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Design of low-sidelobe circularly-polarized microstrip array for RFID readers

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Abstract A low-sidelobe circularly-polarized (CP) microstrip patch array for 2.4 GHz radio frequency identification (RFID) readers is presented. The antenna array with a Chebyshev current distribution is composed of 6 microstrip elements. The CP operation is obtained by the quasi-square patch with difference in lengths of the two sides. The antenna has been investigated numerically and experimentally. Measured results show that the array has a Chebyshev pattern with the sidelobe level of −23 dB, the half-power beamwidth of 16° and an impedance bandwidth ($S_{11} \leqslant -10$ dB) of 130 MHz, which is suitable for RFID reader applications.

Keywords microstrip antenna array, low sidelobe, circular polarization, radio frequency identification (RFID) reader

Introduction

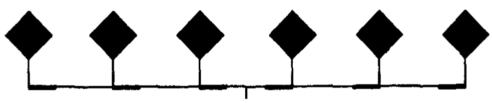
The radio frequency identification (RFID) systems for tracking and controlling goods and products have been growing rapidly in many application areas. The growing development of RFID systems requires more advanced RFID transponders and readers[1−3]. Reader units are usually placed where they can perform efficient transponder interrogation. RFID readers are becoming more and more advanced with more efficient anti-collision procedures, wider bandwidth and greater data filtering capabilities that allow fast and effective integration of RFID readers (systems) into presenting IT systems.

For some applications where the objects to be identified are lined up at a certain distance, low sidelobe and narrower beamwidth are required in the accurate and efficient RFID reader system. This problem can be solved if a Chebyshev array is used, by whom the low sidelobe level with narrower beam can be achieved. For the design of microstrip antenna array with low sidelobe, usually the aperture coupling feed design is preferred[3] because the feed network can be distributed beneath a metal screen which shields the spurious radiation from the feed network. However, this results in a three-layered structure that seems somewhat bulky for the RFID applications.

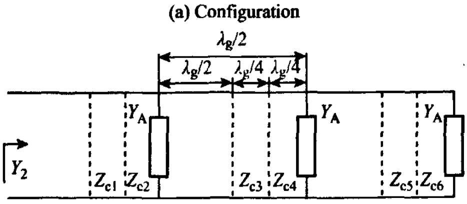
In this paper, a 6-element coplanarly-fed circularly polarized microstrip patch array for RFID reader is proposed, which is of low sidelobe and narrower beam. The design and experimental results are presented whereafter.

1 Antenna design

Fig.1 shows the configuration and the equivalent circuit of the antenna. In order to realize the circularly-polarized (CP) operation, the antenna element is a quasi-square patch with difference in lengths of the two sides. Each patch is corner-fed by a section of $\lambda_g/4$ microstrip line connected to the coplanar feeding network. Each patch is carefully tuned to achieve a better CP performance.



(a) Configuration



(b) Equivalent circuit of the right part of the antenna

Fig.1 Configuration and equivalent circuit of the proposed antenna

The 6-element antenna array is designed to obtain a Chebyshev pattern with −27 dB sidelobe level. Its current ratio of each side of the array is $I_1{:}I_2{:}I_3 = 1{:}0.709{:}0.345$. Fig.1(b) shows the equivalent circuit of

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the right side of the array, in which the characteristic impedance of each section of feed line is determined by the desired current ratio and the corresponding width is then calculated. The antenna is fed by a 50 Ω coax connector on the middle of feed network. The relationships of the current distribution and impedance express as follows[4]:

$$\frac{I_2}{I_1} = \left(\frac{Z_{c4}}{Z_{c3}}\right)^2 = n_1, \tag{1}$$

$$\frac{I_3}{I_2} = \left(\frac{Z_{c6}}{Z_{c5}}\right)^2 = n_2, \tag{2}$$

$$Y_{in} = 2Y_2 = 2\left(\frac{Z_{c2}}{Z_{c1}}\right)^2 Y_A(1 + n_1^4 + n_1^4 n_2^4), \tag{3}$$

where Y_{in} and Y_A refer to the input admittance of the array and the patch, respectively. The resistance of feed lines are Z_{c3}=100 Ω, Z_{c4}=84.2 Ω, Z_{c5}=100 Ω, Z_{c6}=69.8 Ω to minimize the discontinuity of the feed lines. Z_{c1}=100 Ω, Z_{c2}=69.8 Ω are used to achieve 50 Ω input resistance on the middle of feed network. The width of each section of the feed line is optimized to ensure the accurate excitation of every element patch in terms of the current amplitude and phase after the preliminary design[5]. The simulation design for the antenna was carried out by using Ansoft HFSS V.10.0.

2 Experimental results

As shown in Fig.2, a 1×6 array antenna was fabricated on a 500 mm×100 mm substrate with relative permittivity of 2.78 and thickness of 2 mm. Its return loss was measured by the network analyzer Agilent 8722ES. Fig.3 shows both the simulated and the measured return loss. The measured results show that the array has an impedance bandwidth (for $S_{11} \leqslant -10$ dB) of 130 MHz.

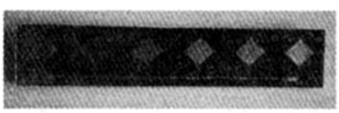


Fig.2 Photograph of the antenna

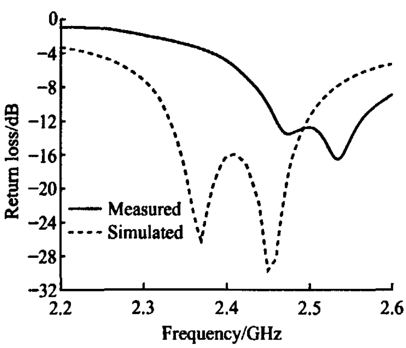
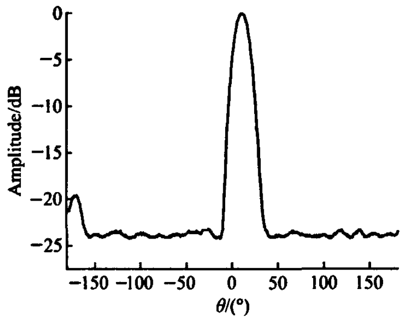


Fig.3 Return loss of the antenna

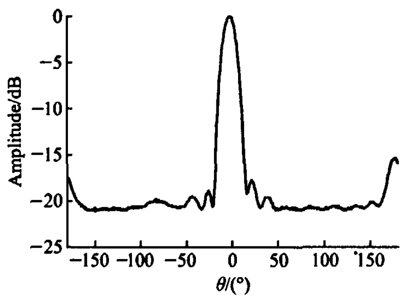
The simulated result agrees with the measured one in trend but with a frequency shift of about 100 MHz, which is probably because of the inexact relative permittivity and fabrication error.

The far field measurement was performed in an anechoic chamber. Fig.4 shows the measured radiation patterns. The sidelobe level of −23 dB at the design frequency of 2.4 GHz and −19 dB at 2.47 GHz are achieved. A gain of 11.2 dBi at 2.47 GHz is measured, which is enough for the RFID reader applications.

The measured polarization radiation pattern is shown in Fig.5.



(a) 2.4 GHz



(b) 2.47 GHz

Fig.4 Measured radiation patterns

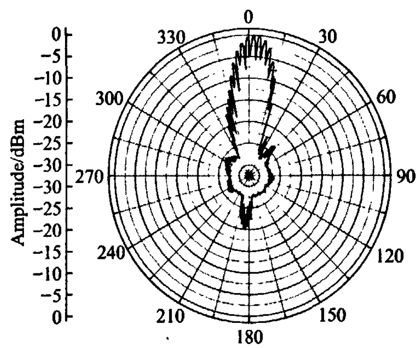


Fig.5 Measured polarization radiation pattern

According to the theory of perturbation, the condition of circular polarization for this rectangular patch is as follows[6]:

$$\frac{a}{b} \approx 1 + \frac{1}{Q}, \tag{4}$$

$$\frac{1}{Q} = \frac{1}{Q_r} + \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_{sw}}, \tag{5}$$

where Q_r, Q_d, Q_c and Q_{sw} refer to quality factors of radiation, dielectric, conductor and surface wave, respectively. Our simulation is based on the dielectric loss tangent of $\tan\delta = 1/Q_d = 0.02$. (5) can be worked out as follows:

$$\frac{1}{Q} = 0.0369.$$

Fig.6 shows the simulated and measured axial ratio. It is noted that there is a 3 dB to 4 dB disagreement between the simulated and measured results. Some simulations with different dielectric loss tangent were made to find the reason of the disagreement. As shown in Fig.6, the axial ratio performance worsens off when the actual dielectric loss tangent is 0.01. The dielectric loss tangent has a significant effect on the axial ratio and the quality factor of the antenna. Therefore the disagreement in the axial ratio may come from the inexact dielectric loss tangent.

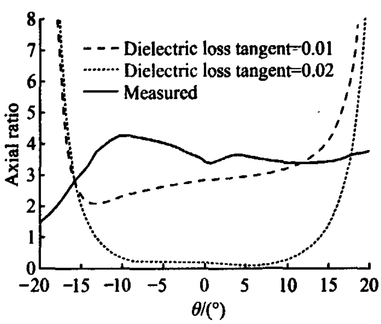


Fig.6 Simulated and measured axial ratio

3 Conclusion

In this paper, we presented a low sidelobe, narrower beamwidth and circularly polarized microstrip patch array for 2.4 GHz RFID readers. With a simple and low cost structure, the antenna shows both good impedance and radiation performance. Measured results showed that the array has a Chebyshev pattern with sidelobe level of −23 dB, the half-power beamwidth of 16° and an impedance bandwidth ($S_{11} \leqslant -10$ dB) of 130 MHz. All these make the design suitable for RFID reader applications.

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