Cross-polarization suppression in C-shaped microstrip patch antenna employing anisotropic dielectrics

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An anisotropic dielectric realized by layered ceramic structures was adopted to design a low cross-polarization C-shaped patch antenna. The anisotropic dielectric performs as a substrate and can cause additional cross-polarized fields which are able to cancel the cross-polarized fields generated by the C-shaped patch itself, and then reduce the cross-polarization level. Compared to the C-shaped patch antenna with an isotropic substrate, the cross-polarization of the proposed antenna is suppressed by more than 15 dB with a little gain enhancement at 2.4 GHz. The anisotropic dielectric has a little impact on the direction of the C-shaped patch antenna. The gain of the proposed C-shaped patch antenna is 6.8 dB with a cross-polarization of -28 dB.

Keywords: Anisotropic dielectrics; layered ceramic structures; low cross-polarization; patch antennas.

1. Introduction

Patch antennas are widely used in various wireless communication systems,¹ such as base stations, Wi-Fi and body area networks. Nowadays, people are seeking patch antennas with smaller size with lower cross-polarization. For symmetric rectangular or circular patch antennas, the cross-polarized radiation results from the higher mode of the patch (e.g., the TM_{02} mode). Different techniques have been developed to suppress the cross-polarization of symmetric patch antennas.

Defected ground structures (DGS) are often used to reduce the cross-polarization component of the rectangular or circular patch antennas. Dot- and arc-shaped DGS have been used in circular patch for a relative cross-polarization suppression around 10 dB.^{2,3} In Ref. 4, an L-shaped DGS is used to reduce the cross-polarization by 15 dB. Although these examples demonstrate that DGS can effectively suppress the cross-polarization of the symmetric patch antenna, the DGS method only works in the H -plane, and will reduce the gain and front-back ratio.

With an additional metal wall⁵ and spiral-ring resonator structure,⁶ the cross-polarization of the E-shaped patch antennas can be reduced. By using the overlapped scheme, Zhou *et al.* designed a low cross-polarization patch antenna array.⁷ In addition, the cross-polarization level can also be

degraded by introducing shorting pins in a rectangular patch antenna.⁸ However, such an approach still can only reduce the cross component in the H -plane.

Although the cross-polarization component can be reduced in patch antennas by the above methods, these methods are only useful for suppressing the cross-polarization component raised by the higher resonate mode in symmetric patch antennas. With an asymmetric C-shaped topology, the size of the patch antennas can be significantly reduced⁹ which is highly desirable in compact wireless communication and body area networks. However, due to the asymmetric topology, C-shaped patch antennas suffer a relatively high cross-polarization which severely limits its applications.¹⁰ Moreover, such a high cross-polarization level can hardly be mitigated by DGS or other techniques using symmetric structures or isotropic materials.

In this paper, by implementing an anisotropic substrate, additional cross-polarized electric field is induced, with opposite phase to the cross-polarization component generated by the asymmetric C-shaped topology. Thus, the overall cross-polarization level of the C-shaped patch antenna can be significantly suppressed. Such anisotropic dielectrics can be realized by stacking two materials of different permittivities periodically.¹¹ To the best of our knowledge, this is the first time for anisotropic dielectrics to be applied in the demonstration of cross-polarization level suppression.

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2. Design of the Low Cross-Polarized C-Shaped Patch Antenna

Anisotropic mediums and metamaterials are widely used to control the polarization of electromagnetic waves.^{12–15} Due to the anisotropy of the substrate, the polarization of the fields in rectangular patch antennas can be tuned as shown in Fig. 1. With an isotropic substrate, the y -polarized fields at the two edges are symmetric and cancel each other as shown in Fig. 1(a). However, compared to Fig. 1(a), in Fig. 1(b), on the left edge, the y component of the electric fields is smaller, meanwhile, on the right edge, the $-y$ component of the electric fields is bigger. Thus, with an anisotropic substrate, the y -polarized fields at the edges are asymmetric and the additional net $-y$ component field is raised. Such additional fields can be used to cancel the cross-polarized fields generated by the asymmetric topology of the C-shaped patch antenna.

Fig. 1. Electric fields in rectangular patch antenna: (a) with isotropic substrate; (b) with anisotropic substrate.

(a)

(b)

Fig. 2. The topology of the designed C-shaped patch antenna: (a) top view; (b) back view.

Then, the cross-polarization level can be suppressed effectively.

The dimensions of the designed C-shaped patch antenna is shown in Fig. 2. The blue area is the anisotropic substrate and the gray area is the ground plane. The geometric parameters are set as: $a = 70$ mm, $p = 18$ mm, $l = 13.3$ mm, $s = 3$ mm, $g = 1.8$ mm and $f = 32.6$ mm. The permittivity of the anisotropic substrate $\bar{\epsilon}$ is

$$\bar{\epsilon} = \begin{pmatrix} 7.0 & 0 & 0 \\ 0 & 4.1 & -2.9 \\ 0 & -2.9 & 4.1 \end{pmatrix}. \quad (1)$$

Such an anisotropic dielectric can be realized by a layered structure as shown in Fig. 3. This structure contains foam layers with $\epsilon_1 = 1$ and ceramic layers with $\epsilon_2 = 36$. The thicknesses of the foam and ceramic layers are $d_1 = 2.9$ mm and $d_2 = 0.6$ mm, respectively. The effective permittivity tensor $\bar{\epsilon}'$ in the 45° rotated axis (x', y', z') of such a structure can be calculated by¹¹

$$\epsilon_{x'} = \epsilon_{y'} = \frac{\epsilon_1 + \eta\epsilon_2}{1 + \eta} = 7, \quad (2)$$

$$\frac{1}{\epsilon_{z'}} = \frac{1}{1 + \eta} \left(\frac{1}{\epsilon_1} + \frac{\eta}{\epsilon_2} \right) = \frac{1}{1.2}, \quad (3)$$

where

$$\eta = \frac{d_1}{d_2}. \quad (4)$$

Fig. 3. The C-shaped patch antenna with layered anisotropic structure.

Thus, $\bar{\epsilon}$ can be calculated from

$$\bar{\epsilon} = \frac{R\bar{\epsilon}'R^T}{\det(R)}, \quad (5)$$

where R is the axial transform matrix

$$R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \\ 0 & -\frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{pmatrix}. \quad (6)$$

To demonstrate the cross-polarization suppression performance of the proposed method, a C-shaped patch antenna with the same dimensions as shown in Fig. 2 and an isotropic substrate is designed for comparison. The permittivity of its isotropic substrate is 4.4.

3. Simulation Results

The numerical models of C-shaped patch antennas with isotropic and anisotropic substrates were set up and simulated in a commercial CST MICROWAVE STUDIO. The impedance of the waveguide port is set as 50Ω .

Figure 4 shows the simulated $|S_{11}|$ results of the C-shaped patch antennas with isotropic and anisotropic substrates. The resonate frequency of these C-shaped patch antennas is 2.4 GHz. The simulated $|S_{11}|$ are -19 dB and -18.7 dB for

Fig. 4. The simulated $|S_{11}|$ of the designed C-shaped patch antennas with isotropic and anisotropic substrates.

(a)

(b)

Fig. 5. The simulated radiation patterns of the designed C-shaped patch antennas with anisotropic substrate in (a) H -plane; and (b) E -plane.

the C-shaped patch antennas with anisotropic and isotropic substrates, respectively.

The radiation patterns of the C-shaped patch antennas with anisotropic and isotropic substrates are shown in Figs. 5 and 6, respectively. As shown in Fig. 5, the gain of the antenna is 6.8 dB and the cross-polarization is -28 dB. The radiation patterns in H -plane (yo z plane) and E -plane (xo z plane) are shown in Figs. 5(a) and 5(b). In Fig. 5(a), the maximum value of the cross-polarization is -22 dB. As shown in Fig. 5(b), the maximum value of the cross-polarization is -18 dB. Thus, in the whole angular span, the cross-polarization is below -25 dB compared to the co-polarized gain for both H - and E -planes. Such an omnidirectional angular span is significantly more advanced compared to the widely used DGS methods.

To demonstrate the cross-polarization suppression of the proposed method, a C-shaped patch antenna with the same dimensions is simulated and compared to the antenna with the anisotropic substrate.

The simulated radiation patterns of the C-shaped patch antenna with isotropic substrate are shown in Fig. 6. Due to

Fig. 6. The simulated radiation patterns of the designed C-shaped patch antennas with isotropic substrate in (a) H -plane; and (b) E -plane.

Table 1. Comparison of cross-polarization.

θ [deg]	H -plane	E -plane
	isotropic/anisotropic [dB]	isotropic/anisotropic [dB]
90	-20/-24.35	-14.2/-21.7
45	-13.7/-22	-10/-25.8
0	-12.8/-28	-12.8/-28
-45	-15.8/-24.4	-14/-24
-90	-17.7/-23.3	-16.7/-18.9

the asymmetric topology, the cross-polarization level of the C-shaped patch antenna is greatly higher than the typical rectangular patch antenna.¹⁰

As shown in Fig. 6, the gain and cross-polarization of the C-shaped patch antenna with isotropic substrate are 6.1 dB and -12.8 dB. The maximum value of the cross-polarization component is -12.4 dB and -10 dB in H - and E -planes, respectively. In Fig. 6(a), compared to the co-polarized gain, the cross-polarization is below -18.5 dB in H -plane. The maximum value of the cross-polarization compared to the co-polarized gain is 16.2 dB in E -plane, as shown in Fig. 6(b). Thus, for the antenna with anisotropic substrate, in the radiation direction, the cross component level is significantly reduced by 15.2 dB, and the co-polarized gain is enhanced gently by 0.7 dB.

To further discuss the data in Figs. 5 and 6, Table 1 shows a more clear comparison of the cross-polarization component of these two antennas. The cross-polarization of the C-shaped patch antenna is suppressed in a wide angular span. At the main radiation direction ($\theta = 0^\circ$), the cross-polarization is suppressed greatly by 15.2 dB. According to Table 1, in H - and E -planes, the cross component is reduced at least by 8.3 dB and 10 dB from 45° to -45° , and by 4.35 dB and 2.2 dB from 90° to -90° , respectively.

4. Conclusion

In this paper, a novel method for cross-polarization suppression in a compact C-shaped patch antenna is proposed. By applying an anisotropic substrate, additional cross-polarized field is induced and cancels the cross-polarization generated by the asymmetric patch. Thus, the cross-polarization level in the C-shaped patch antenna can be significantly reduced which makes such a compact antenna much more practical. This method has potential for cross-polarization reduction in other patch antennas with asymmetric structures.

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