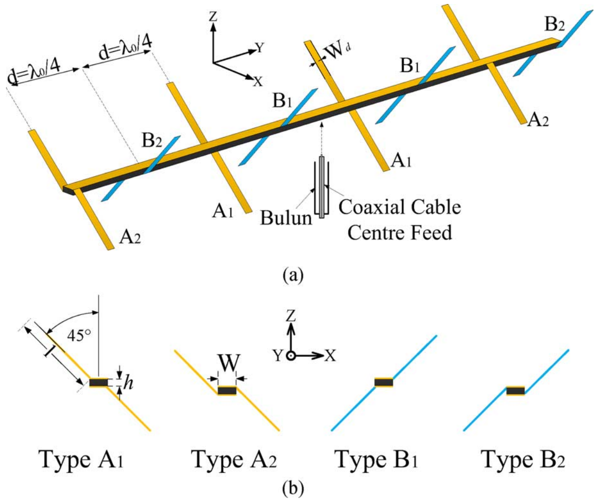
A Bidirectional Array of the Same Left-Handed Circular Polarization Using a Special Substrate

Wendong Liu, *Student Member, IEEE*, Yue Li, *Member, IEEE*, Zhijun Zhang, *Senior Member, IEEE*, and Zhenghe Feng, *Fellow, IEEE*

***Abstract*—A novel bidirectional circularly polarized array is presented. The type of circular polarization is the same in both axial directions. The array consists of eight dipoles spaced by $\lambda_0/4$ (λ_0 is the wavelength in free space), which combines endfire array, crossed dipoles, and substrate loading. For the bidirectional circular polarization of the same rotation, the adjacent elements need to be excited in phase, and the adjacent $+45^\circ/-45^\circ$ dipoles need to be excited with 180° phase difference. To satisfy the special phase distribution, a substrate with dielectric constant of 6.0 is used, which makes the guided wavelength λ_g equal to $\lambda_0/2$. A prototype is developed at 2.5 GHz. With this array, the measured 3-dB axial-ratio (AR) bandwidth is 770 MHz (2.05 ∼ 2.82 GHz), and the 10-dB return-loss bandwidth achieved is 580 MHz (2.32 ∼ 2.9 GHz). The maximum bidirectional left-handed circular polarization (LHCP) gain is about 7.3 dBic achieved at 2.45 GHz.**

***Index Terms*—Antenna array, bidirectional circular polarization of the same rotation, dipole, series-fed array, substrate loading.**



(a)

(b)

Fig. 1. Schematic of the proposed array. (a) 3-D view. (b) Side view of the four types of dipole. Values of the parameters are $d = 30$, $h = 1.27$, $l = 26$, $W = 3$, $W_d = 3$ (unit: millimeter).

I. INTRODUCTION

NOWADAYS, communication in long streets, tunnels, or on long bridges is quite common. In these circumstances, the communicable cells are formed along these areas. For these environments, a bidirectional antenna is more suitable to apply serving these demands. Therefore, much research and development on bidirectional antennas has been extensively conducted. Linearly polarized bidirectional antennas [2], [3] are the most common. However, polarization mismatch becomes a problem when the antennas are not aligned in practical application. Bidirectional circular polarized antenna is a good candidate. Slot type [4] and wire type [5] have been proposed. However, the bidirectional rotations of both types are not the same. Such antennas are not suited for the communication between relay stations because the rotations of the receive antenna and the transmit antenna are inverse. Thus, bidirectional circular polarized antenna of the same rotation is needed. To realize this goal, the traditional solution is to combine two circular polarized unidirectional antennas back to back. However, such a technique needs an additional feed network and thus suffers from feed losses and complicated structure. On the other hand, for bidirectional radiation, the realized gain suffers from 3 dB loss compared to that of the original unidirectional antennas such as the patch antenna in [6].

In this letter, we propose, design, and experimentally verify an eight-element array for bidirectional circular polarization. The type of circular polarization (CP) is the same in both axial directions. The distance between adjacent elements is $\lambda_0/4$. The array element is fed by the balanced parallel stripline. To satisfy the special phase distribution, a substrate with dielectric constant of 6.0 is used, which makes the guided wavelength λ_g equal to $\lambda_0/2$. The proposed array possesses 1-D feed network and can achieve higher gain with lower feed losses and lower wind resistance compared to the traditional design.

II. ANTENNA DESIGN

Fig. 1 presents the configuration of the proposed array. The working mechanics of the proposed array are shown in Fig. 2. Two crossed dipoles separated in space by $\lambda_0/4$ are excited in phase or with 180° phase difference. With this arrangement, the type of circular polarization is the same in both axial directions. The difference caused by the two kinds of the exciting phase difference is the sense of the rotation of CP that can be achieved as shown in Fig. 2. The problem is that the maximum of the radiation pattern does not point in the axial directions as shown in

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The authors are with the State Key Laboratory on Microwave and Digital Communications, Tsinghua National Laboratory for Information Science and Technology, Department of Electronic Engineering, Tsinghua University, Beijing 100084, China (e-mail: zjzh@tsinghua.edu.cn).

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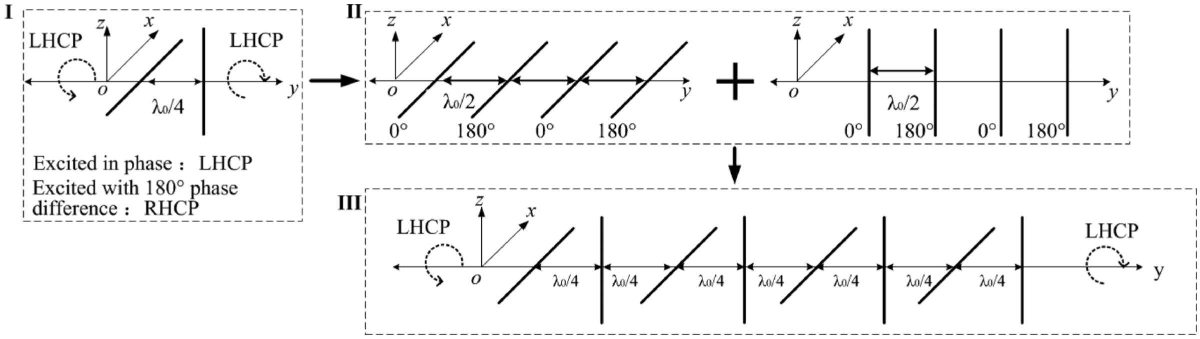

Fig. 2. Working mechanics of the proposed antenna.

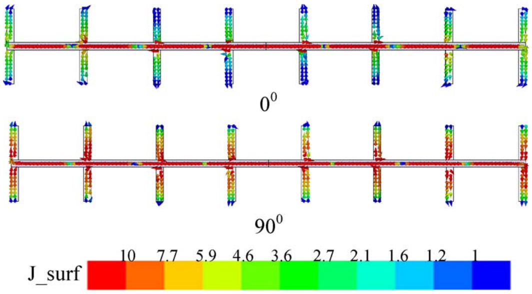

Fig. 3. Distribution of the surface current on the feedline and the array at 2.5 GHz in 0° and 90° phase.

Fig. 2. The solution is to replace the dipoles with some kinds of endfire antennas, which means to combine two endfire antennas orthogonally with a distance of $\lambda_0/4$.

In the letter, the endfire dipole array is chosen as shown in Fig. 2. The adjacent elements are spaced by $\lambda_0/2$ and excited with 180° phase difference. To merge such two endfire dipole arrays together, the final theoretical model is shown in Fig. 2. As a result, the distance between adjacent elements in the array is $\lambda_0/4$. The proposed structure is concise and uniform, which makes it easier to feed all elements in phase. The array element is fed by the balanced parallel stripline. To feed each element as expected, the substrate of the balanced parallel stripline is chosen to be RT/duriod 6006 with a dielectric constant of 6 and a thickness of 1.27 mm, which makes the guided wavelength λ_g equal to $\lambda_0/2$. Thanks to the special dielectric, all the adjacent elements now can be fed with 180° phase difference. It is not a problem for circular polarization because only rotation is changed in both ends.

As for bidirectional radiation, the connection type of the adjacent $+45°/-45°$ dipoles needs to be changed alternatively between types in Fig. 1(b) to keep the radiating currents just out of phase. The whole design is similar to that in [7], but the goal and the basic working principle is completely different from our design. In [7], the crossed dipoles are excited with a 90° phase difference to create a rotation field and an omnidirectional radiation pattern. To verify the proposed structure in Fig. 1(a), full-wave simulation has been performed using Ansoft simulation software High Frequency Structure Simulator (HFSS). Fig. 3 shows the vector current distributions of the proposed array at 2.5 GHz viewed from the $+z$-direction. All the currents resonate in the same rhythm, and the currents of the adjacent $+45°/-45°$ dipoles are just out of phase, which correspond to the theoretical analysis above. Note that the current distributions in 180° and 270° are equal in magnitude and opposite in phase of 0° and 90°. In the design, the spacing between the array elements is fixed. For the series-fed array, the impedance matching is adjusted by the radiation impedance of the dipoles and characteristic impedance of the transmission line, which mainly corresponds to the parameters W and h. The influence of the width

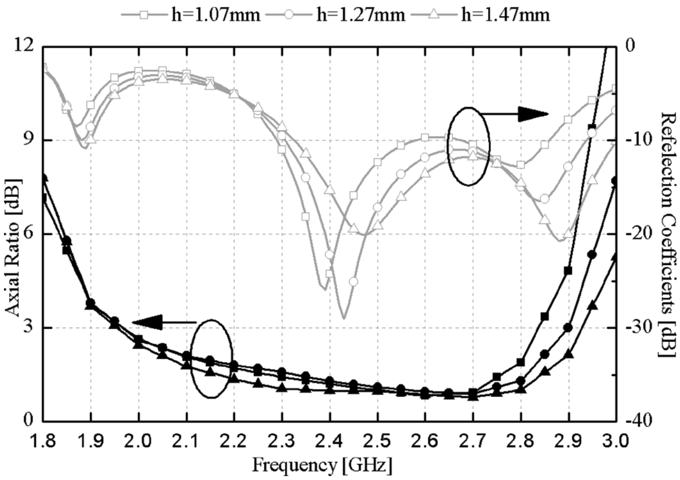

Fig. 4. Effect of h on AR and reflection coefficients.

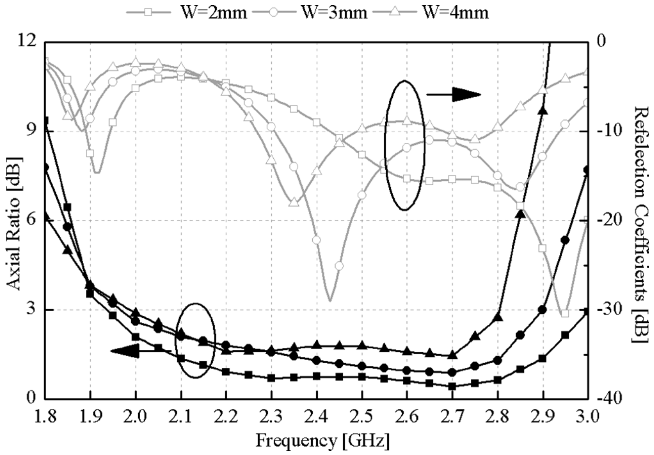

Fig. 5. Effect of W on AR and reflection coefficients.

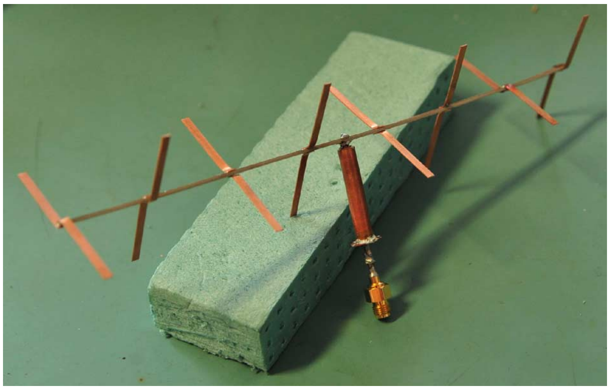

Fig. 6. Photograph of the realized prototype.

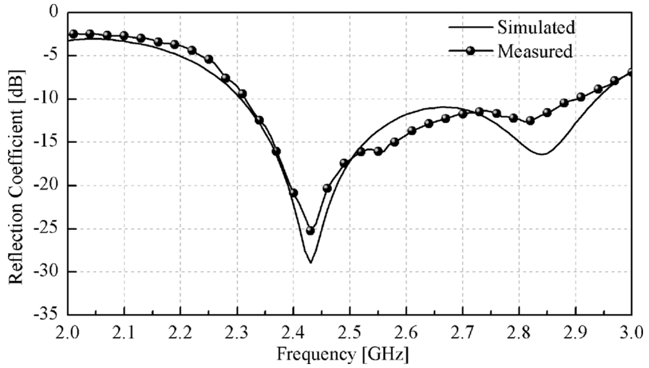

Fig. 7. Simulated and measured reflection coefficients of the proposed array.

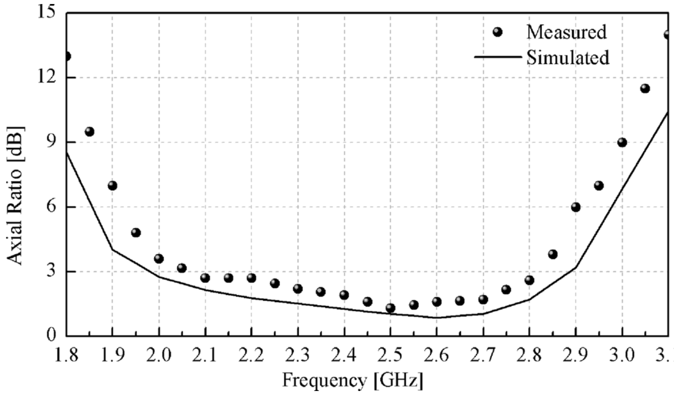

Fig. 8. Simulated and measured ARs in axial direction of the proposed array.

W and height *h* of the transmission line on the reflection coefficient and axial ratio (AR) is shown in Figs. 4 and 5, respectively. These two parameters determine the characteristic impedance of the transmission line. Thus, they mainly affect the impedance matching result. They have a slight influence on the guided wavelength λ_g and the phase distribution. Hence, no apparent difference can be found.

III. EXPERIMENTAL RESULT

The eight-element array presented in Section II is fabricated and experimentally tested. A photograph of the simple prototype is shown in Fig. 6. Fig. 7 shows the simulated and measured reflection coefficient of the fabricated array. The measured 10-dB return-loss bandwidth is 580 MHz (2.32–2.9 GHz), and the simulated bandwidth is 650 MHz (2.3–2.95 GHz).

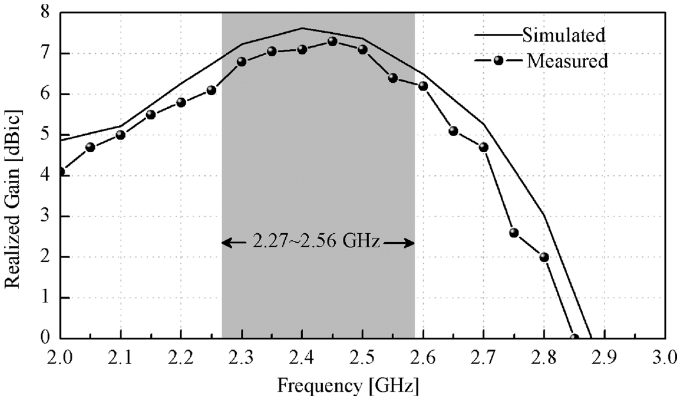

Fig. 9. Simulated and measured gains in axial direction of the proposed array.

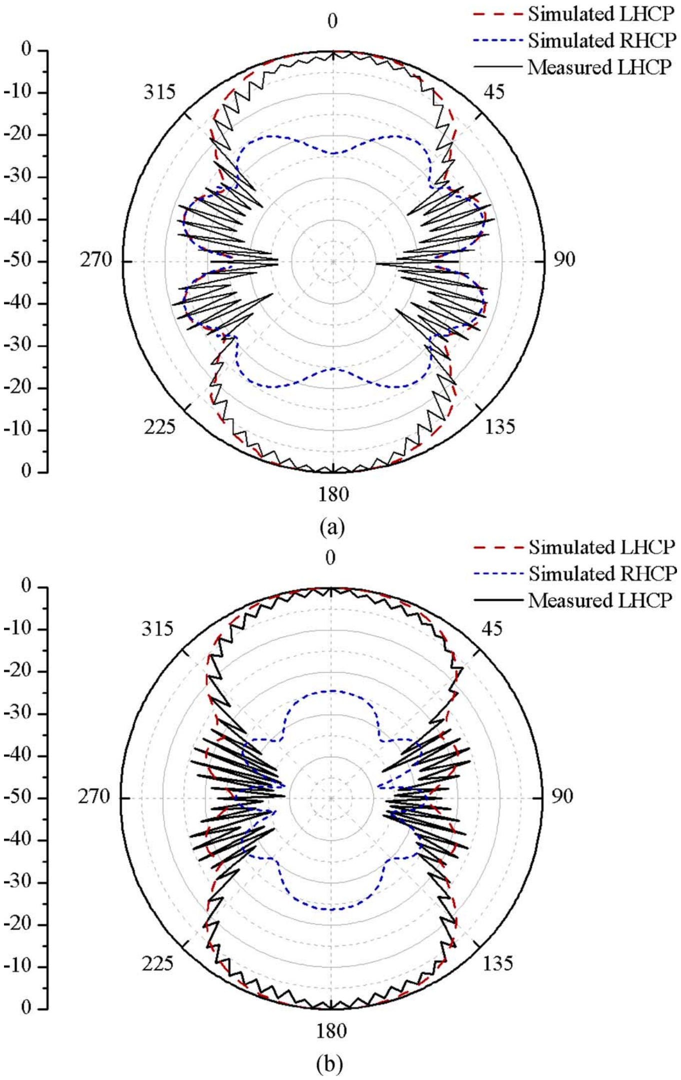

Fig. 10. Measured and Simulated normalised AR patterns of the array at 2.5 GHz. (a) yoz-plane. (b) xoy-plane.

The AR is measured using a spinning linear method where a rotating linearly polarized transmit horn antenna is used to measure the CP performance of the antenna. The measured and simulated ARs at two ends of the array are shown in Fig. 8. The measured 3-dB AR bandwidth is around 770 MHz (2.05–2.82 GHz), and the simulated 3-dB AR bandwidth is about 900 MHz (1.98–2.88 GHz). The measured 3-dB AR variation with frequency agrees well with the simulated results.

Fig. 9 shows the measured and simulated gain at the two ends of the array. The phase center in the gain measurement is just the center of the array. The measured maximum gain is 7.3 dBic at 2.45 GHz, and the simulated maximum gain is 7.6 dBic at 2.4 GHz. The simulated and the measured 1-dB gains bandwidth are 360 MHz (2.24–2.6 GHz) and 290 MHz (2.27–2.56 GHz), respectively.

Shown in Fig. 10 is the far-field pattern of the proposed array at 2.5 GHz. The original idea is to design a bidirectional endfire array. Therefore, the phase distribution of the dipole elements is designed so that the AR is the best in the two axis directions or the direction adjacent to the axis directions.

As for other direction, the space distance and the polarization cannot be guaranteed, so the variation of AR with angle is hard to predict. The slight discrepancy between the xoy and yoz planes AR patterns is due to the antenna installation error in an anechoic chamber, when the antenna is mounted for xoy and yoz planes on AUT stand. The array is fed at the centre by a coaxial cable. A balun is needed to accomplish the transition between the balanced parallel stripline and the unbalanced coaxial line. The current on the balun itself which is induced by the radiation fields from the dipoles can be ignored.

IV. CONCLUSION

A novel bidirectional circular polarized array with the same rotation has been developed in this letter. The method is to combine two linearly polarized endfire dipole arrays. The two arrays are assigned orthogonally and spaced by $\lambda_0/4$. To feed the array, a special substrate with dielectric constant of 6.0 is used, which makes the guided wavelength $\lambda_{\rm g}$ equal to $\lambda_0/2$. The antenna achieves an impedance bandwidth ($|S_{11}| < -10$ dB) of 580 MHz (2.32–2.9 GHz) and the bidirectional right-handed circular polarization (RHCP) gain of 7.3 dBic at 2.45 GHz. The 3-dB axial-ratio bandwidth is 770 MHz (2.05 ~ 2.82 GHz). The antenna may be very useful for the relay communication in tunnels, long streets, or long bridges.

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