Spatial Polarization Characteristic of orthogonal polarization binary array antenna

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Abstract: Antenna polarization states always vary with scan direction which can be named as Spatial Polarization Characteristic (SPC) of antenna. We present a novel antenna module named orthogonal polarization binary array antenna (OPBAA). The advantage of the design is its simple design and prominent SPC. Which can be used for polarimetric application. The theoretical model is derived and spatial polarization characteristic is especially analyzed. Measurement results of an OPBAA formed by two horns are analyzed to verify the conclusions. The OPBAA can reduce the complexity of the communication system which has good application prospect in the future.

Keywords: Spatial Polarization Characteristic, antenna, binary array

Classification: Microwave and millimeter wave devices, circuits, and systems

References

- [1] H. Y. Dai, Y. Z. Li, and X. S. Wang, "A simple design of alternating polarized array antenna and interference suppression technology," *Applied Mathematics and Information Science*, vol. 6, no. 1S, pp. 15s–18s, 2012.
- [2] N. F. Chamberlain, E. K. Walton, and F. D. Garber, "Radar Target Identification of Aircraft Using Polarization-Diverse Features," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 27, no. 1, pp. 58–67, 1991.
- [3] H. Y. Dai, X. S. Wang, J. Luo, Y. Z. Li, and S. P. Xiao, "Spatial polarization characteristics and scattering matrix measurement of orthogonal polarization binary array radar," *Science in China (Series F)*, vol. 53, no. 12, pp. 2687–2695, 2010.
- [4] H. Y. Dai, X. S. Wang, Y. Liu, and Y. Z. Li, "A Novel Discrimination Method of Digital Deceptive Jamming in Mono-pulse Radar," *J. Systems Engineering and Electronics*, vol. 22, no. 6, pp. 910–916, 2011.

- [5] H. Y. Dai, X. S. Wang, and Y. Z. Li, “A new polarimetric method by using spatial polarization characteristics of scanning antenna,” *IEEE Trans. Antennas and Propag.*, vol. 60, no. 3, pp. 1653–1656, 2012.
- [6] W. Wiesbeck and E. Heidrich, “Wide-band multiport antenna characterization by polarimetric RCS measurements,” *IEEE Trans. Antennas Propag.*, vol. 46, no. 3, pp. 341–350, 1998.

1 Introduction

Recently, polarization information has gotten wide applications in such fields as target detection [1], target identification [2, 3] and anti-jamming [4]. By estimating polarization state of active jamming signal, polarization radar can greatly improve its electric counter countermeasures (ECCM) performance [4]. However, single polarized radar does not own polarization information processing ability which restricted the application in polarization area. Ref [5] proposed a novel polarimetric method based on antenna SPC and signal processing in single polarization channel instead of two orthogonal polarized channels, which greatly reduce the development complexity and production cost of fully polarimetric radar. However, the reflector antenna’s SPC is not varied fast and obviously which restrict the polarimetric performance. To solve this problem, a novel antenna module formed by two spatially separated elements is designed, which is named orthogonal polarization binary array antenna (OPBAA). The theoretical model of OPBAA is derived and its spatial polarization characteristic is especially discussed here. Finally, an OPBAA formed by two horns is measured in anechoic chamber, and measurement results verify the theoretical conclusions. Compared with the traditional dual-port orthogonal-polarization aperture antenna [6], the advantage of OPBAA is its simple design and prominent SPC, it has only one radio frequency (RF) channel, so the system development expenditure is reduced, which will be widely used in the near future.

2 Theoretical model of OPBAA

OPBAA consists of two separated elements with identical characteristics is shown in Fig. 1. In Fig. 1, $(\hat{x} - \hat{y} - \hat{z})$ is the global coordinate system, and the phase center of element one is located at o_1 , while that of element two

Fig. 1. OPBAA configuration

is located at o_2 , and the distance from o_1 to o_2 is d . Taking ideal rectangle aperture antenna model as an example, the spatial polarization characteristic of OPBAA is theoretically analyzed. The length of two rectangle aperture edges are L_1 and L_2 , and $L_1, L_2 \gg \lambda$ (wave length). Antenna element one is the reference element and its aperture electric field is along $+\hat{y}$, i.e.

$$\mathbf{E}_1 = E_0 \hat{y} \quad (1)$$

Where E_0 is the intensity of electric field.

It is assumed far field condition is satisfied at position P in free space, and azimuth angle is θ and elevation angle is φ , and the range between P and element one is r . When the frequency is f , the orthogonal polarization components of radiated electric field of element one at P is

$$\begin{cases} E_\theta^1(\theta, \varphi) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \sin \varphi \\ \quad \cdot \frac{\sin[(kL_1/2) \sin \theta \cos \varphi]}{(kL_1/2) \sin \theta \cos \varphi} \frac{\sin[(kL_2/2) \sin \theta \sin \varphi]}{(kL_2/2) \sin \theta \sin \varphi} \\ E_\varphi^1(\theta, \varphi) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \cos \theta \cos \varphi \\ \quad \cdot \frac{\sin[(kL_1/2) \sin \theta \cos \varphi]}{(kL_1/2) \sin \theta \cos \varphi} \frac{\sin[(kL_2/2) \sin \theta \sin \varphi]}{(kL_2/2) \sin \theta \sin \varphi} \end{cases} \quad (2)$$

Where $k = 2\pi f/c$, and c is the speed of light, and $j = \sqrt{-1}$.

The physical and geometrical structure of element two is identical with that of element one. While the rectangle aperture is rotated 90° in $(\hat{y} - \hat{z})$ plane, and its aperture electric field is along $+\hat{z}$, i.e.

$$\mathbf{E}_2 = E_0 \hat{z} \quad (3)$$

However, the range from P to element two is longer than the range from P to element one, and the range difference is $\Delta r = d \sin \theta$. Though the value of Δr is much smaller compared with r , and the power loss caused by this range difference can be ignored, the phase difference must be considered, with value of $\Delta \varphi = 2\pi d \sin \theta / \lambda$. Through changing the elevation angle from φ to $90^\circ - \varphi$, we can express two orthogonal polarization components of radiated electric field of element two at P as

$$\begin{cases} E_\theta^2(\theta, \varphi) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \cos \varphi \\ \quad \cdot \frac{\sin[(kL_1/2) \sin \theta \sin \varphi]}{(kL_1/2) \sin \theta \sin \varphi} \frac{\sin[(kL_2/2) \sin \theta \cos \varphi]}{(kL_2/2) \sin \theta \cos \varphi} e^{-j2\pi d \sin \theta / \lambda} \\ E_\varphi^2(\theta, \varphi) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \cos \theta \sin \varphi \\ \quad \cdot \frac{\sin[(kL_1/2) \sin \theta \sin \varphi]}{(kL_1/2) \sin \theta \sin \varphi} \frac{\sin[(kL_2/2) \sin \theta \cos \varphi]}{(kL_2/2) \sin \theta \cos \varphi} e^{-j2\pi d \sin \theta / \lambda} \end{cases} \quad (4)$$

The radiated electric field of OPBAA at P is the coherent sum of independent electric fields from above two elements, so the orthogonal polarization components of its radiated electric field can be expressed as

$$\begin{cases} E_\theta = E_\theta^1 + E_\theta^2 \\ E_\varphi = E_\varphi^1 + E_\varphi^2 \end{cases} \quad (5)$$

When only its spatial polarization characteristic with azimuth θ is considered (i.e. setting $\varphi = 90^\circ$ in $(\hat{x} - \hat{y})$ plane), two components expressed in (5) can be abbreviated to

$$\begin{cases} E_\theta(\theta) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \frac{\sin[(kL_2/2) \sin \theta]}{(kL_2/2) \sin \theta} \\ E_\varphi(\theta) = jk \frac{e^{-jkr}}{2\pi r} E_0 L_1 L_2 \cos \theta \frac{\sin[(kL_1/2) \sin \theta]}{(kL_1/2) \sin \theta} e^{-j2\pi D \sin \theta} \end{cases} \quad (6)$$

Where electric size is defined as

$$D = \frac{d}{\lambda} \quad (7)$$

Assuming $L_1 = L_2 = L$, the normalized beam pattern of OPBAA can be obtained as

$$\begin{aligned} G(\theta) &= \frac{\sqrt{|E_\theta(\theta)|^2 + |E_\varphi(\theta)|^2}}{\sqrt{|E_\theta(\theta=0)|^2 + |E_\varphi(\theta=0)|^2}} \\ &= \frac{\sin[(kL/2) \sin \theta]}{(kL/2) \sin \theta} \sqrt{\frac{1 + |\cos \theta|^2}{2}} \end{aligned} \quad (8)$$

In addition, antenna polarization state is determined by the relationship between $E_\theta(\theta)$ and $E_\varphi(\theta)$ of its radiated electric field. Based on (6), it is clearly noticed that the polarization state of OPBAA is not constant in free space but varies with azimuth θ . This property is referred to antenna spatial polarization characteristic. The spatial polarization ratio of OPBAA can be derived from (6) as

$$\rho(\theta) = \frac{E_\varphi(\theta)}{E_\theta(\theta)} = \cos \theta e^{-j2\pi D \sin \theta} \quad (9)$$

Usually, the beam patterns of two antenna elements are highly directive, i.e. their main beam width $\Omega_m \ll 1$. So in range of $[-\Omega_m/2, \Omega_m/2]$, $\sin \theta \approx \theta$ and $\cos \theta \approx 1$ are satisfied. Then the spatial polarization ratio is expressed as

$$\rho_m(\theta) = \frac{E_\varphi(\theta)}{E_\theta(\theta)} \approx e^{-j2\pi D \theta}, \quad \theta \in \Omega_m \quad (10)$$

Taking Fourier transform of above spatial polarization ratio about θ in the main beam, we can obtain the spectrum of spatial polarization ratio as

$$P(f_s) = \text{FT} \{ \rho_m(\theta) \} = \frac{\sin[\pi(f_s - D)\Omega_m]}{\pi(f_s - D)\Omega_m} \quad (11)$$

Where f_s is the spatial frequency, $f_s = D$.

Supposed the antenna working frequency $f_0 = 3$ GHz, the wavelength $\lambda = 0.1$ m, the 3 dB beam width $\Omega = 2^\circ$, the electrical length of OPBAA $D=\frac{1}{\Omega}=28.6$, accordingly, the array element spacing $d = 2.86$ m, the theoretical results of spatial polarization ratio is shown in Fig. 2.

Fig. 2. theoretical results of spatial polarization ratio

3 Actual measurement results

In order to verify the theoretical model in above section, one OPBAA is formed by two horns in L band. Its full polarization beam patterns are measured in anechoic chamber, and then its spatial polarization characteristic is analyzed. The aperture electric field of the first horn is assigned horizontally (i.e. H polarization), and the aperture electric field of the second horn is assigned vertically (i.e. V polarization). The distance between them can be adjusted manually. During the measurement process, the whole antenna module is fixed on the controller which can be rotated in horizontal plane. Firstly, the standard emitting signal is adjusted to H polarization, and the receiving signals of two horns are mixed into one and input to data acquisition equipment. The H polarization beam pattern is obtained after the controller is rotated in the range of azimuth angle. Secondly, the emitting signal is adjusted to V polarization, and then the V polarization beam pattern is obtained after repetition of above operation. Lastly, through comparing above two measurement results, we analyze its spatial polarization characteristic.

The element distance is adjusted as $d = 0.45$ m. The azimuth angle range is $\Omega = -50^\circ \sim 50^\circ$ and azimuth sampling interval is $\Delta\theta = 0.2^\circ$. The measurement frequency (f_m) is from 1 GHz to 2 GHz, the frequency sampling

Fig. 3. (a) Beam pattern at $f_m = 1.5$ GHz. (b) Spatial polarization ratio at $f_m = 1.5$ GHz.

Fig. 3. (c) Spectrum of spatial polarization ratio in measurement frequency range [1 GHz ~ 2 GHz]

interval is $\Delta f_m = 5$ MHz. The range of electrical size is $D = 1.50 \sim 3.00$. Theoretical beam pattern characteristic of horn antenna can be referred in [6]. The normalized power gain beam pattern at one measurement frequency ($f_m = 1.5$ GHz) is shown in Fig. 3 (a), where $\theta \in [-50^\circ, 50^\circ]$. The absolute and phase values of its spatial polarization ratio in the range of $[-20^\circ, 20^\circ]$ are shown in Fig. 3 (b). In Fig. 3 (c), the spectrum of spatial polarization ratios at different measurement frequencies are shown, where, the measurement results approximately verify the theoretical results.

4 Conclusion

A novel antenna module named OPBAA is introduced, and its spatial polarization characteristic is theoretically analyzed. Then one dual polarization antenna formed by two horns is measured in anechoic chamber, and the measurement results are approximately identical with the theoretical results. In the future, we would like to apply the spatial polarization characteristic of OPBAA to anti-jamming and target polarization scattering coefficients measurement.

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