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# Reconfigurable Radar Absorbing Structure Applied to the Antenna Radar Cross Section Reduction

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**Abstract**—An active reconfigurable radar absorbing structure (RAS) with the pin diode was proposed to reduce the radar cross section (RCS) of antenna. The operating states of the RAS reflector can be switched by using the pin diode. For ON-state and OFF-state diodes, the reflection coefficients of the RAS reflector were less than −25 dB and more than −0.8 dB around 8.3 GHz, respectively. The RAS reflector with ON-state diodes can be used as a dipole antenna reflector and has the same radiation performance as a dipole with a metal reflector, while the RAS reflector with OFF-state diodes can be used as a radar absorber for RCS reduction. Meanwhile, chessboard-like geometry RAS reflector was proposed to achieve wideband RCS reduction. The RCS reduction band covers the working band and is extended to 5–18 GHz. The results show that the reconfigurable RAS reflector can contribute to the antenna RCS reduction at working frequency without loss of radiation performance of dipole antenna.

## 1. INTRODUCTION

With the detection and stealth technology developing rapidly, radar cross section (RCS) reduction [1–4] has been a serious problem in military applications and has attracted significant attention recently. Since the scattering of the antennas has contributed a lot to the total RCS for low observable platforms, more and more attention has been paid to antenna scattering. Shaping, coating with radar absorbing materials (RAM) and using passive and active cancellation technology are basic methods in stealth technology [5–7]. Furthermore, a number of new structures and materials are applied to the RCS reduction of antenna, such as artificial magnetic conductor (AMC), radar absorbing structure (RAS), frequency selective surface (FSS), etc. [8–11]. However, these structures and materials cannot be used for stealth in the working band. When RAS is used, the gain of the antenna has a large degeneration [12], and the application of AMC will increase the profile of the antenna. All of them greatly deteriorate the stealth performance and application of radar system or other platform.

In early years, antennas did not need to work in airborne or missile borne systems continuously. To realize the stealth of antenna, the radar was opened in close proximity to the target and shut down through the dangerous area. This method has the advantages of simple, feasible, and good stealth characteristic. In addition, the radiation performance of the antenna is preserved. However, this method can only reduce the antenna mode scattering, and the structural mode scattering still exists. Meanwhile, general metamaterials are completely passive structures, and the properties of these metamaterials cannot be changed. Therefore, in the complex electromagnetic environment, these metamaterials cannot be able to quickly adapt to the changes in the external electromagnetic environment and reduce its effect.

In order to overcome these problems, reconfigurable RAS is put forward as a new concept. Reconfigurable technology has been successfully applied to antenna design. Early research focused on changing the current distribution by adjusting the radiator structure, which made the frequency, pattern, polarization or impedance of antenna changed. Currently, the reconfigurable metamaterial is

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merely used in antenna RCS reduction. At the same time, because the time domain steal method can preserve the radiation performance well, active reconfigurable RAS is combined with the time domain steal method.

In this paper, the application of active reconfigurable RAS in antenna RCS reduction is proposed. The reflection coefficient of an RAS reflector can be switched by a reconfigurable reflector using pin diodes. The RAS reflector can be used as a radar absorber during radar non-operating and as a metal reflector during radar operation. The reconfigurable RAS reflector can contribute to the RCS reduction of dipole without degrading radiation performance. In addition, the proposed method can contribute to antenna RCS reduction without degrading the antenna performance at any radiation frequency. The simulated and measured results show that the radiation performance of the antenna is preserved when active reconfigurable FSS is used. The RCS of the antenna has been considerably reduced.

## 2. RECONFIGURABLE RAS REFLECTOR APPLIED TO THE ANTENNA RCS REDUCTION

The configuration of a dipole antenna is shown in Fig. 1, which is fed by a $50\,\Omega$ coaxial line. The antenna is fabricated on a 1 mm-thick substrate, and $\varepsilon_r = 2.65$, loss tangent is 0. The design values of the dipole antenna are shown in the figure. The working frequency was taken at 5.5 GHz–8 GHz. To achieve better performance, a metal reflector was often added to the dipole antenna. Therefore, mirror scattering will be produced, which is the main reason for increasing the RCS of an antenna. In order to reduce the RCS of a dipole antenna without degrading radiation performance, the original metal reflector antenna was replaced by a reconfigurable RAS in this paper.

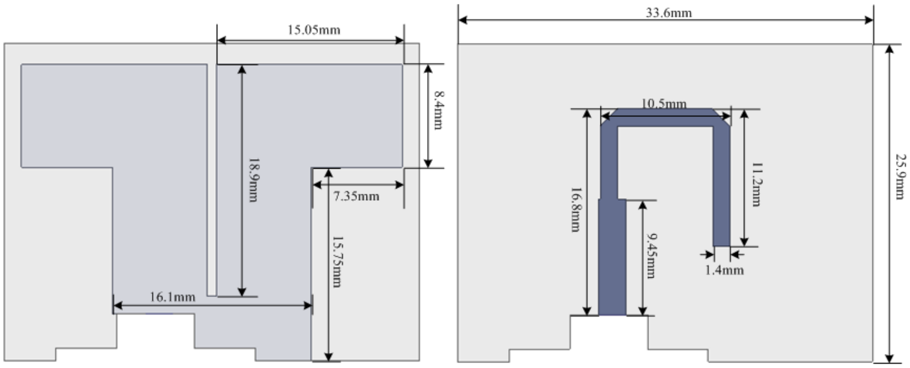


**Figure 1.** The configuration of dipole antenna.

The reconfigurable RAS can be used as an absorber when antenna is not working and as a metal reflector when antenna is working. The RAS can be switched as an absorber and metal reflector by pin diodes with or without DC bias, respectively.

The absorbing bandwidth of the RAS should cover operating band of the dipole antenna for RCS reduction. The RAS is fabricated on the substrate with relative permittivity $\varepsilon_r = 4.4$. Fig. 2 shows the structure of the proposed reconfigurable RAS unit. Metal patterns are made of copper. The copper's thickness is 0.035 mm, and pin diodes are arranged on the surface. The design values of the reconfigurable RAS unit are marked in Fig. 2.

Figure 3 shows the structure of the proposed reconfigurable RAS reflector#1 which is designed by switching reflection level. The RAS metal-backed dielectric spacer is made of FR4. Relative dielectric constant is 4.4, $\tan\delta$ 0.02, and height of the substrate 2 mm. Metal patterns made of copper and pin diodes paralleled to the incident electric field are arranged on the surface. The RAS reflector has two DC supply lines on its top and bottom for biasing the pin diodes. The width of square patch is 6.5 mm, and the gap between adjacent edges of two square patches is 2.5 mm.

In the case that RAS is much thinner than wavelength, the impedance can be treated as inductance $L_s$, and the equivalent circuit model is shown in Fig. 4. $L_c$ is the inductance of copper strip lines on the surface, $C_g$ the capacitance of copper strip line's gap, $Z_0$ the vacuum impedance, and $R_{\mathrm{OFF}}$ and $R_{\mathrm{ON}}$

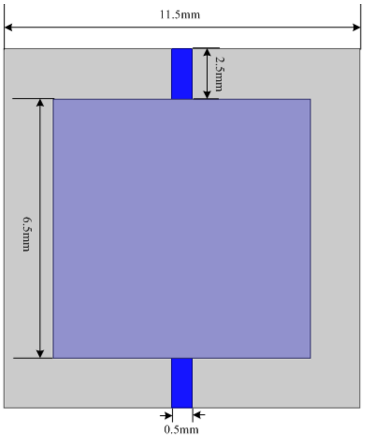


**Figure 2.** The configuration of reconfigurable RAS unit.

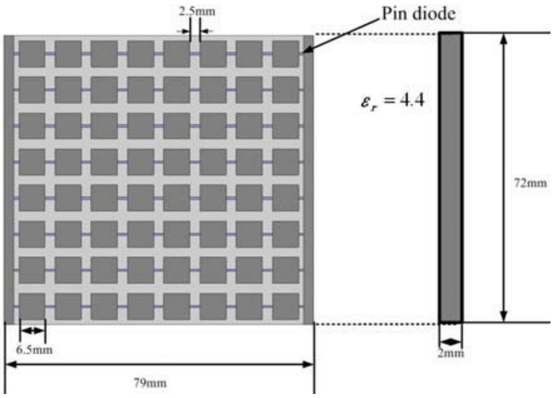


**Figure 3.** The structure of the reconfigurable RAS reflector#1.

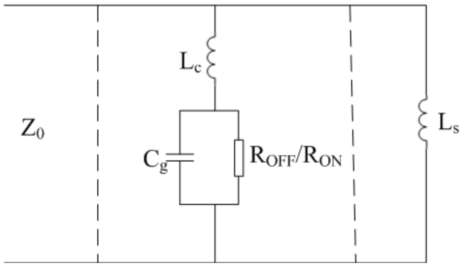


**Figure 4.** Equivalent circuit of the RAS reflector.

are resistance of the loaded pin diode in the OFF and ON-state, respectively. In order to achieve the reconfigurable characteristic, a 300 ohm resistor is in series with the pin diodes, so $R_{\text{ON}}$ is $300\,\Omega$ and $R_{\text{OFF}}$ similar to infinity.

The RAS reflector#1 was fabricated. The reflection coefficient of the reflector with OFF and ON-state diodes was simulated by using the analysis software HFSS 13 by ANSYS. Fig. 5 shows the reflection coefficient result of the proposed RAS reflector with OFF and ON-state diodes. According to the results, it is confirmed that the reflection coefficient can be switched with diodes between OFF and ON-state. With ON-state diodes, the minimum reflection coefficient was less than −15 dB at 8.3 GHz. From the low reflection level, the RAS reflector can be used as a radar absorber at the frequency. With OFF-state diodes, more than −0.8 dB reflection was obtained, and it can be used as a metal reflector. Therefore, it can be reconfigurable between a radar absorber and a metal reflector.

Since the advent of ultra-wideband (UWB) radars and military high-data-rate wireless communications, wideband RCS reduction is critical in future military applications. The control and reduction of the RCS in wideband frequency are becoming more and more important. Therefore, the designed RAS unit cells are combined in a chessboard-like geometry, as shown in Fig. 6, denoted as RAS reflector #2. Three planar RAS prototypes have been manufactured, and the detailed configuration and design values of the chessboard RAS reflector #2 are marked in Fig. 6.

As mentioned above, the dipole antenna with RAS reflectors #1 and #2 was fabricated, as shown in Fig. 7. A printed dipole antenna is simulated and measured with the proposed reflectors #1 and #2 and a metal reflector with the same size as the proposed reflector. Fig. 7 shows the dipole antenna loaded proposed reflectors #1 and #2 with OFF-state diodes, where diodes are biased from DC supply line.

In order to demonstrate the effectiveness of this method, the radiation performance of the antenna with the metal reflector and the proposed reflectors #1 and #2 with OFF-state diodes was evaluated. Fig. 8 shows the simulated and measured $S_{11}$ of the dipole antenna with metal and the proposed

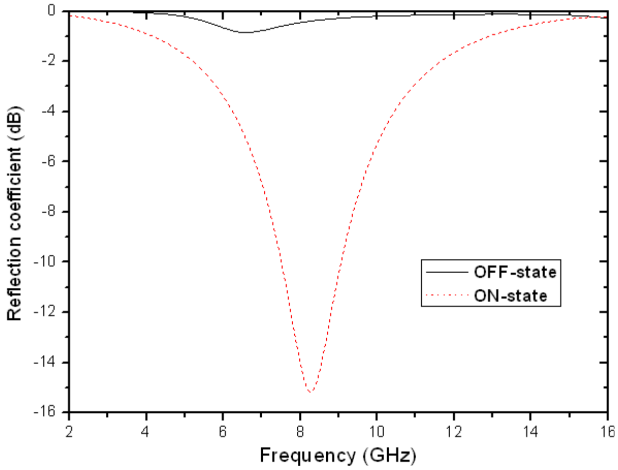


**Figure 5.** Reflection coefficient of the reconfigurable reflector#1.

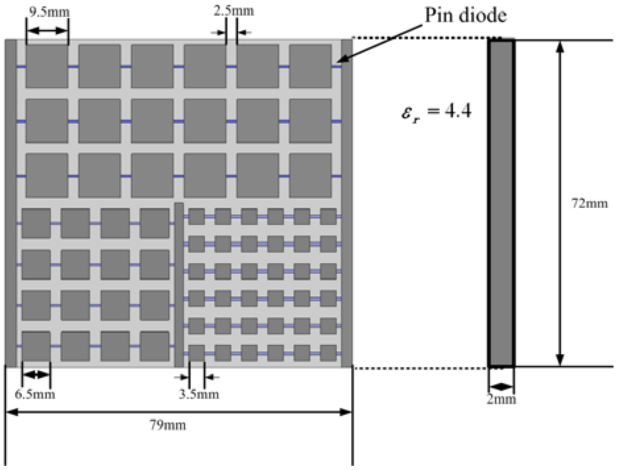
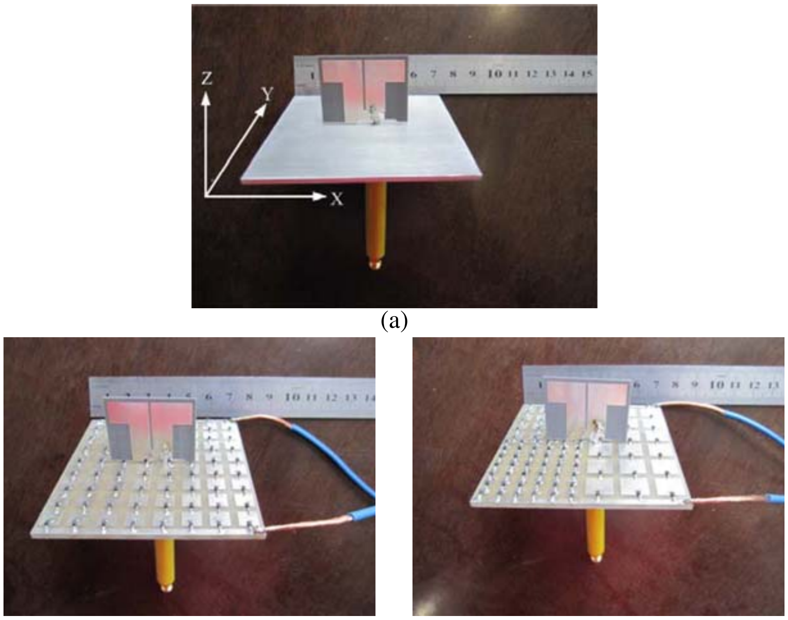


**Figure 6.** The structure of the reconfigurable chessboard RAS reflector #2.



(a)

(b)

(c)

**Figure 7.** The photograph of the dipole. (a) Metal reflector. (b) RAS reflector#1. (c) RAS reflector#2.

reflector#1 and #2. $S_{11}$ with the metal and the proposed reflectors #1 and #2 was less than $-10$ dB in 5.5–8 GHz, which covers the operating frequency band. The proposed reflector with OFF-state diodes has the minimum reflection coefficient as shown in Fig. 5. The measured results agreed well with the simulated ones.

Figure 9 shows the comparison of simulated and measured radiation patterns of the dipole antenna with reflectors in the *xoz*-plane and *yoz*-plane. In both of the *xoz*-plane and *yoz*-plane, the forward powers received by RAS reflectors #1 and #2 are almost the same as the dipole antenna with metal reflector. The simulated and measured radiation performances with the proposed reflectors #1 and #2 were equivalent to that with the metal ones. Therefore, the proposed reflectors #1 and #2 with OFF-state diodes applied to the antenna reflector have equivalent performance to the metal reflector.

Then, the scattering performance of dipole with the metal reflector and the proposed reflectors #1 and #2 was evaluated. The proposed reflector with ON-state diodes is equivalent to a radar absorber

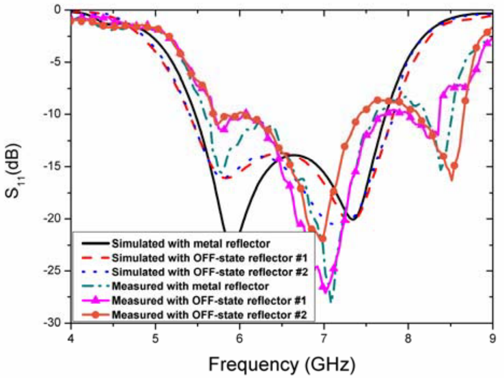
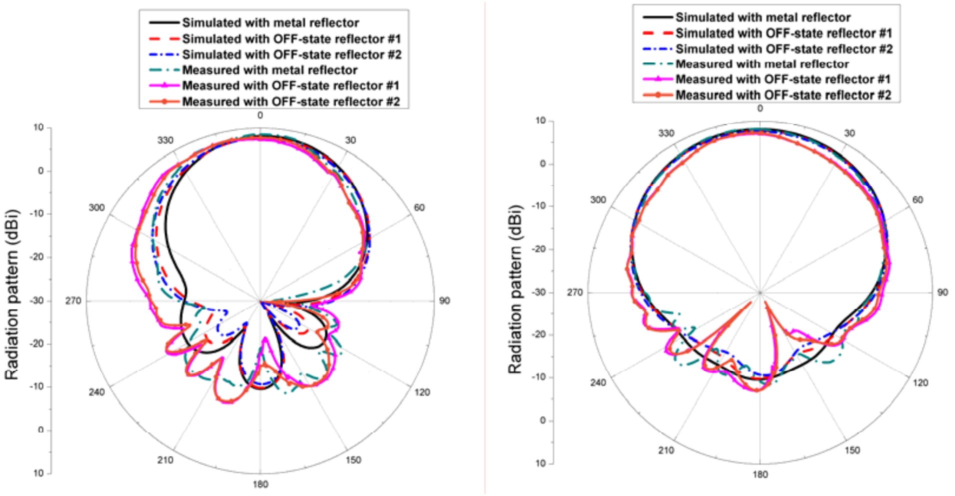


**Figure 8.** The simulated and measured $S_{11}$ of the dipole with metal and proposed reflector#1 and #2.

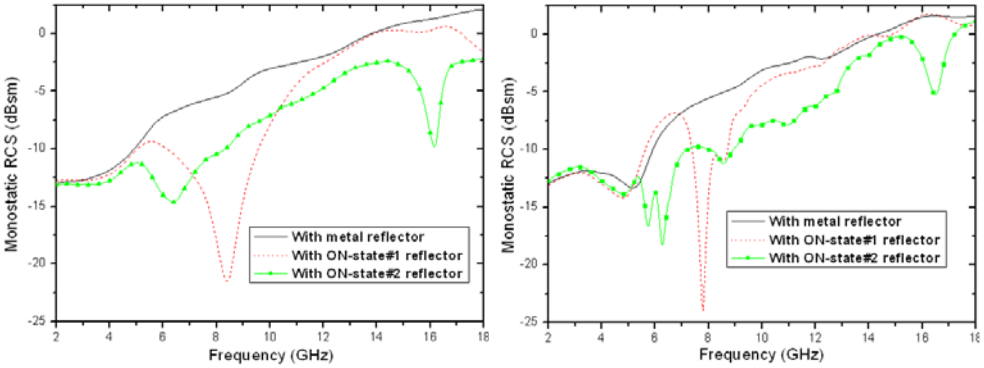


(a) (b)

**Figure 9.** The simulated and measured radiation pattern of the dipole with metal and proposed reflector#1 and #2 (6 GHz). (a) *xoz*-plane, (b) *yoz*-plane.

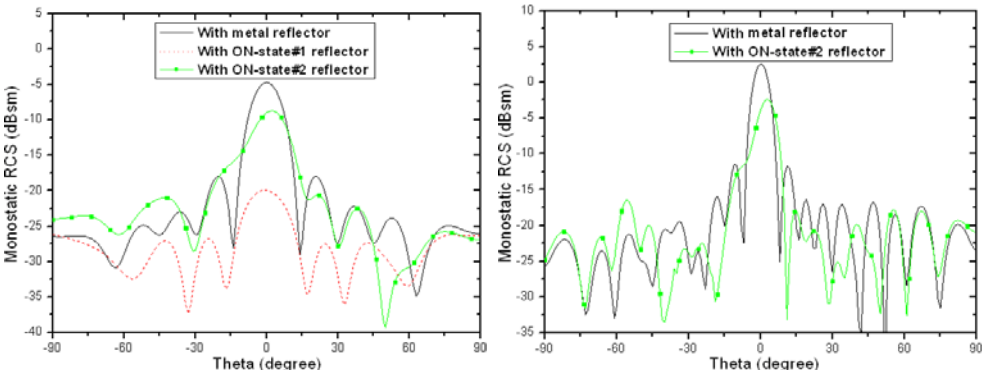
when plane incident wave was illuminated. Fig. 10 shows the analysis of the monostatic RCS of the dipole with RAS reflectors #1, #2 and the metal reflector. The incident wave is perpendicular to the ground plane of the antenna. The dipole is terminated with a matching load. From Fig. 10(a), the incident wave is $\varphi$-polarization, and there is considerable RCS reduction of the dipole with the proposed reflector #1 at 6 GHz–11 GHz, and the largest reduction is more than 16 dB at 8.2 GHz. The bandwidth of the RCS reduction with the proposed reflector #2 is 5 GHz–18 GHz, and it can be seen that the RCS reduction bandwidth of the dipole with reflector #2 is wider than that with reflector #1. Fig. 10(b) shows the analysis of the monostatic RCS under $\theta$-polarization, and the obtained result is similar to that in Fig. 10(a). Therefore, the RCS of the antenna can be reduced by the proposed reflector with ON-state diodes, and the bandwidth performance of the RCS reduction is obviously improved by chessboard-like geometry.

The analysis of the monostatic RCS reduction under different incident angles is proposed in Fig. 11, and the incident wave is $\varphi$-polarized. Fig. 11(a) shows the RCS of the *xoz*-plane at 8.5 GHz, and it can be seen that there is evident RCS reduction of the dipole with reflector #1 in the angular region $-60^\circ \leq \theta \leq +60^\circ$. In contrast, the RCS reduction angular region of the dipole with reflector #2 is $-45^\circ \leq \theta \leq +45^\circ$, and the reduction level is lower than RAS reflector #1. To confirm the wideband performance of reflector #2 by chessboard-like geometry, the comparison of the monostatic RCS of the dipole with RAS reflector #2 and metal reflector is proposed in Fig. 11(b) at 16 GHz. As shown in



(a) (b)

**Figure 10.** The comparison of the simulated RCS of the dipole with the metal reflector, proposed reflector#1 and #2, (a) $\varphi$-polarization, (b) $\theta$-polarization.



(a) (b)

**Figure 11.** The comparison of the simulated RCS of the dipole with the metal reflector, proposed reflector#1 and #2 under different incident angles, (a) 8.5 GHz, (b) 16 GHz.

Fig. 11(b), the RCS reduction angular region of the dipole with reflector #2 in the angular region is $-30° \leq \theta \leq +30°$. Therefore, the monostatic RCS of the dipole using RAS reflector with ON-state diodes can be reduced. Meanwhile, the RCS of dipole with reflector #2 has been reduced in favorable bandwidth.

This section proposes an active reconfigurable RAS reflector with pin diodes applied to the antenna reflector for the antenna RCS reduction. The reconfigurable RAS reflector had different reflection levels switched by pin diodes with or without DC bias and was able to perform between a radar absorber and a metal reflector. The reflector switched as a metal reflector was applied to the dipole antenna reflector and had equivalent radiation characteristic to the same size metal reflector. Therefore, the reconfigurable RAS reflector can contribute to the broadband in-band RCS reduction of the dipole without degrading radiation performance.

## 3. CONCLUSION

An active reconfigurable RAS with pin diodes applied to an antenna reflector for the antenna RCS reduction was proposed. The reconfigurable RAS reflector had different reflection levels switched by pin diodes with or without DC bias and was able to perform between a radar absorber and a metal reflector. The reflector switched as a metal reflector was applied to a dipole antenna reflector and had an equivalent radiation pattern to metal reflector of the same size. The reconfigurable RAS reflector can contribute to the broadband in-band RCS reduction of the dipole without degrading the radiation performance, and the largest RCS reduction is more than 17 dB.

## ACKNOWLEDGMENT

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## REFERENCES

1. Pozar, D. M., "Radiation and scattering from a microstrip patch on a uniaxial substrate," *IEEE Trans. Antennas and Propag.*, Vol. 2, 613–621, Aug. 1987.
2. Gustafsson, M., "RCS reduction of integrated antenna arrays and radomes with resistive sheets," *IEEE Trans. Antennas and Propag. Soc.*, Vol. 3, 3479–3482, 2006.
3. Li, Y.-Q., H. Zhang, Y.-Q. Fu, and N.-C. Yuan, "RCS reduction of ridged waveguide slot antenna array using EBG radar absorbing material," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 473–476, 2008.
4. Cui, G., Y. Liu, and S. Gong, "A novel fractal patch antenna with low RCS," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 15, 2403–2411, 2007.
5. Jiang, W., Y. Liu, S. X. Gong, and T. Hong, "Application of bionics in antenna radar cross section reduction," *IEEE Antenna and Wireless Propagation Letters*, Vol. 8, 1275–1278, 2009.
6. Wang, F., W. Jiang, T. Hong, Q. H. Xue, S. Gong, and Y. Zhang, "Radar cross section reduction of wideband antenna with a novel wideband radar absorbing materials," *IET Microwaves, Antennas and Propag.*, Vol. 8, No. 6, 491–497, 2014.
7. Shang Y., S. Xiao, M.-C. Tang, Y.-Y. Bai, and B. Wang, "Radar cross-section reduction for a microstrip patch antenna using PIN diodes," *IET Microwaves, Antennas and Propag.*, Vol. 6, No. 6, 670–679, 2012.
8. Munk, B. A., *Frequency Selective Surfaces, Theory and Design*, Wiley, New York, NY, USA, 2000.
9. Li, M., S. Q. Xiao, Y.-Y. Bai, and B.-Z. Wang, "An ultrathin and broadband radar absorber using resistive FSS," *IEEE Antenna and Wireless Propagation Letters*, Vol. 11, 748–751, 2012.
10. Genovesi, S., F. Costa, and A. Monorchio, "Wideband radar cross section reduction of slot antennas arrays," *IEEE Trans. Antennas and Propag.*, Vol. 62, 163–173, 2014.
11. Edalati, A. and K. Sarabandi, "Wideband, wide angle, polarization independent rcs reduction using nonabsorptive miniaturized-element frequency selective surfaces," *IEEE Trans. Antennas and Propag.*, Vol. 62, 747–754, 2014.
12. Wang, F.-W., S.-X. Gong, S. Zhang, X. Mu, and T. Hong, "RCS reduction of array antennas with radar absorbing structures," *Journal of Electromagnetic Waves and Applications*, Vol. 25, Nos. 17–18, 2487–2496, 2011.