DESIGN AND POLARIZATION SCATTERING CHARACTERISTICS OF L-SHAPE REFLECTOR

Jiankai Huang¹, ZhanLing Wang¹, Chen Pang¹, Jianbing Li^{1*}, Yongzhen Li¹

¹State Key Laboratory of Complex Electromagnetic Environment Effects on Electronics and Information System,
College of Electronic Science and Engineering, National University of Defense Technology,
Changsha, Hunan 410073, China;
jianbingli@nudt.edu.cn

Keywords: L-SHAPE REFLECTOR, DIPOLE, RADAR CROSS SECTION (RCS), POLARIZATION, LINEAR DEPOLARIZATION RATIO (LDR_{vh})

Abstract

This paper presents a new L-shape reflector to enhance the cross-polarization radar cross section (RCS). Cross-polarization component can increase the jamming effect against the polarization radars. Such L-shape reflectors can also be used as radar tags in cars, books and so on for radar target detection. By bending the structure of traditional dipole reflector to L shape, the direction of surface current is changed, which produces the cross-polarization component. We have simulated L-shape reflector with different lengths of branches in X-band. Compared with the scattering characteristics of traditional dipole reflector, the linear depolarization ratio (LDR_{vh}) of the L-shape reflector can be easily controlled by changing the length of two branches.

1 Introduction

Deploying strong radar reflectors around a target can produce a significant scattering to a radar in a specific frequency range [1]. Compared with active devices, passive ones are cheaper and simpler, thus widely used to enhance the radar cross section [2]. The existing passive radar reflectors include corner reflectors, Luneberg lenses and impedance loading. However, they have large volumes and complex structures [2-4], and need mechanical fixing devices, which are not easy to be installed in the aircrafts. The cost of manufacture and maintenance is also high, making them not suitable for large-scale promotion and use.

The traditional dipole reflectors have the advantages of low profile, cost-effective production and good interference effect in different application scenarios [5]. The dipole reflectors are the most widely used passive jammer with the longest service time since World War II. Tens of thousands of reflectors are thrown into the air to diffuse and form chaff cloud, which generates strong radar echo to shield aircraft targets and jam the radar normal operation. The jamming can be divided into deception jamming and barrage jamming. Deception jamming refers to that aircraft or ships produce effective angle jamming on radar seeker, thus affecting radar angle tracking, and realizing jamming to seeker searching and tracking targets [6]. The typical application of deception jamming is chaff throwing by ships to jam the terminal guidance radar of incoming missiles. It is the last way to

protect the ships. Barrage jamming means that a large amount of chaff is put into a wide range of airspace, such as chaff corridor jamming and chaff area jamming. When the radar target enters the airspace, the strong echo of chaff jamming will submerge the target echo, which can suppress the radar [6].

However, the traditional dipole reflectors can only produce co-polarization backscatter. With the development of polarization radar and polarization information processing technology, the interference performance of traditional dipole reflectors is decreased [7-9].

On the other hand, the resulting radar cross section of the reflector can be much larger than the physical size, which may lead to a good radar detectability of the targets in complex environments. The increase in responses to cooperative radar interrogation also requires the backscattering enhancement [10]. When dipole reflectors are used as tags attached on the targets, the polarization radars can't effectively use its full-polarization information, because the background noise is usually much larger than the cross-polarization echo. In order to enhance the cross-polarization, a planar array of compact conductive film radar reflectors with inductance embedded was proposed [11], [12]. However, such reflectors with additional inductance are too complex. In addition, the influence of the parameters on the polarization scattering performance is not analysed in detail.

Considering a wider range of uses, in this paper, we designed the L-shape reflector and simulated in X-band. Moreover, the relationship between scattering characteristics and parameters is also studied. This article is organized as follows. Section 2 describes structure design and scattering characteristics of the L-shape reflector. Section 3 contains the simulation results and corresponding analysis. Finally, the conclusions are drawn in Section 4.

2. Structure design of L-shape reflector

2.1 Scattering description of a target

When the target is illuminated by the incident EM wave in a specific polarization, the scattering wave depends on the intensity of the incident wave, polarization state and

polarization characteristics of the target. As a general description of the interaction between the incident wave and target, polarization scattering S-matrix is generally used as following [13]

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \mathbf{S}_{vh} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}, \quad (1)$$

$$\mathbf{S}_{vh} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}, \quad (2)$$

where E^s is the scattering field intensity and E^i is the intensity of the incident electric field; h and v refer to the horizontal and vertical polarization. And the S-matrix of the dipole reflector placed horizontally is $\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$.

Most of the targets will scatter polarization waves orthogonal to the incident electric field, which is called depolarization or cross polarization. Linear depolarization ratio (LDR_{vh}) is used to describe the level of depolarization, which is defined as [13]

$$\text{LDR}_{vh} = 10 \log_{10} \frac{|S_{vh}|^2}{|S_{hh}|^2}. \quad (3)$$

2.2 Generation of cross polarization

It is known that the length of an ideal dipole is 0.5λ , where λ is the wavelength of the incident radar wave. If the plane microwave E_i is parallel to an ideal dipole, the excited current distribution along the dipole is (the time harmonic factor is omitted)

$$I(y') = \begin{cases} I_0 \sin[k(0.25\lambda - y')] & (y' > 0) \\ I_0 \sin[k(0.25\lambda + y')] & (y' < 0) \end{cases}, \quad (4)$$

where the dipole is placed along the y axis, and I_0 is the max value of the current. For monostatic station RCS, the far field electric field caused by this current distribution can be written as [13]

$$E_{dipole}^s = \hat{\phi} \frac{jw\mu_0 \sin \varphi}{4\pi R} e^{-jkr} \int_{-l}^l I(y') e^{jkz' \cos(\varphi)} dy'. \quad (5)$$

Fig. 1 The geometry of the L-shape reflector. L_1 and L_2 are the lengths of two branches.

As shown in Fig. 1, the L-shape reflector is formed by bending the traditional dipole at a certain position. In order to excite the resonance, the constraint on length is $L_1 + L_2 = L$.

The current can still flow on the surface because the impedance at the bend does not change greatly. With the current generated in z -direction, the cross polarized electric field is generated as following

$$E_s' = \frac{jw\mu_0 e^{-jkr}}{4\pi R} \left[\hat{\phi} \sin \varphi \int_0^{L_2} I_y'(y') e^{jky' \cos(\varphi)} dy' + \hat{\theta} \sin \theta \int_0^{L_1} I_z'(z') e^{jkz' \cos(\theta)} dz' \right]. \quad (6)$$

In this sense the linear depolarization ratio can be rewritten as

$$\text{LDR}_{vh} = 10 \log_{10} \frac{|\sin \theta \int_0^{L_1} I_z'(z') e^{jkz' \cos(\theta)} dz'|^2}{|\sin \varphi \int_0^{L_2} I_y'(y') e^{jky' \cos(\varphi)} dy'|^2}. \quad (7)$$

Without loss of generality, we choose a horizontal polarization wave $\hat{E}_\varphi$ as the incident wave (see Fig. 1). The right-hand helix rule is composed of horizontal polarization, vertical polarization and the electric field incident direction.

2.3 The shortening effect of dipole

In practice, the diameter of the dipole is not infinitely thin. When the current passes through the end of the dipole, the distributed inductance of the dipole decreases while the distributed capacitance increases, which makes the terminal current larger than that on the ideal dipole. Practically the actual length is shorter than ideal length. This phenomenon is called shortening effect. The total length L is slightly less than half wavelength [14]

$$L = \left[0.5 - \frac{0.11284}{\ln(\lambda / \pi d)} \right] \lambda. \quad (8)$$

3. Simulation results and analysis

3.1 Simulation parameters setting

Shown in Fig. 1, after preliminary optimization, the total length L of the L-shape reflector is 14.156mm at 10 GHz (X-band). The diameter d of the thin slice is 0.238 mm. The reflector material is set as ideal conductor PEC. In all the simulations, the incident wave vector is $\hat{k} = (-1, 0, 0)$, and the incident electric field is $\hat{e} = (0, 1, 0)$ (that is $\hat{E}_y$ or $\hat{E}_\varphi$), with the sweeping frequency from 9 GHz to 11 GHz.

3.2 Current on the L-shape reflector

The electric field amplitude of the incident plane wave is 1 V/m. Fig. 2 shows the electric field and current distribution excited by the horizontal polarization plane wave on the L-shape reflectors with different L_1 . And all the initial phases of the incident wave are 0 deg. Fig. 2(a) shows that the value of the surface current distribution on a traditional dipole almost conforms to the sinusoidal function, indicating that it is resonated with the incident plane wave.

Fig. 2 Current and electric field distribution on L-shape reflector with different L_1 at 10 GHz. (a) $L_1 = 0$; (b) $L_1 = \frac{1}{4}L$; (c) $L_1 = \frac{1}{2}L$; (d) $L_1 = \frac{3}{4}L$; (e) $L_1 = L$; (f) $L_1 = L$.

From Fig. 2(b) to (f), the branch L_1 is gradually becoming longer and L_2 is correspondingly becoming shorter. The incident field is horizontally polarized, but the branch in the z-axis direction generates current, so cross polarized RCS can be generated. The longer L_1 , the larger the current integral on the z-axis branch and the smaller current integral on the y-axis. The cross-polarization becomes larger and the co-polarization component becomes smaller.

It is known that for different L_1 , the position of the maximum current is always at the middle of the two branches. Particularly, when $L_1 = L_2 = 0.5L$, the maximum value happens at the inflection point, and co-polarization current is equal to the cross-polarization current. When L_2 becomes shorter, the effective coupling to the incident field is further reduced, so the absolute value of surface current becomes smaller.

3.3 Dual-polarization backscattering characteristics of L-shape reflector

Fig. 3 shows the monostatic RCS simulation results of the L-shape reflector in X-band with different polarizations. When $L_2 = L$, the L-shape reflector is a traditional dipole reflector. The RCS is mainly contributed by the components of the co-polarization, and the cross-polarization value is almost negligible. The RCS value reaches the maximum at 10 GHz. In the concerned bandwidth (9 GHz-11 GHz) the minimum value is about 4.4dB smaller than the maximum value. The RCS changes are relatively slow with the frequency. When L_1 is specified, and the difference between the co-polarization and cross polarization is stable, and LDR_{vh} is not sensitive to the frequency change. The RCS of traditional dipole reflector is -31.3 dBsm at 10 GHz.

Fig. 3 RCS of L-shape reflector varying with frequency.

When $L_1 = L_2 = 0.5L$, the theoretical values of cross polarization and co-polarization are almost the same. The maximum deviation of the difference is only 1.3dB from 9 GHz to 11 GHz. The LDR_{vh} is only 0.05dB at 10 GHz. The total RCS is 3dB larger than that of the alike polarization or cross polarization, and about 4.4dB smaller than that of the traditional dipole.

As shown in Fig. 4, the longer L_2 , the large total RCS, because the length of electric field coupling part L_2 becomes longer. When L_2 is less than $0.5L$, the cross-polarization component is larger than the co-polarization component. When L_2 becomes large, the co-polarization component increases gradually as well as the total RCS. If L_2 is large enough, the total RCS is almost all contributed by the co-polarization. With L_2 increasing, the cross-polarization increases first and then decreases. The reason is that the effective area of coupling with incident electric field will be smaller and the excited current on the L-shape reflector surface is dominant when L_2 is shorten. With L_2 becoming large than $0.5L$, the coupling current along with z-axis decreases rapidly, which also causes the cross-polarization to decrease quickly. And according to Fig. 4 and Equation (3), any LDR_{vh} can be constructed theoretically.

When $L_2 = 0.5L$, the total RCS of L-shape reflector is 3.227dB, close to 3 dB, smaller than that of the traditional dipole one, because the effective coupling integral length is about one half of the traditional dipole. The co-polarization RCS and cross-polarization RCS is equal. If the incident wave is vertical polarization, $\hat{E}_z$ or $\hat{E}_\theta$, similar results can be obtained. So at the center frequency, the S-matrix of L-shape reflector based on $(\hat{\theta} \ \hat{\phi})^T$ is close to $S_{vh} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$, with $LDR_{vh} = 0$.

Fig. 4 RCS of L-shape reflector varying with L_2 .

The polarization base can be changed though transformation matrix [15]

$$S_{LR} = U^H S_{vh} U, \quad (9)$$

where unitary matrix is $U = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$. When the polarization base is circularly polarization $(\hat{L} \ \hat{R})^T$, S-matrix is $S_{LR} = \frac{1}{\sqrt{2}} \begin{bmatrix} j & 1 \\ 1 & -j \end{bmatrix}$. That means such L-shape reflector works well based on circular polarizations.

4. Conclusion

In this paper, an improved L-shape reflector working in X-band is proposed to be used as the chaff for jamming to cover targets. This reflector enhances the cross-polarization RCS, which can resist the detection of polarization radar. For the circularly polarized waves, scattering components can be also received. The total length of L-shape reflector is slightly less than half wavelength considering the shortening effect. Since the impedance at the bend nodes almost does not change, current will be generated on the branch perpendicular to it. By changing the length of two branches, the ratio between the cross-polarization and co-polarization can be controlled. Theoretically, any linear depolarization ratio LDR_{vh} can be obtained. The parameters are verified by surface current analysis and far-field RCS simulation. The L-shape reflector is simple in structure, easy for manufacture, small in size, and suitable for multiple scenarios. In addition, L-shape reflectors can also be used for target identification, such as car tags and book tags, which can greatly enhance the cross-polarization scattering component of the target and facilitate detection.

5. Acknowledgements

This work is supported by the National Natural Science Foundation of China (NSFC) under Grant 61490690, Grant 61490694, Grant 61625108, Grant 61971429, Grant 61701512, Grant 61771479 and Grant 61625108.

6 References

- [1] Shang Y., Xiao S., Shen Z.: 'Edge-on backscattering enhancement based on quasi-superdirective reradiation', *IEEE Antennas & Wireless Propagation Letters*, 2015, 14, pp. 539-542
- [2] Chandran A R, Gopikrishna M, Aanandan C K, et al.: 'Radar cross-section enhancement of dihedral corner reflector using fractal-based metallo-dielectric structures', *Electronics Letters*, 2006, 42(20), pp. 1135-1136
- [3] E. Dumanis, et al.: 'Design of engineered reflectors for radar cross section modification', *IEEE Transactions Antennas Propag.*, 2013, 61, (1), pp. 232-239
- [4] LI J. L., WANG X. S., LI Y. Z.: 'Polarization characteristics of Gaussian oriented chaff clouds', *Chinese journal of radio science*, 2008, 23, (3), pp. 3-9 (*in Chinese*)
- [5] Liu Y., Xing S., Li Y., et al.: 'Jamming recognition method based on the polarisation scattering characteristics of chaff clouds', *IET Radar, Sonar & Navigation*, 2017, 11(11), pp. 1689-1699
- [6] LI S. S., FU Z. Q., YU J., et al.: 'Research on anti-chaff jamming method based on radar echo signal', *Radar science and technology*, 2016, 14(5):478-482 (*in Chinese*)
- [7] Sherman W., Marcus.: 'Electromagnetic wave propagation through chaff clouds', *IEEE Transactions on AES*, 2007, 55(7), pp. 2032-2042
- [8] W. D. Wood, Jr.: 'An open-cavity RCS enhancement device for airborne applications', in *Proc. IEEE Int. Symp. Antennas Propag. Soc*, 1998, pp. 2190-2193
- [9] M. F. Donovan et al.: 'Polarimetric Observations of Chaff Using the WSR-88D Network', *Journal of Applied Meteorology and Climatology*, 2018, 57(5), pp. 1063-1081
- [10] Wu, Xinzhou, Subramanian, et al.: 'Vehicular communications using dsrc: challenges, enhancements, and evolution,' *IEEE Journal on Selected Areas in Communications*, 2013, 31(9), pp. 399-408
- [11] Yang P., Wu W., Moniri M., et al.: 'Efficient object localization using sparsely distributed passive RFID tags', *IEEE Transactions on Industrial Electronics*, 2013, 60(12):5914-5924
- [12] Guan, Yang.: 'An X-band compact radar reflector tag', 2011 *International Conference on Electronics, Communications and Control (ICECC)*, 2011, pp. 1875-1877
- [13] H. W. J. Russchenberg and L. P. Ligthart.: 'Deriving the linear depolarisation ratio of precipitation from copolar radar measurements', *Electronics Letters*, 1993, 29(12), pp. 1051-1053
- [14] H. Nakano, H. Tagami, A. Yoshizawa, J. Yamauchi.: 'Shortening ratios of modified dipole antennas', *IEEE Transactions on Antennas and Propagation*, 32(4), pp. 385-386
- [15] H. Maurya, R. K. Panigrahi.: 'PolSAR coherency matrix optimization through selective unitary rotations for model-Based decomposition scheme', *IEEE Geoscience and Remote Sensing Letters*, 2019, 16(4), pp. 658-662