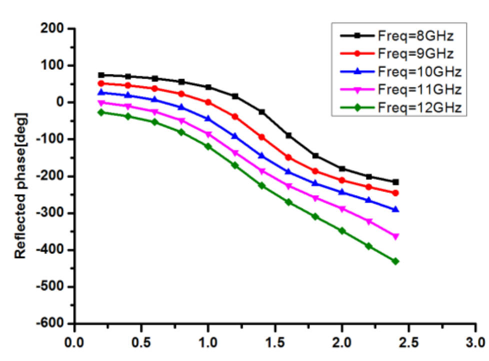


Figure 2: Reflected phase curves versus length of different frequencies.

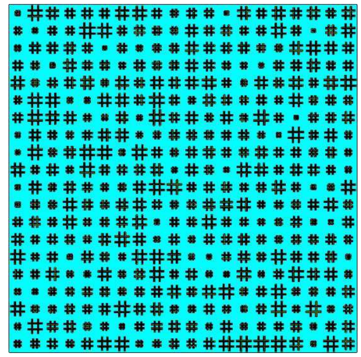
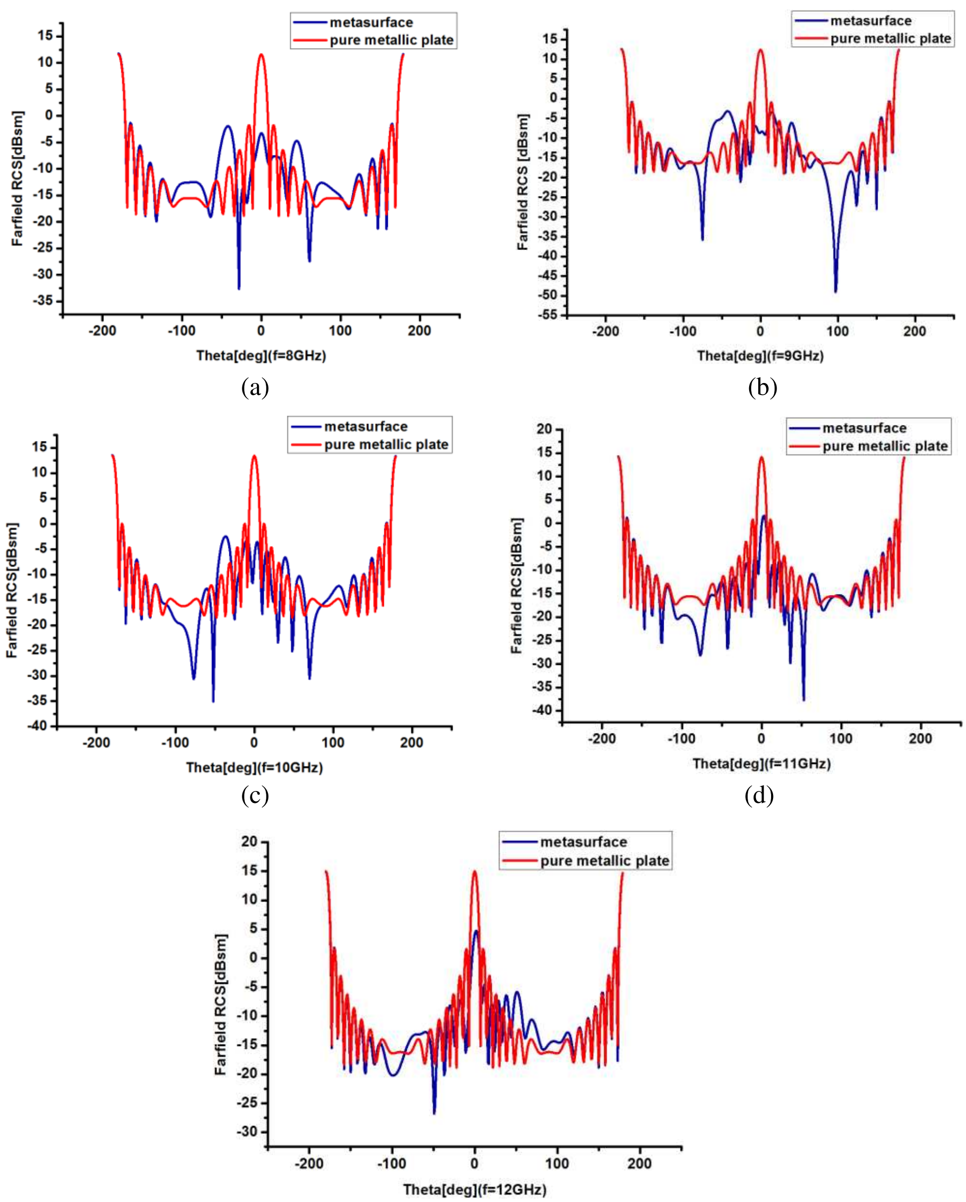


Figure 3: The final design of the metasurface for backward RCS reduction.



(a) (b) (c) (d) (e)

Figure 4: Comparison between the backward RCS of the metasurface and that of the pure metallic plate at (a) 8 GHz, (b) 9 GHz, (c) 10 GHz, (d) 11 GHz, (e) 12 GHz under normal incident waves.

The final metasurface is a $20 * 20$ array as shown in Fig. 3. For waves incident normally, the reflected energy from the single layer metasurface will be scattered in various directions since the phase shifts of metallic patches are designed to be randomly distributed. And it can be concluded that the phase has a linear relationship with the length l from Fig. 2. In our design, we have randomly produced a $20*20$ phase matrix ranging from 0 to 360 degrees first. Then the corresponding dimensions for the phases can be obtained from Fig. 2. With all these parameters confirmed, we construct the model through the electromagnetic simulation tool CST and compare the RCS of the metasurface and that of a pure metallic plate in X band, as shown in Fig. 4.

Also we have plotted the backward RCS reduction in Fig. 5 based on the simulation results. From Fig. 5, we can conclude that when covered by the designed metasurface, the RCS of targets can be reduced by at least 10 dB in the whole X band. And it can even reach above 20 dB at some frequencies, which proves the correctness of our design.

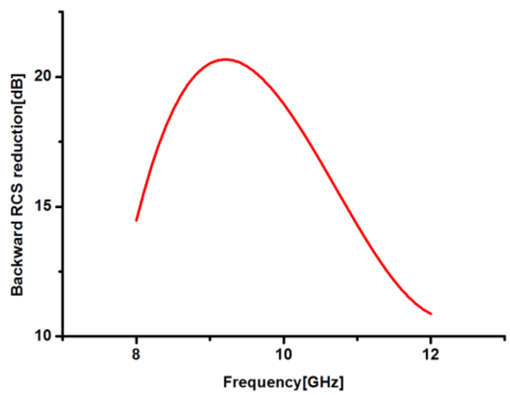


Figure 5: Backward RCS reduction in X band under normal incident waves.

REFERENCES

1. Schurig, D., J. J. Mock, B. J. Justice, et al., "Metamaterial electromagnetic cloak at microwave frequencies," *Science*, Vol. 314, No. 5801, 977–980, 2006.
2. Cai, W., U. K. Chettiar, A. V. Kildishev, et al., "Optical cloaking with metamaterials," *Nature Photonics*, Vol. 1, No. 4, 224–227, 2007.
3. Valentine, J., J. Li, T. Zentgraf, et al., "An optical cloak made of dielectrics," *Nature Materials*, Vol. 8, No. 7, 568–571, 2009.
4. Milton, G. W., M. Briane, and J. R. Willis, "On cloaking for elasticity and physical equations with a transformation invariant form," *New Journal of Physics*, Vol. 8, No. 10, 248, 2006.
5. Landy, N. I., S. Sajuyigbe, J. J. Mock, et al., "Perfect metamaterial absorber," *Physical Review Letters*, Vol. 100, No. 20, 207402, 2008.
6. Hao, J., L. Zhou, and M. Qiu, "Nearly total absorption of light and heat generation by plasmonic metamaterials," *Physical Review B*, Vol. 83, No. 16, 165107, 2011.
7. Cheng, Q., T. J. Cui, W. X. Jiang, et al., "An omnidirectional electromagnetic absorber made of metamaterials," *New Journal of Physics*, Vol. 12, No. 6, 063006, 2010.
8. Hao, J., Y. Yuan, L. Ran, et al., "Manipulating electromagnetic wave polarizations by anisotropic metamaterials," *Physical Review Letters*, Vol. 99, No. 6, 063908, 2007.
9. Menzel, C., C. Helgert, C. Rockstuhl, et al., "Asymmetric transmission of linearly polarized light at optical metamaterials," *Physical Review Letters*, Vol. 104, No. 25, 253902, 2010.
10. Yu, A., F. Yang, and A. Z. Elsherbeni, "A dual band circularly polarized ring antenna based on composite right and left handed metamaterials," *Progress In Electromagnetics Research*, Vol. 78, 73–81, 2008.
11. Qureshi, F., M. A. Antoniades, and G. V. Eleftheriades, "A compact and low-profile metamaterial ring antenna with vertical polarization," *IEEE Antennas and Wireless Propagation Letters*, Vol. 4, 333–336, 2005.
12. Papasimakis, N., Y. H. Fu, V. A. Fedotov, et al., "Metamaterial with polarization and direction insensitive resonant transmission response mimicking electromagnetically induced transparency," *Applied Physics Letters*, Vol. 94, No. 21, 211902, 2009.

13. Ma, Y., Q. Chen, J. Grant, et al., "A terahertz polarization insensitive dual band metamaterial absorber," *Optics Letters*, Vol. 36, No. 6, 945–947, 2011.
14. Huang, L. and H. Chen, "Multi-band and polarization insensitive metamaterial absorber," *Progress In Electromagnetics Research*, Vol. 113, 103–110, 2011.
15. Chen, H., C. T. Chan, and P. Sheng, "Transformation optics and metamaterials," *Nature Materials*, Vol. 9, No. 5, 387–396, 2010.
16. Rius, J. M., M. Ferrando, and L. Jofre, "High-frequency RCS of complex radar targets in real-time," *IEEE Transactions on Antennas and Propagation*, Vol. 41, No. 9, 1308–1319, 1993.
17. Mosallaei, H. and Y. Rahmat-Samii, "RCS reduction of canonical targets using genetic algorithm synthesized RAM," *IEEE Transactions on Antennas and Propagation*, Vol. 48, No. 10, 1594–1606, 2000.
18. Edalati, A., K. W. Sarabandi, and A. Wide, "Polarization independent RCS reduction using non-absorptive miniaturized-element frequency selective surfaces," 2013.
19. De Cos, M. E., Y. Alvarez, and F. Las-Heras, "On the influence of coupling amc resonances for RCS reduction in the SHF band," *Progress In Electromagnetics Research*, 117, 2011.
20. Zhao, Y. and A. Alù, "Manipulating light polarization with ultrathin plasmonic metasurfaces," *Physical Review B*, Vol. 84, No. 20, 205428, 2011.