Design of Controlling Edge Scattering Based on Tapered Periodic Surfaces Loading

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Abstract— In this paper, a novel method for controlling trailing edge scattering is proposed based on tapered periodic surfaces (TPS) loading. The TPS is realized by periodic square metallic patches with tapered dimensions at the direction perpendicular to the considered edge but keeping its period unchanged. The backscattering properties from the trailing edge with the proposed TPS loading are analyzed and compared with that of original trailing edge for various frequencies. It is observed that wide angular radar cross section (RCS) reduction can be achieved and the maximum reduction of mono-static RCS is 25 dB. Furthermore, it is found that the proposed TPS loading can more effectively suppress edge backscattering for a wide range of azimuth angles than the popular trailing-edge serration method.

1. INTRODUCTION

With the rapid development of detecting technology, radar cross section (RCS) reduction becomes very important for stealth techniques for military aircrafts or ships [1]. Basic techniques used for RCS reduction involve appropriate shaping, use of radar absorbing materials, and passive and active cancellation of scattered field. Experimental evidence indicates that edges are a major potential scattering source of stealth objects after typical sources such as specular reflection, cavity or ducting scattering and angular scattering are effectively controlled [2]. Edge diffraction can be interpreted by the scattering from discontinuous electromagnetic property between edges and its surrounding. In the region of low RCS, edge scattering should be significantly reduced. Resistive strip is widely used in electromagnetic scattering suppression, especially for surface discontinuities [3–6]. It can break up a single strong echo into many weak ones. Serration is a geometric treatment and also be widely applied to the trailing edges of wings. Obvious examples are the B-2 and F-117A aircraft [7]. It can avoid reflection in the direction of the incoming wave so as to reduce the backscattering from the edges. Therefore, resistive loading and serrated edge are two main methods for suppression of edge scattering.

In this paper, a novel method for trailing edge scattering control using tapered periodic surfaces (TPS) loading is presented. The TPS is realized by periodic square metallic patches with tapered dimensions at the direction perpendicular to the considered edge but keeping its period unchanged. The mono-static RCS is simulated for various frequencies in VV-polarization. The VV-polarization is defined that the electric field vector is perpendicular to the considered edge. To further demonstrate that the method of TPS loading is feasible, the mono-static RCS of the trailing-edge serration, a popular design method, is proposed for comparison.

2. DESIGN AND RESULT

The basic unit cell structure of TPS is shown in Figure 1(a) which consists of metallic square patch printed on a grounded lossless dielectric substrate. By changing the size of patch arrays but keeping its period unchanged, the structure of TPS is realized. The periodicity of square patch arrays is p, the length of the patch is a, the thickness and relative dielectric constant of the substrate are d and ε_r, respectively. Figure 1(b) shows the geometry of TPS loading applied to the square metallic plate with a certain thickness. The length and thickness of the plate are $L = 600$ mm and $t = 2$ mm, respectively. For TPS, the length of the patches reduces along the negative x-direction gradually. And the thickness of the substrate is equal to the thickness of the target. The plate lies in the x-y plane with plane wave incident at angle $0^\circ \leq \theta \leq 90^\circ$ and $\varphi = 0^\circ$, where θ is defined as the pitching angle, and φ represents the azimuth angle. Considered that strong trailing edge scattering occurs for VV-polarization [8], in the following discussion, the analysis is limited electromagnetic scattering properties at VV-polarization.

The abrupt termination of the conducting edge gives rise to a very strong scattering field. The TPS can provide a gradual transition from the considered edge to free space to eliminate the abrupt

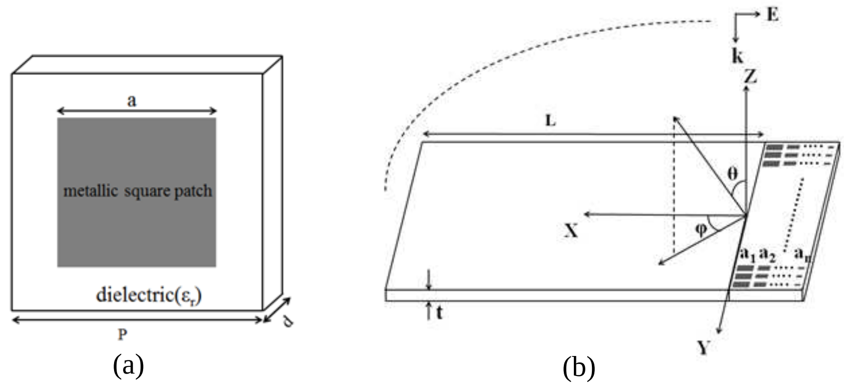

Figure 1: (a) Geometry of a unit cell of uniform periodic square patches printed on a grounded substrate. (b) Geometry of the tapered periodic surfaces loading.

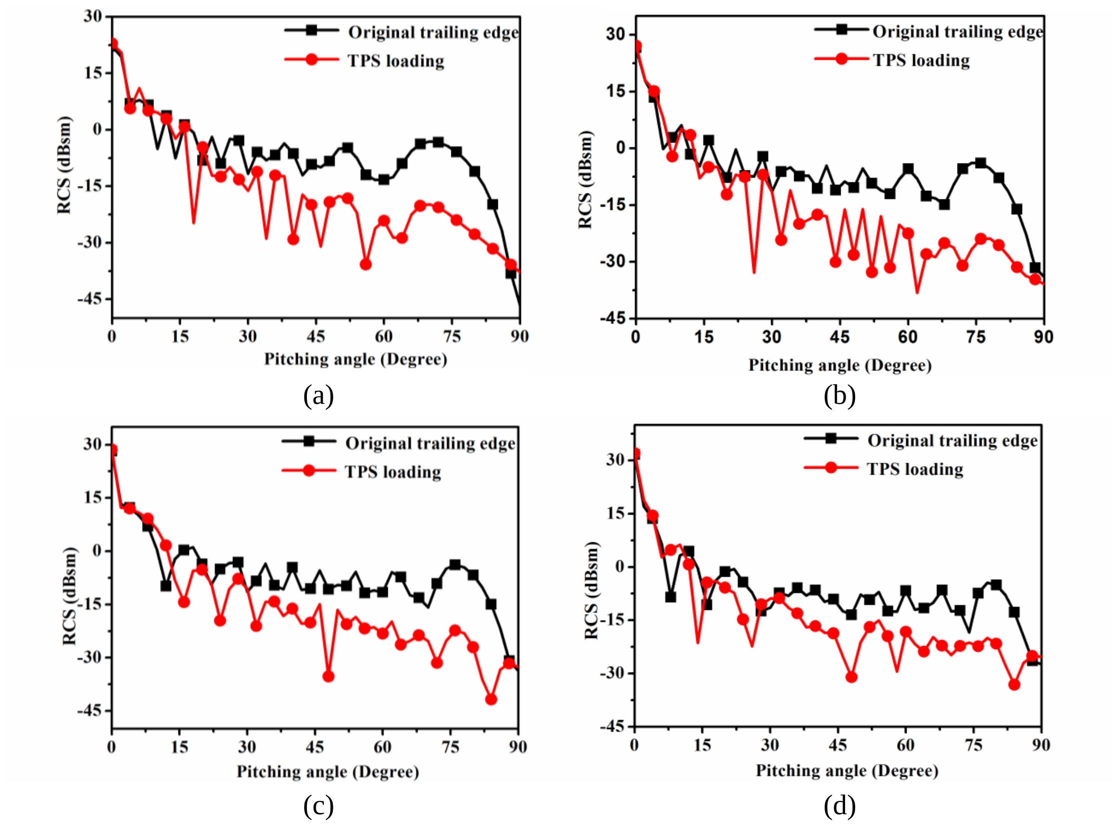

Figure 2: Mono-static RCS from a square plate with original edge and TPS loading for various frequencies: (a) $f = 3\,\text{GHz}$, (b) $f = 5\,\text{GHz}$, (c) $f = 6\,\text{GHz}$, (d) $f = 9\,\text{GHz}$.

edge. Figure 2 shows mono-static RCS pattern for original trailing edge and TPS loading trailing edge at 3 GHz, 5 GHz, 6 GHz and 9 GHz, respectively. For 3 GHz, after the element period and the size patches of TPS are optimized by genetic algorithm, the element period is selected as $P = 25\,\text{mm}$ and the side lengths are selected as $a_1 = 23.6\,\text{mm}$, $a_2 = 21.4\,\text{mm}$, $a_3 = 18.5\,\text{mm}$, $a_4 = 18.5\,\text{mm}$, and $a_5 = 18.5\,\text{mm}$. Similarly, for 5 GHz, $P = 15\,\text{mm}$, $a_1 = 14\,\text{mm}$, $a_2 = 12.5\,\text{mm}$, $a_3 = 11\,\text{mm}$, $a_4 = 9.5\,\text{mm}$, $a_5 = 8\,\text{mm}$, $a_6 = 6.5\,\text{mm}$. For 6 GHz, $P = 12.5\,\text{mm}$, $a_1 = 11.8\,\text{mm}$, $a_2 = 10.7\,\text{mm}$, $a_3 = 9.25\,\text{mm}$, $a_4 = 7.7\,\text{mm}$, $a_5 = 6.3\,\text{mm}$, $a_6 = 5.1\,\text{mm}$. For 9 GHz, $P = 8.33\,\text{mm}$, $a_1 = 7.98\,\text{mm}$, $a_2 = 7.38\,\text{mm}$, $a_3 = 6.43\,\text{mm}$, $a_4 = 5.38\,\text{mm}$, $a_5 = 4.43\,\text{mm}$, $a_6 = 3.58\,\text{mm}$. The parameters of lossless dielectric substrate are fixed as $\varepsilon_r = 2.2$ for various frequencies. Obviously, the TPS loading can effectively suppress the backscattering from trailing edges by the optimal design. The mono-static RCS is reduced up to 20 dB when the pitching angular θ is between 60° and 80°, and the maximum reduction exceeds 25 dB.

To identify the validity of TPS loading, the trailing-edge serration and the TPS loading to reduce mono-static RCS are compared. Serration is widely applied to the trailing edges of wings, which can avoid reflection in the direction of the incoming wave so as to reduce the backscattering from the edges. In this paper, the angle of serration is selected as 114° based on [9]. The element period and the size patches of TPS are selected as $P = 15\,\mathrm{mm}$, $a_1 = 14\,\mathrm{mm}$, $a_2 = 12.5\,\mathrm{mm}$, $a_3 = 11\,\mathrm{mm}$, $a_4 = 9.5\,\mathrm{mm}$, $a_5 = 8\,\mathrm{mm}$, $a_6 = 6.5\,\mathrm{mm}$, and the lossless dielectric substrate is fixed as $\varepsilon_r = 2.2$. Serrated edge and TPS loading applied to the triangle metallic plate with a certain thickness are

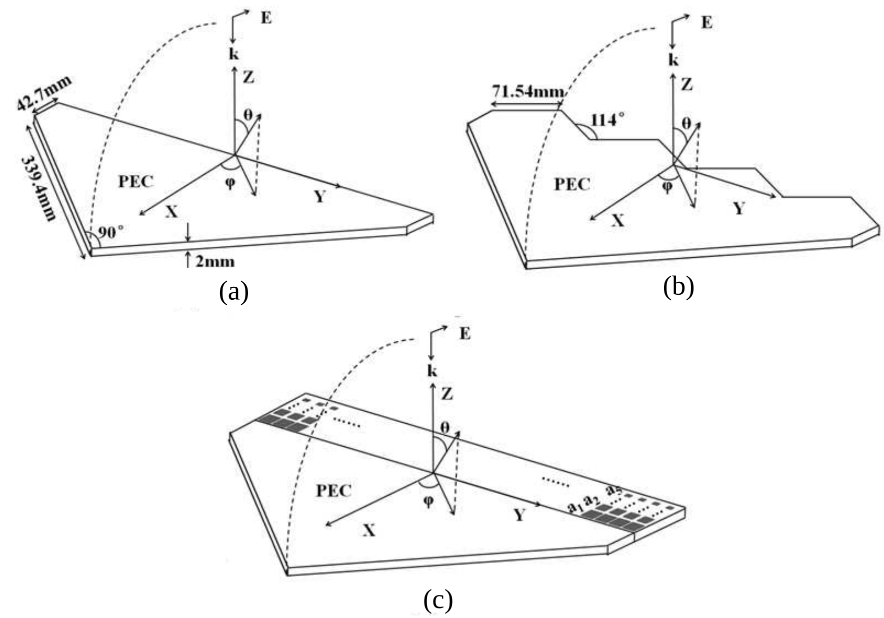

Figure 3: Models for various edge treatments. (a) Original trailing edge. (b) Serrated edge. (c) TPS loading.

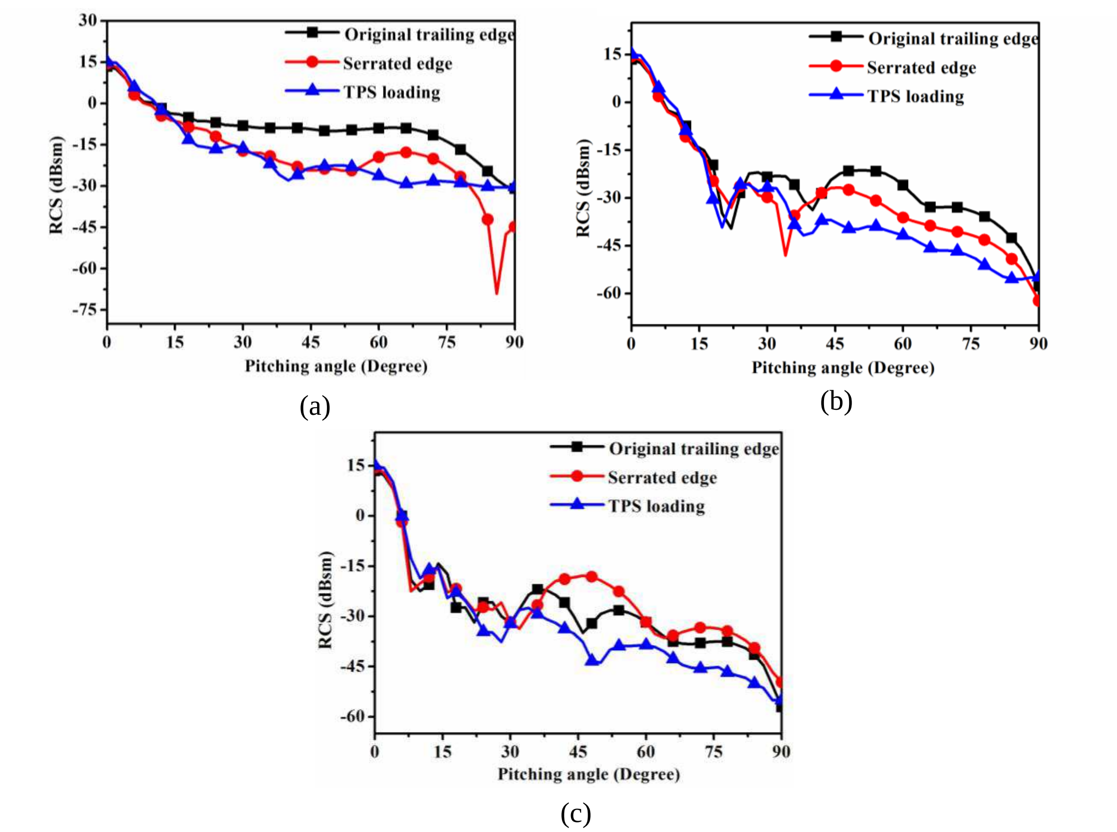

Figure 4: Mono-static RCS from a triangle plate with original trailing edge, serrated edge and TPS loading for various azimuth angles: (a) $\varphi = 0°$, (b) $\varphi = 10°$, (c) $\varphi = 20°$.

shown in Figure 3.

Figure 4 shows electromagnetic scattering patterns for original trailing, serrated edge and TPS loading cases at 5 GHz for the azimuth angle $\varphi = 0°$, $10°$ and $20°$, respectively. Obviously, when the azimuth angle is $0°$, the serrated edge and TPS loading can effectively suppress edge backscattering and the average reduction of mono-static RCS exceeds 10 dB. When the azimuth angle is $10°$, the TPS loading is more effective for the suppression of trailing scattering than serrated edge. When the azimuth angle is $20°$, the mono-static RCS of serrated edge surpasses to the original trailing edge, but the mono-static RCS can still be reduced up to 7∼8 dB at pitching angle $20° < \theta < 90°$ by the TPS loading. Therefore, the TPS loading can effectively suppress edge backscattering for various azimuth angles. However, when the azimuth angle deviates from $0°$, the serrated edge does not work well for edge scattering suppression.

3. CONCLUSION

In this paper, it is shown that tapered periodic surfaces loading can reduce the mono-static RCS of trailing edge. By TPS loading, the average value of RCS reduction up to 20 dB can be achieved in a wide angle range for various frequencies. The trailing-edge serration is a popular and effective method for wide angular RCS reduction of a simple target edge. To identify the validity of TPS loading, the trailing-edge serration and the TPS loading to reduce mono-static RCS are compared. With the azimuth angle deviating from $0°$, the serrated edge is increasingly close to and even surpasses to the original edge. However, for the TPS loading case proposed in this paper, the RCS reduction is rather considerable for a wide range of azimuth angles.

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REFERENCES

1. Mallahzadeh, A. R., M. Soleimani, and J. Rashed-Mohassel, "RCS computation of airplane using parabolic equation," *Asia-Pacific Conference Proceedings Microwave Conference Proceedings, APMC 2005*, Vol. 4, Dec. 4–7, 2005.
2. Ivrissimtzis, L. P. and R. J. Marhefka, "Edge-wave diffraction for flat-plate structures," *IEE Proceedings — Microwaves, Antennas and Propagation*, Vol. 141, No. 1, 30–36, 1994.
3. Chen, H. Y., L. J. Deng, and P. H. Zhou, "Suppression of surface wave from finite conducting surfaces with impedance loading at margins," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 14–15, 1977–1989, 2010.
4. Chen, H. Y., L. J. Deng, P. H. Zhou, et al., "Tapered impedance loading for suppression of edge scattering," *IET Microwaves, Antennas & Propagation*, Vol. 5, No. 14, 1744–1749, 2011.
5. Knott, E. F., "Suppression of edge scattering with impedance strings," *IEEE Transactions on Antennas and Propagation*, Vol. 45, No. 12, 1768–1773, 1997.
6. Chen, H. Y, Z. W. Zhu, L. J. Lu, et al., "Design and implementation of the tapered resistive sheets to control edge scattering," *Journal of Applied Physics*, Vol. 115, No. 16, 164906, 2014.
7. Jenn, D. C., *Radar and Laser Cross Section Engineering*, American Institute of Aeronautics and Astronautics, 2005.
8. Knott, E. F., J. Shaeffer, and M. Tuley, *Radar Cross Section,* SciTech Publishing, 2004.
9. Liu, Z. H., P. L. Huang, Z. Wu, and X. Gao, "Analysis of scattering from serrated edge plate on aircraft with MLFMA," *Journal of Beijing University of Aeronautics and Astronautics*, Vol. 34, No. 05, 499–502, 2008 (in Chinese).