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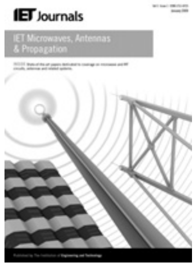

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Single-layer integrated microstrip array antenna for dual circular polarisation

Y. Ushijima   E. Nishiyama   M. Aikawa

Graduate School of Science and Engineering, Saga University, 1, Honjo-machi, Saga-shi 840-8502, Japan
E-mail: ushi@ceng.ec.saga-u.ac.jp

Abstract: A single-layer integrated microstrip array antenna for dual circular polarisation is proposed. It consists of an orthogonal linearly polarised microstrip array antenna and a 90° hybrid circuit using a single-layer substrate. The orthogonally polarised array antenna uses double-sided microwave-integrated circuit (MIC) technology including airbridges, effectively. It has excellent isolation and cross-polarisation suppression performance between the orthogonal modes and flexibility of the antenna size extension. By integrating it with the 90° hybrid circuit, the proposed array antenna can excite the orthogonal circular polarisations [right-hand circular polarisation (RHCP), left-hand circular polarisation (LHCP)] simultaneously. It is possible to easily realise wireless integration modules because of a single-layer structure. The simulated and experimental results show good circular polarisation performance for both the RHCP and LHCP. The design frequency is 10 GHz and the 3 dB axial ratio bandwidths of both the RHCP and LHCP are approximately 10% in the experiment.

1 Introduction

Recently, along with the rapid development of wireless communication technology, highly advanced antennas have been required. Polarisation agile antennas are a promising candidate in future wireless communication systems because of their attractive capability [1]. One type of polarisation agile antenna is the dual-polarised antenna. Basic studies on dual linearly polarised and circularly polarised antennas have been reported [2–7]. In [2–5], orthogonal linear polarisations were achieved by a microstrip antenna using aperture and matching feed lines. These antennas generally have multi-layer configurations. In [6], a circular polarisation diversity antenna with two PIN diodes was proposed. By switching the diodes, the circular polarisations [right-hand circular polarisation (RHCP), left-hand circular polarisation (LHCP)] can be obtained. In [7], circular polarisation was achieved by using a Wilkinson power divider consisting of coplanar waveguide (CPW) feed lines. These antennas generally have narrow bandwidth or low gain. Two kinds of dual-polarised array antennas using multi-layer substrates have also been reported [8–10]. These may be integrated easily with radio frequency (RF) functional circuits or monolithic microwave integrated circuits (MMICs). However, there have been no reports investigating dual-polarised array antennas using a single-layer substrate.

In this paper, a single-layer integrated microstrip array antenna for dual circular polarisation is proposed. The array antenna consists of an orthogonal linearly polarised microstrip array antenna and a 90° hybrid circuit in a single-layer substrate. An orthogonally polarised array antenna has been reported in [11]. This uses double-sided microwave-integrated circuit (MIC) technology including airbridges, effectively [12, 13]. A single-layer orthogonal feed circuit which is essential to the array antenna can be realised by using the above-mentioned technology. It has excellent isolation and cross polarisation suppression performance between the orthogonal modes, and also allows antenna size extension. Consequently, it can be used to implement 4×4 and 8×8 arrays and so on. By integrating it with the 90° hybrid circuit, the proposed array antenna can simultaneously excite the orthogonal circular polarisations (RHCP, LHCP). It is much simpler and more compact than conventional dual-polarised antennas. Moreover, it is possible to realise wireless integration modules because of the single-layer structure. Therefore it will be attractive for various wireless applications. The array antenna design and basic behaviour are discussed in Sections 2 and 3. The simulated and experimental results are shown and discussed in Section 4. Finally, Section 5 concludes this paper.

2 Array antenna design

2.1 Orthogonal linear polarisation microstrip array antenna

Fig. 1 shows the schematic of the proposed array antenna for dual circular polarisation. The proposed array antenna comprises an orthogonally polarised array antenna [11] and a 90° hybrid circuit. In the array antenna, the microstrip antennas, microstrip lines and airbridges are arranged on the surface of the substrate. The cross-shaped slot line is on the reverse side. As stated above, the

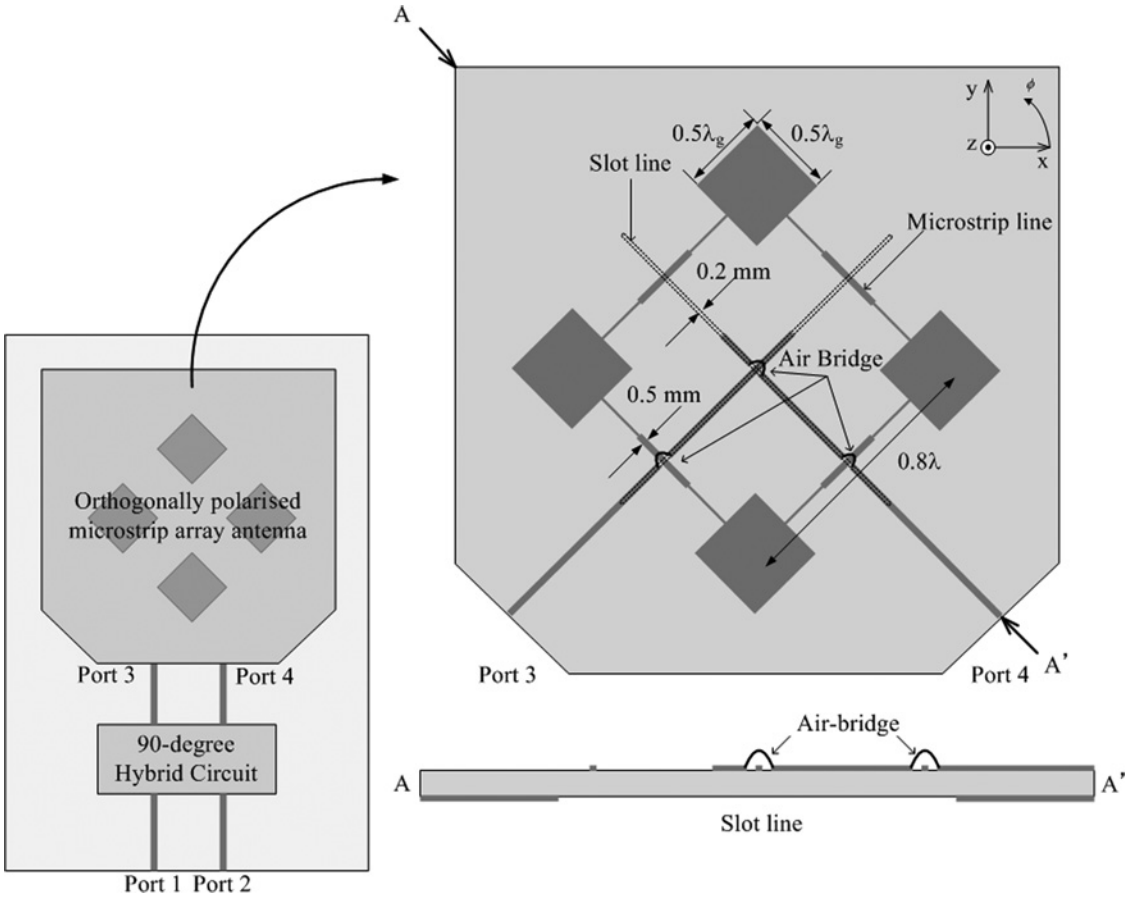

Fig. 1 *Schematic diagram of the single-layer integrated microstrip array antenna for dual circular polarisation*

orthogonally polarised array antenna actively uses double-sided MIC technology including airbridges. Consequently, impedance transformers and bends are not required as shown in Fig. 1, that is, the orthogonal antenna feed circuit is composed of microstrip and slot lines in the single layer. In addition, the array antenna feed circuit can realise a mirror symmetrical structure [8]. Moreover, the airbridges are effectively used for realising a simple and compact feed circuit in the array antenna. They are often used for uniplanar MMIC's and double-sided MICs because it is possible to ease the circuit complexity [12, 13]. Practically, they are required to be optimised because they generally interfere with the under microstrip lines. In this research, the width, height and length of them are optimised by using a Teflon glass fibre substrate with a relative dielectric constant ε_r of 2.15. Fig. 2*a* shows the structure of the optimised airbridge at the design frequency of 10 GHz, where the dimensions are shown in Fig. 2*a*. Also, Fig. 2*b* shows the simulated S-parameters of the optimised airbridge. In Fig. 2*b*, the return loss (S11) of −18 dB is obtained at 10 GHz. The insertion loss (S21) is very small and the isolations (S31, S41) are −20 dB at 10 GHz. The isolations of −20 dB are comparatively good. Even if the airbridges interfere with the under microstrip lines, the cross-polarisation is not caused by the interference because the mirror symmetrical feed scheme has a complementary effect [8].

In addition, the microstrip lines are arranged just over the cross-shaped slot lines as shown in Fig. 1. The feed circuit uses orthogonal transmission modes (an even mode, odd mode) effectively in the array antenna. As shown in Fig. 3, the microstrip line transmission mode is the even mode and

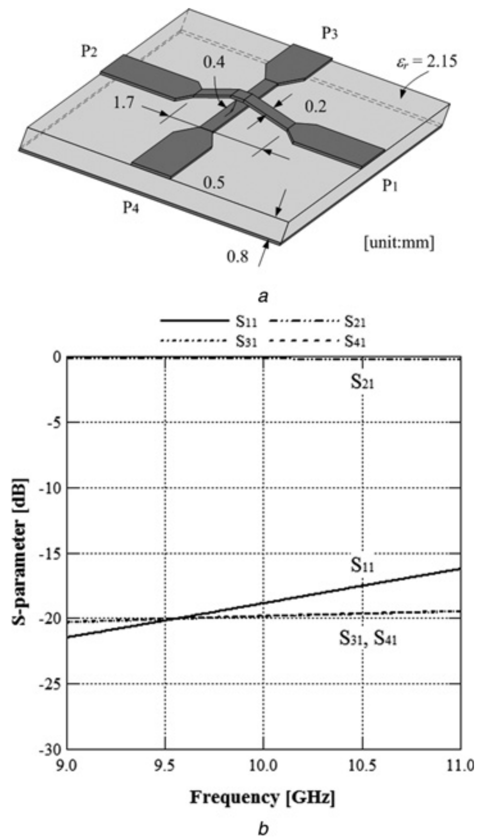

Fig. 2 *Optimised airbridges*

a Structure
b Simulated S-parameter

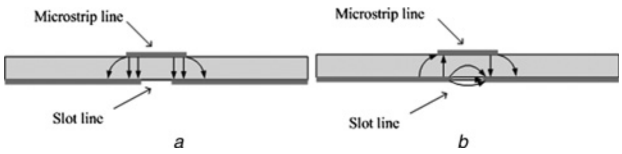

Fig. 3 *Orthogonal transmission modes*

a Even mode
b Odd mode

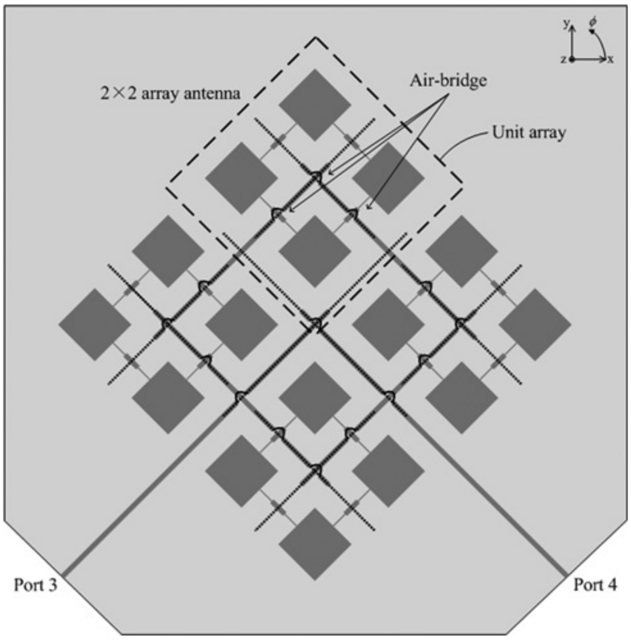

Fig. 4 *Orthogonally polarised array antenna (4 × 4)*

the slot line transmission mode is the odd mode. Since these modes are orthogonal to each other, two RF input signals do not interfere with each other, that is, the orthogonally

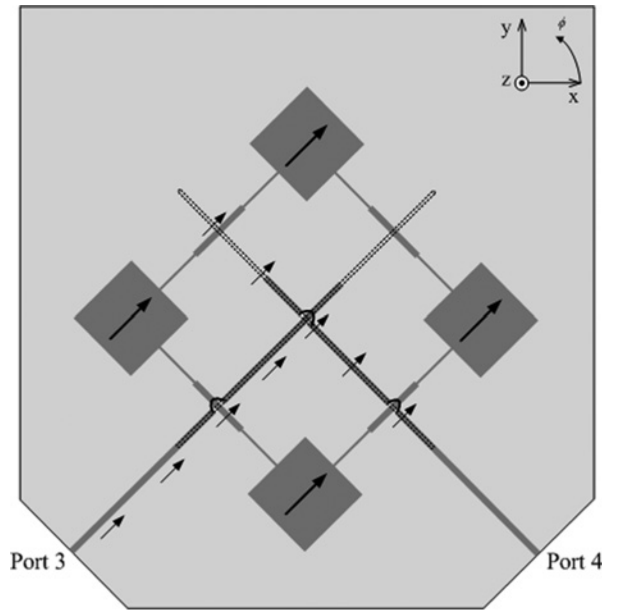

Fig. 5 *Schematic electric fields on the proposed array antenna (+45° linear polarization)*

polarised array antenna has excellent isolation and cross-polarisation suppression performances in principle. As mentioned above, it allows antenna size extension, that is, it is easily possible to expand the antenna array to sizes such 4 × 4 and 8 × 8 arrays and so on. Fig. 4 shows a 4 × 4 orthogonally polarised array antenna. For instance, if the 2 × 2 array antenna is defined as a unit array, the 4 × 4 array antenna can be realised by using four units as shown in Fig. 4.

Fig. 5 shows the schematic electric fields on the orthogonally polarised array antenna. For example, when the RF signal is fed to Port 3, it propagates on the microstrip line as the even mode (Fig. 3*a*). It is equally

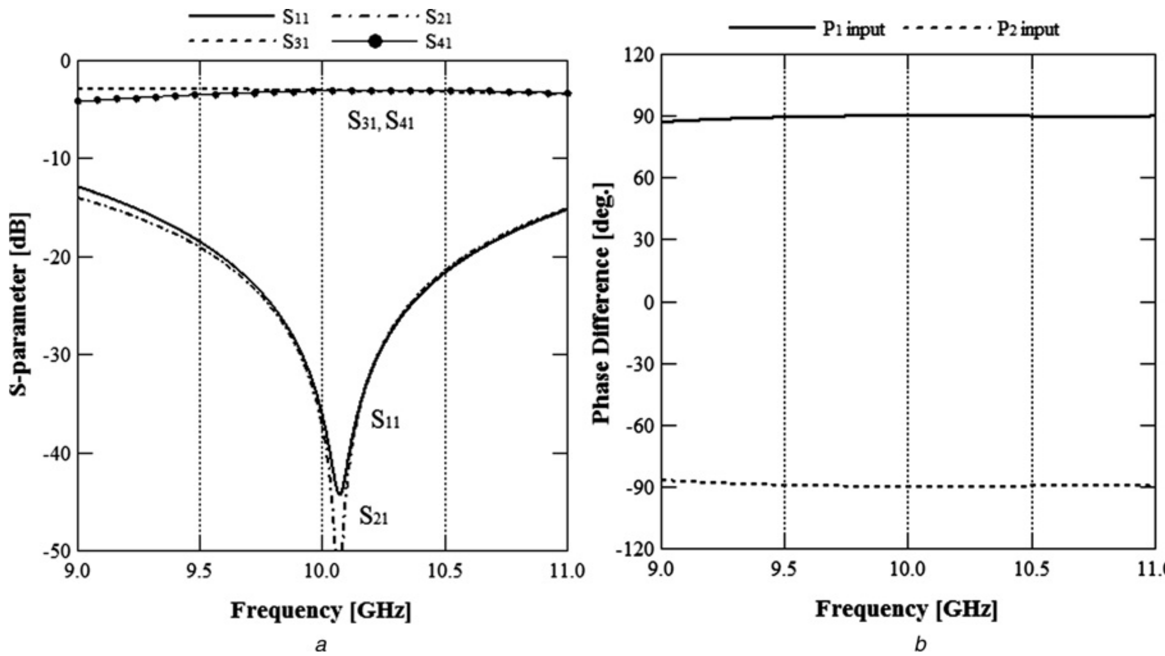

Fig. 6 *Simulated results of the 90° hybrid circuit*

a S-parameter
b Phase of Port 3 against Port 4

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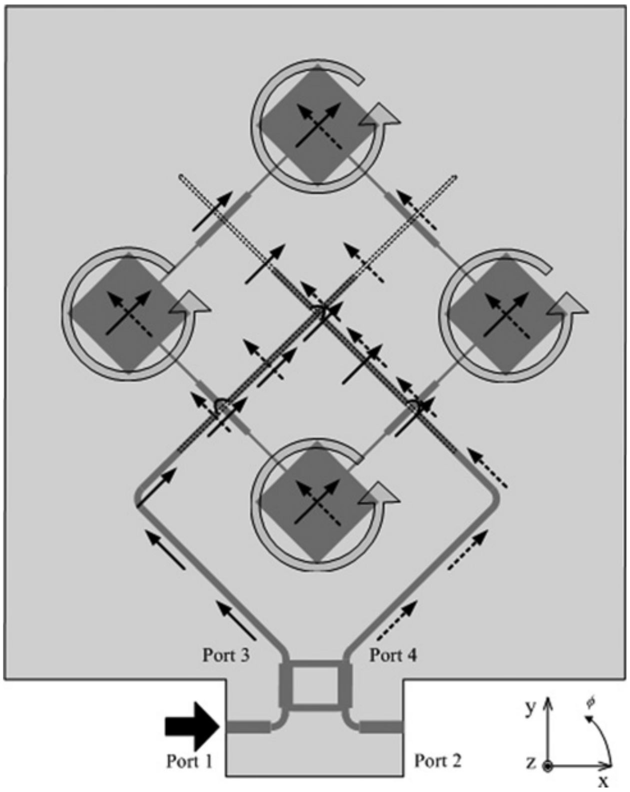


Fig. 7 *Basic behaviour of the proposed array antenna (RHCP)*

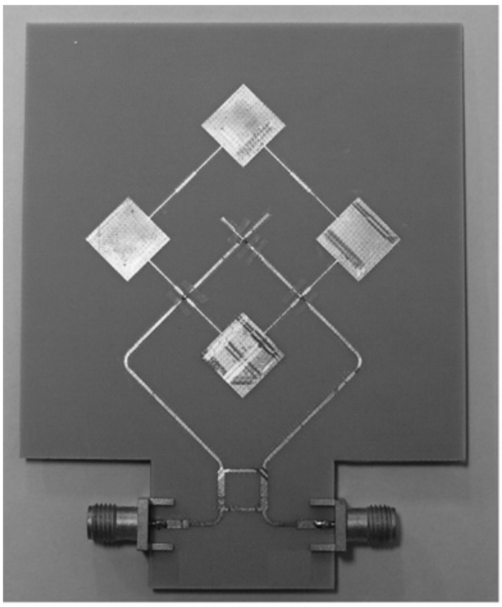
divided to the slot line in parallel (in phase) through the microstrip-slot parallel branch. The propagation mode is the odd mode (Fig. 3*b*). Then, the signals are successively divided in series (out of phase) to the microstrip lines connected to the antenna elements through the slot-microstrip series branches [11]. Finally, these signals are fed symmetrically to the antenna elements. In this case, the +45° linear polarisation is excited. In the same way, when the RF signal is fed to Port 4, the behaviour is almost the same. In this case, the −45° linear polarisation is excited. The RF signals are not coupled in principle, that is, excellent isolation performance can be obtained between Ports 3 and 4.

2.2 90° hybrid circuit

The 90° hybrid circuit is well known as a branch line hybrid circuit [14]. This circuit is a type of 90° hybrid circuits. There are other kinds of quadrature hybrid circuits such as the tandem coupler and interdigitated coupler. This branch-line hybrid circuit is a very simple structure, and the input and output port arrangement is very suitable for planar circuits. Therefore it is possible to integrate the hybrid circuit easily with the array antenna in Fig. 1. The 90° hybrid circuit is simulated with advance design system (ADS) (Agilent). Fig. 6*a* shows the simulated S-parameters when the RF signal is fed to Port 1. As a result, the return loss is better than 20 dB from 9.5 to 10.5 GHz. The insertion loss is very small at 10 GHz. Fig. 6*b* shows the phase characteristics of Port 3 against Port 4. As a result, ±90° phase difference is obtained at 10 GHz in the simulation.

3 Basic behaviour of the proposed microstrip array antenna

Fig. 7 shows the schematic electric fields on the proposed array antenna. For example, when the RF signal is fed to Port 1, the signal is equally divided by the 90° hybrid circuit. Port 2 is the isolated port. In this case, the phase of Port 3 is 90° advanced to Port 4. Consequently, the RHCP is excited as shown in Fig. 7. In the same way, when the



a

b

Fig. 8 *Fabricated array antennas*

a Top view
b Bottom view

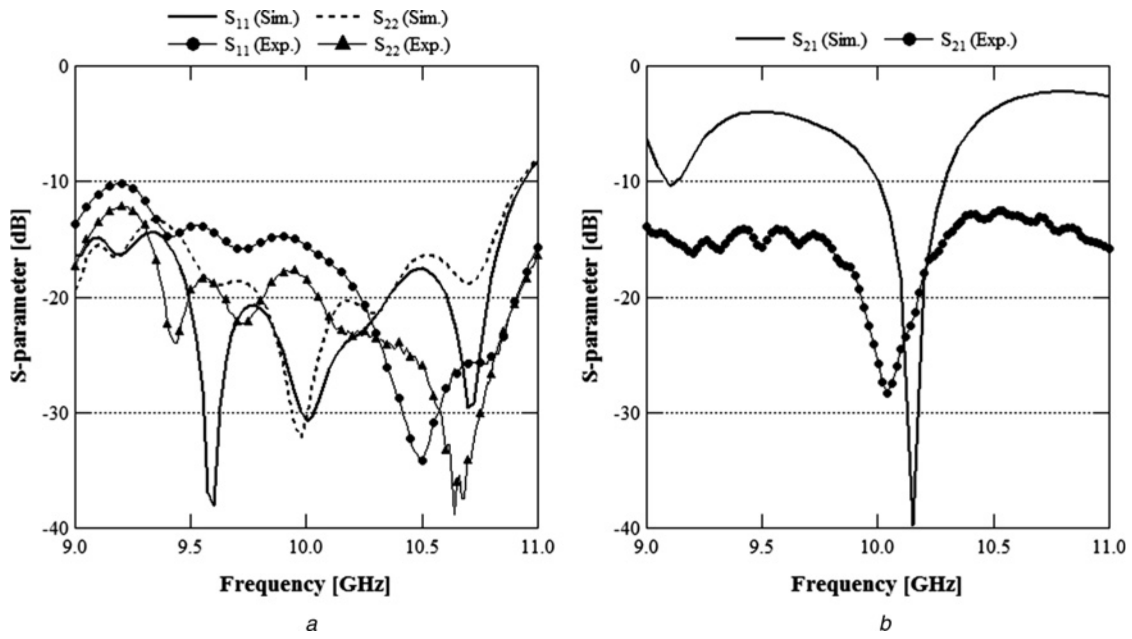


Fig. 9 *S-parameter of the proposed array antennas*
a Reflection coefficient
b Isolation

RF signal is fed to Port 2, the signal is also equally divided by the hybrid circuit. Port 1 is the isolated port. In this case, the phase difference between Ports 3 and 4 is -90°. Consequently, the LHCP is excited. Therefore the dual circular polarisations are excited simultaneously by the proposed array antenna.

4 Array antenna performance

Fig. 8 shows the fabricated array antenna. The array antenna is fabricated on a Teflon glass fibre substrate with a relative dielectric constant ε_r of 2.15. The thickness is 0.8 mm. The design frequency is 10 GHz. In this study, the fabricated array antenna integrates the 2×2 orthogonally polarised microstrip array antenna with the 90°. hybrid circuit as shown in Fig. 8, and is investigated both by simulation and experiment. The characteristics of the proposed array antenna are analysed using the Agilent electromagnetic simulator (EMPro, FEM). In the analysis, a delta error of 0.03 is set, and the consecutive passes of it are from 3 to 20. Also, the array antenna is measured using an Agilent Network Analyzer 8510C in an anechoic chamber.

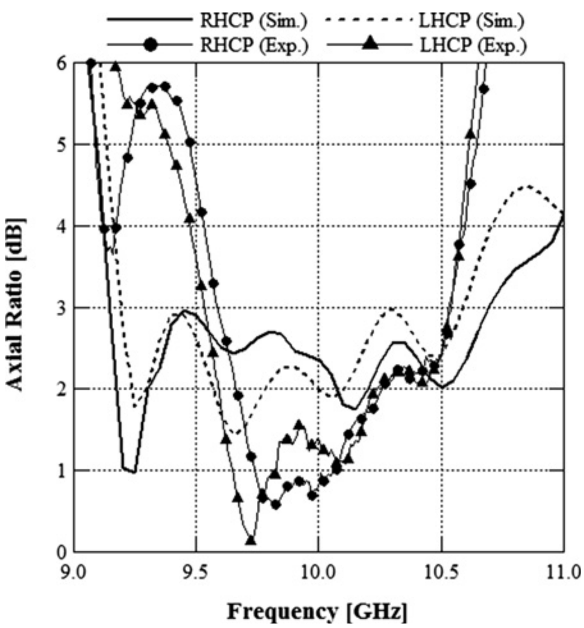


Fig. 10 *Axial ratios of the proposed array antenna*

Fig. 9 shows the S-parameters of the array antenna for dual circular polarisation. In the simulation, the reflection coefficients (S11, S22) are better than -15 dB in the frequency range from 9.5 to 10.75 GHz as shown in Fig. 9*a*. Also, the return loss of 30 dB is obtained at 10 GHz. In the experiment (Fig. 9*b*), the reflection coefficients S11 and S22 are -16 and -18 dB, respectively. In addition, the isolation in the simulation and the experiment are -40 and -28 dB at the design frequency, respectively. They show similar tendencies. Generally, it is confirmed that the characteristics are fairly good in both the simulation and the experiment at the design frequency. Fig. 10 shows the experimental characteristics of the axial ratio together with the simulated results. As a result, the axial ratios of both the simulation and the experiment show a similar tendency. The 3 dB bandwidths are approximately 10% in the experiment. Therefore the wide band axial ratio performances are confirmed on the array antenna. Fig. 11 shows the simulated gains. The gains of both *xz*-plane and *yz*-plane are almost the same. These gains of both RHCP and LHCP are 12.5 dBi, and are almost the same as the orthogonally polarised array antenna. Fig. 12 shows the experimental radiation patterns. In Fig. 12, the radiation patterns of *xz*-plane and *yz*-plane are almost the same with the simulated results as well. Therefore it is confirmed that the dual circular polarisations are successfully radiated by the proposed array antenna.

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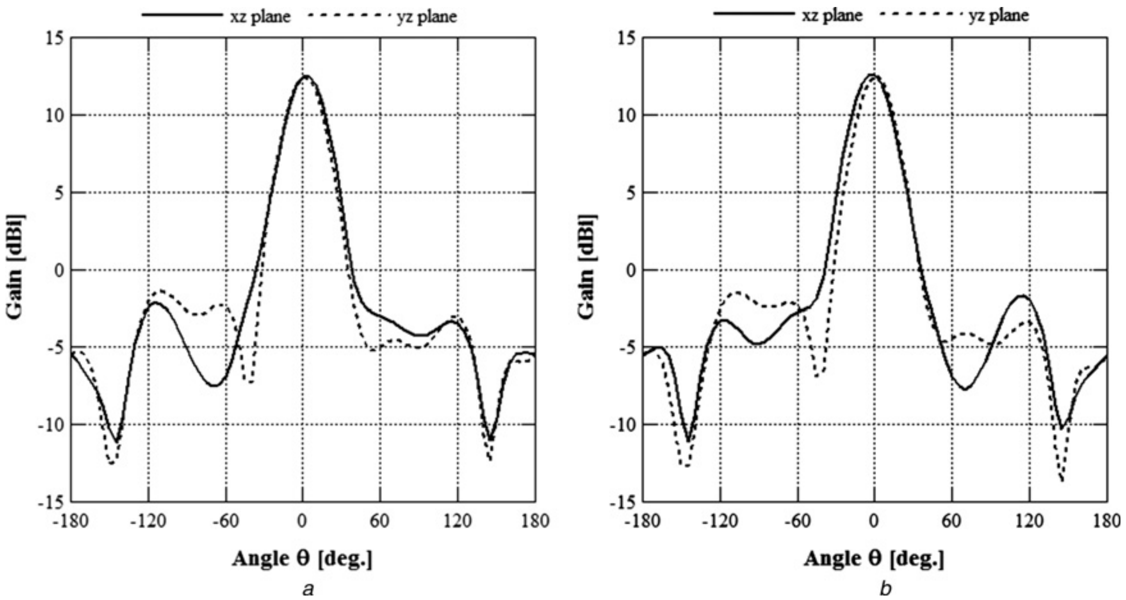

Fig. 11 *Simulated gains*
a RHCP
b LHCP

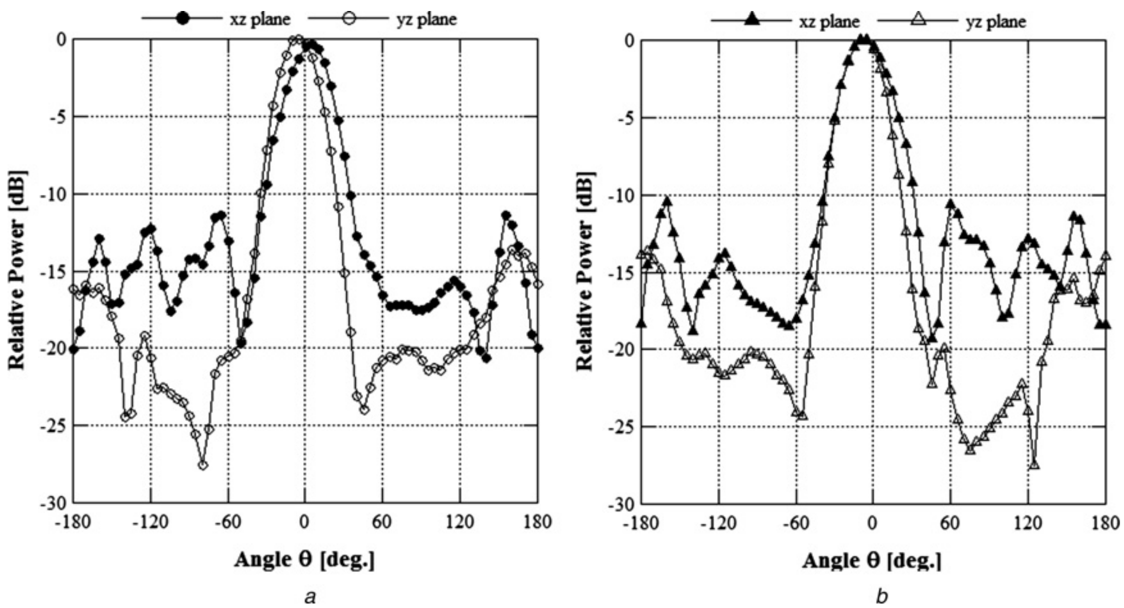

Fig. 12 *Experimental radiation patterns*
a RHCP
b LHCP

5 Conclusion

A single-layer integrated microstrip array antenna for dual circular polarisation is proposed and investigated by both simulation and experiment. The 3 dB axial ratio bandwidths are about 10% for RHCP and LHCP in the experiment. By using double-sided MIC technology including airbridges, the array antenna structure is much simpler and more compact than conventional array antennas. Moreover, the proposed array antenna's size scales well, that is, it is possible to readily expand the antenna array to a 4×4 or 8×8 array and so on. Since the proposed array antenna has a single-layer structure, it is possible to easily realise wireless integration modules. The proposed array antenna is very promising in many wireless application areas, such as radar systems and various kinds of sensors.

6 Acknowledgment

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