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Linear polarisation switchable ring-slot array antenna using single-pole double-throw switch circuit

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Abstract: A linear polarisation switchable ring-slot array antenna is presented. The antenna is comprised of a four-element ring-slot array and a single-pole double-throw (SPDT) switch circuit. The linear polarisation switchable function is achieved using the SPDT switch circuit. Two Schottky barrier diodes are mounted on a slot ring of the SPDT switch circuit. Since the orthogonal linear polarisation switching depends on the diode ON/OFF conditions, the polarisation angle is easily controlled by the polarity of the bias voltage. The excellent design flexibility of double-sided microwave integrated circuit technology is effectively employed in forming this type of antenna. Experimental results show that the proposed antenna has good polarisation characteristics for the two orthogonal linear polarisations. The radiation performances of the two orthogonal polarisations are almost identical. Consequently, a linear polarisation switchable ring-slot array antenna is successfully verified.

1 Introduction

In recent years, microwave planar antennas have attracted increased attention in wireless communication system design because of their miniaturisation potential and low profile. As part of this trend, the polarisation diversity technique is also of interest.

Various antenna architectures, offering polarisation agility, have been proposed [1–4]. In these antennas, polarisation diversity is achieved by using P-intrinsic-N (PIN) diodes or varactor diodes embedded in the antennas. In [2], the polarisation angle is controlled by switching the resonant mode of the patch antenna, where the switching of resonant modes is achieved by adjustment of the conditions of the PIN diodes. These antennas are attractive for wireless communications, being especially effective for polarisation diversity because of their simple structures. Moreover, a ring-slot antenna that allows polarisation diversity has been reported [5]. The characteristics of a single element antenna with polarisation diversity have been discussed in these papers; however, investigation of an array antenna with polarisation diversity has not been discussed. Recently, a slot-ring array antenna with a polarisation switchable function has been proposed [6], where a four-element ring-slot array antenna, whose orthogonal polarisation can be switched, was investigated. The orthogonal polarisation is switched by using 16 switching diodes embedded in the slot-ring antenna elements. However, this array antenna requires many diodes for fabrication.

In this paper, a linear polarisation switchable ring-slot array antenna utilising a novel single-pole double-throw (SPDT) switch circuit is proposed and the characteristics of the antenna are investigated theoretically and experimentally. The ring-slot array antenna has two feed networks and radiates a dual-polarised wave. The Schottky barrier diodes are mounted on a slot-ring of the SPDT switch circuit which connects with the feed networks of the array. The orthogonal polarisation is switched by the polarity of bias voltage for the diodes. Double-sided microwave integrated circuit (MIC) technology [7] is effectively employed in forming this proposed slot array antenna. A very simple antenna configuration and wide range of antenna return loss bandwidth are obtained due to the features of the double-sided MIC technology. In this antenna, a low-profile and wide-band ring-slot array antenna is used to achieve the switching of the orthogonal linear polarisation. The good cross-polarisation suppression of the polarisation switchable ring-slot array antenna is obtained because of the mirror-symmetry feed of the antenna [8].

2 Design of ring-slot array antenna for linear polarisation switching

The proposed linear polarisation switchable ring-slot array antenna is shown in Fig. 1. The antenna consists of the ring-slot array antenna and the SPDT switch circuit. The ring-slot array antenna can radiate two orthogonal linear polarisations. The SPDT circuit switches two feed circuits of the radio frequency (RF) signal to the ring-slot array antenna. The array antenna is constructed with two-layer dielectric substrates and three conductive layers. In this section, the configuration and basic operation of the ring-slot array antenna and the SPDT switch circuit are explained in Sections 2.1 and 2.2, respectively.

2.1 Configuration and basic operation of the ring-slot array antenna

The configuration of the ring-slot array antenna is shown in Fig. 2. The array antenna has two input ports (Port-I and Port-II). The microstrip lines are on layer-1 and layer-3. The four ring-slot antenna elements and slot lines are on layer-2. The four slot antenna elements are excited orthogonally by the orthogonal feed circuits on the three layers. The upper feed circuit is constructed with Port-I and microstrip lines on layer-1. The lower one is constructed with Port-II and microstrip lines on layer-3.

Figs. 3*a* and *b* show the schematic electric fields fed by Port-I and Port-II, respectively. The ring-slot array antenna has a very simple circuit configuration, which is mainly because of the excellent performance of both the microstrip-slot parallel branch circuit and the slot-microstrip series branch circuit [8, 9]. When an RF signal is fed to the feed circuit (Port-I or Port-II), the signal is distributed in parallel (in phase) to the cross-slot by the strip-slot branch circuit and then the resulting signals are distributed in series (out of phase) to the microstrip lines connected to the ring-slot antenna elements through the slot-strip branch circuit. As Fig. 3 shows, the structures of the two feed circuits (the upper feed circuit and the lower feed circuit) are orthogonal to each other. When the input port is Port-I, the RF signal is fed to the upper feed circuit and the linear polarisation is aligned with the y-axis. When the input port is Port-II, the linear polarisation is aligned with the x-axis. Therefore the two orthogonal linear polarisations can be realised easily.

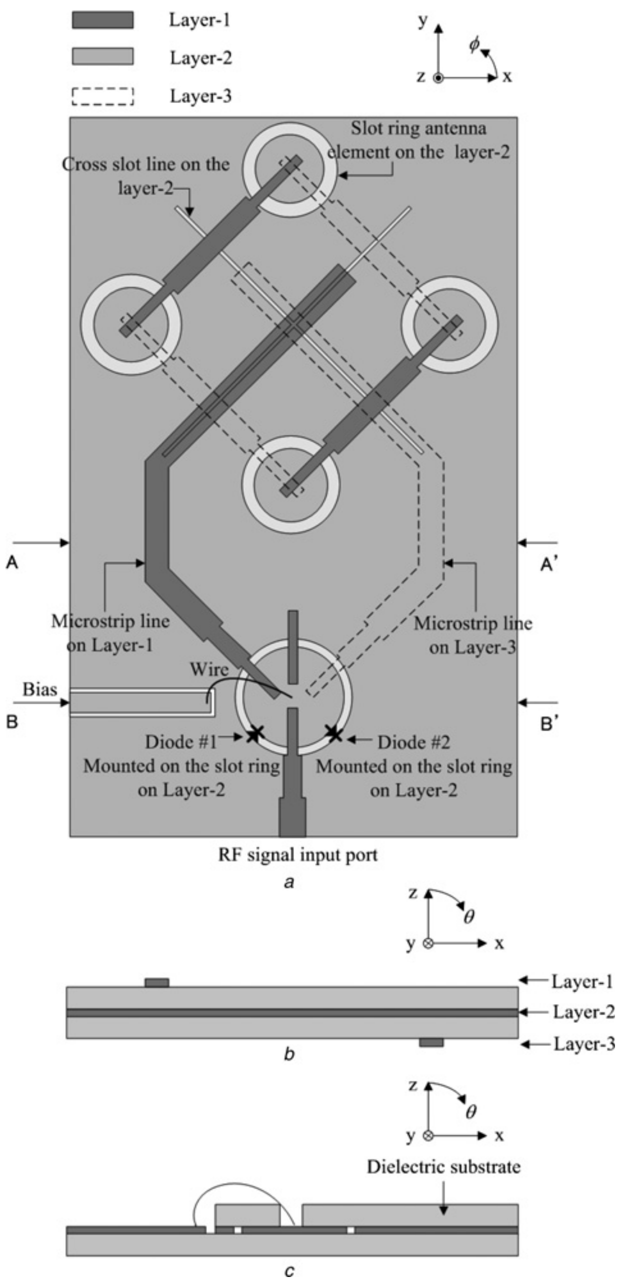

Figure 1 *Structure of proposed polarisation switchable ring-slot array antenna*

a Top view
b Side view (A–A′)
c Side view (B–B′)

2.2 Configuration and basic operation of the SPDT switch circuit

The proposed antenna implements the orthogonal linear polarisation switching function using a novel three-layer SPDT switch circuit. Fig. 4 shows the configuration of the proposed SPDT switch circuit. The SPDT circuit consists of a dual wavelength ring-slot on layer-2, an input microstrip line and output microstrip lines connected to Port-II on layer-1 and Port-III on layer-3, respectively, with two Schottky barrier diodes mounted on the ring-slot. The

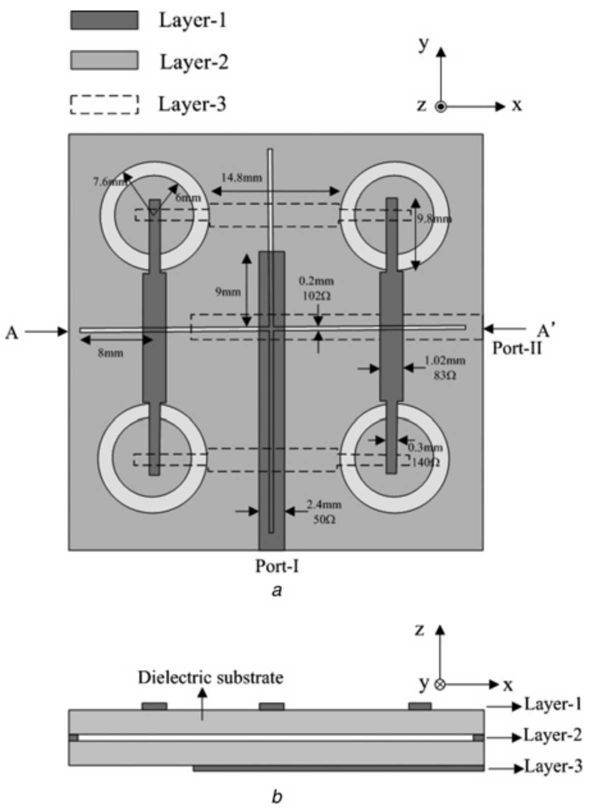

Figure 2 *Structure of four elements ring-slot array antenna*

a Top view
b Side view (A–A′)

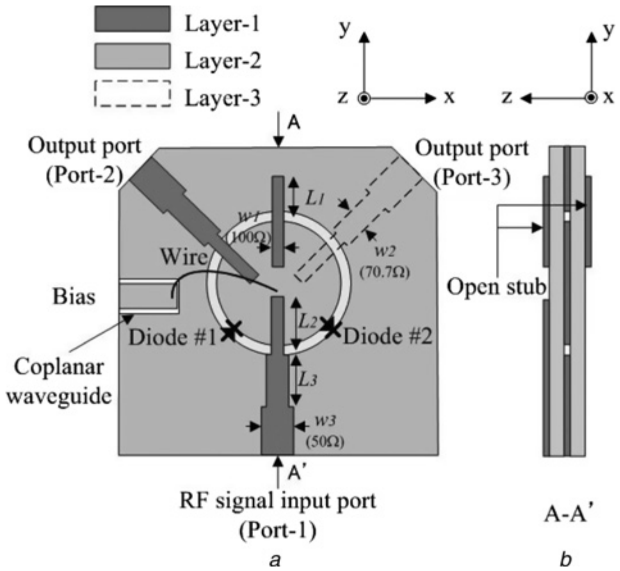

Figure 4 *Structure of three-layer SPDT switch circuit*

a Top view
b Side view (A–A′)

switching bias is supplied to the switching diodes through the conductor wire connected to the coplanar wave guide. Two half-wavelength open stub microstrip lines on layer-1 and layer-3 are used in the switch circuit to isolate the two output ports. As shown in Fig. 4, two Schottky barrier diodes are loaded on the ring-slot at $\pm 45^\circ$ with respect to the input microstrip line (Port-I).

The basic behaviour of the proposed SPDT switch circuit is shown in Fig. 5. In this type of three-layer SPDT switch circuit, the RF signal propagates along each slot line according to the polarity of the switching bias voltage. When a positive voltage is applied to the inner conductor of the ring-slot, diode 2 is ON and diode 1 is OFF. In this condition, the switch circuit transmits the RF signal to Port-II on layer-1 as shown in Fig. 5*a*. When the polarity of the bias voltage applied to the diode is reversed, the switch circuit transmits the RF signal to Port-III on layer-3 as shown in Fig. 5*b*. Therefore the output port of the RF signal can be switched easily.

As a result, the orthogonal linear polarisation switchable ring-slot array antenna integrating the four-element

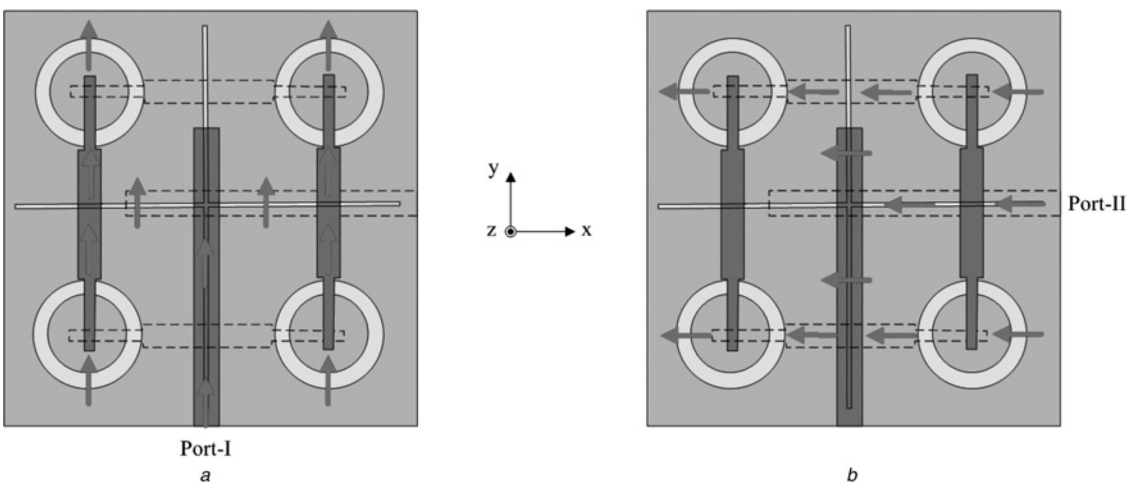

Figure 3 *Schematic electric field of the feed circuit*

a Upper feed circuit
b Lower feed circuit

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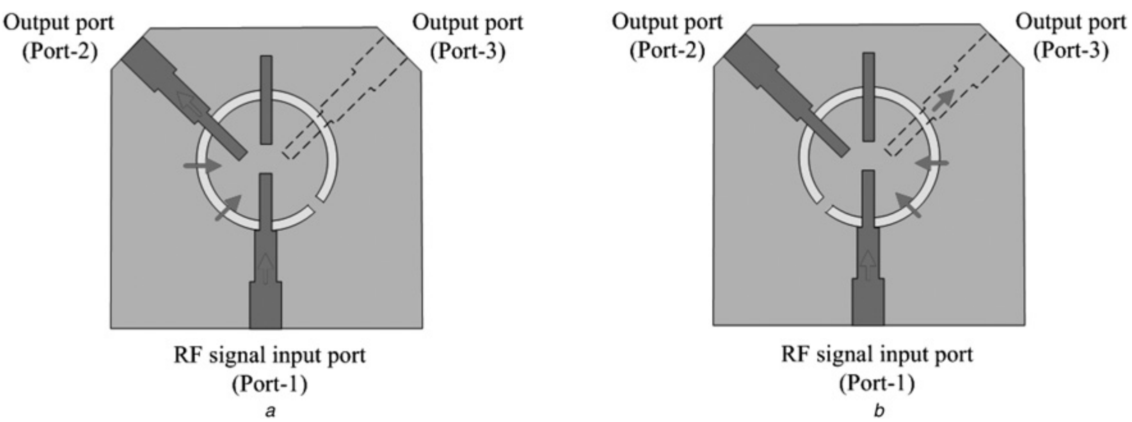

Figure 5 *Schematic electric field of the SPDT switch circuit*
a Diode #1 OFF, diode #2 ON
b Diode #1 ON, diode #1 OFF

ring-slot array antenna and the SPDT switch circuit can be realised in the same substrate.

3 Characteristics and discussion of ring-slot array antenna for polarisation switching

The proposed linear polarisation switchable ring-slot array antenna has been designed and fabricated. The performance is simulated using high frequency structure simulator (HFSS) (Ansoft) and measured using a network analyser (Agilent 8510C) in an anechoic chamber. In this section, the characteristics of the ring-slot array antenna are discussed. The performance of the SPDT switch circuit is then investigated experimentally. Finally, the experimental results of the integrated linear polarisation switchable array antenna of the ring-slot array antenna and the SPDT switch circuit are described.

3.1 Characteristics of the ring-slot array antenna

The array antenna shown in Fig. 2 has been designed and fabricated. The array antenna is etched using dielectric substrates with relative dielectric constant of $\varepsilon r = 2.15$ and a thickness of $h = 0.8$ mm. The design frequency is 7.5 GHz. The size of the antenna ground plane is 60 mm × 60 mm. The RF signal is fed to either the Port-I or Port-II microstrip line with 2.4 mm width. The characteristic impedance of the feed microstrip lines and the slot lines are 50 and 102 Ω, respectively. The characteristic impedance of the microstrip lines connected to the ring-slot antennas is 83 Ω for impedance matching. The length of the ring-slot is 48 mm, which is a guided wavelength λ_g at the design frequency of 7.5 GHz, and the width is 1.6 mm.

Fig. 6 shows the *S*-parameters of the ring-slot array antenna. The isolation between the two input ports is better than 30 dB in both the simulation and the experiment. The excellent isolation between the two input ports is obtained because of the lack of interference between the microstrip lines and the slot lines in the feed circuit [8]. The calculated return loss for both Port-I and

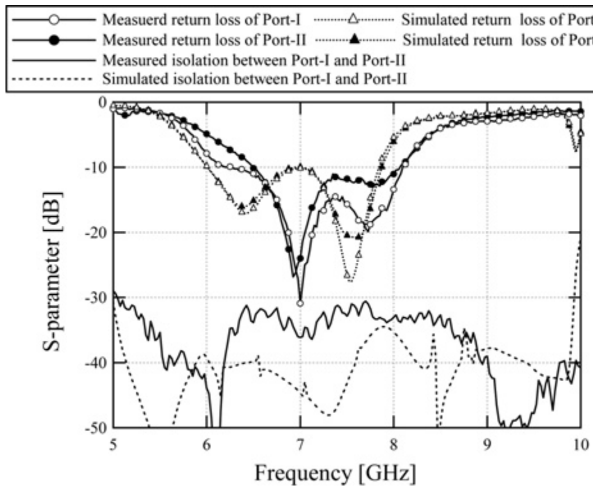

Figure 6 *S-parameter of array antenna*

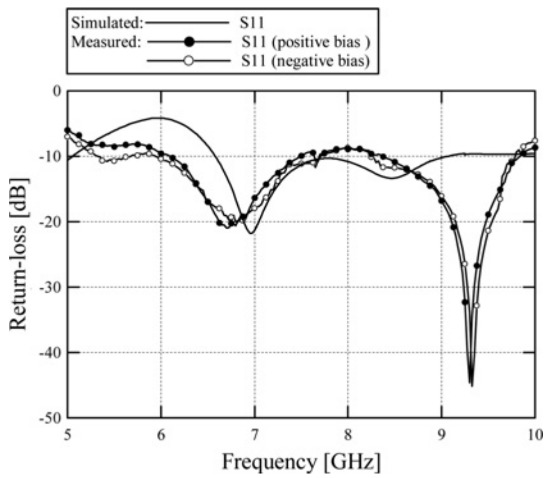

Figure 7 *Return loss of SPDT switch circuit*

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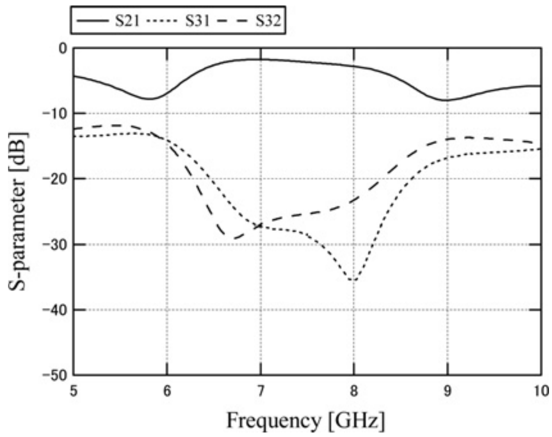

Figure 8 *Simulated S-parameter of SPDT switch circuit (diode #1 OFF, diode #2 ON)*

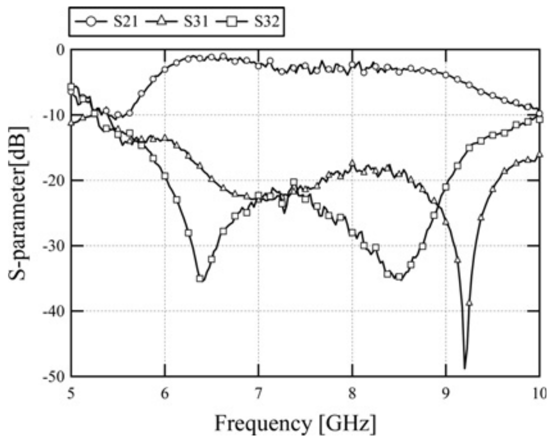

Figure 9 *Measured S-parameter of SPDT switch circuit (diode #1 OFF, diode #2 ON)*

Port-II is better than 10 dB from 6 to 7.8 GHz. The measured return loss for both Port-I and Port-II is better than 10 dB in the frequency range over 6.5–8.1 GHz. Broadband performance is obtained both in the simulation and in the measurement.

As a result, the excellent bandwidth and isolation are confirmed. The measured far field radiation patterns of the antenna array including the SPDT switch circuit will be discussed at the end of this section.

3.2 Characteristics of the SPDT switch circuit

The SPDT switch circuit shown in Fig. 4 has also been fabricated for the design frequency of 7.5 GHz. The optimised parameters of the proposed SPDT switch circuit dimensions are as follows: $L_1 = L_2 = 0.25\lambda_g = 7.6$ mm, $L_3 = 0.25\lambda_g = 7.46$ mm, $w1 = 0.7$ mm, $w2 = 1.4$ mm, $w3 = 2.4$ mm; the characteristic impedance of the feed microstrip lines (Port-I, II and III) is 50 Ω. The characteristic impedance of the microstrip lines connected to the ring-slot is 70.7 Ω for impedance matching. The length of the conductor wire is 1.5 cm. The length and width of the ring-slot are 68.44 and 0.2 mm, respectively. Two Schottky barrier diodes (Metelics MSS30, 154-B10B) are used in the SPDT switch circuit.

The measured return loss is shown in Fig. 7. The 10 dB return loss bandwidth is 1.45 GHz from 6 to 7.45 GHz and 1.38 GHz from 8.4 to 9.78 GHz for both the positive and the negative bias. The simulated result is also shown in the same figure. When a positive voltage is applied to the SPDT switch circuit, diode 2 is ON and diode 1 is OFF. The simulated *S*-parameters are shown in Fig. 8. The

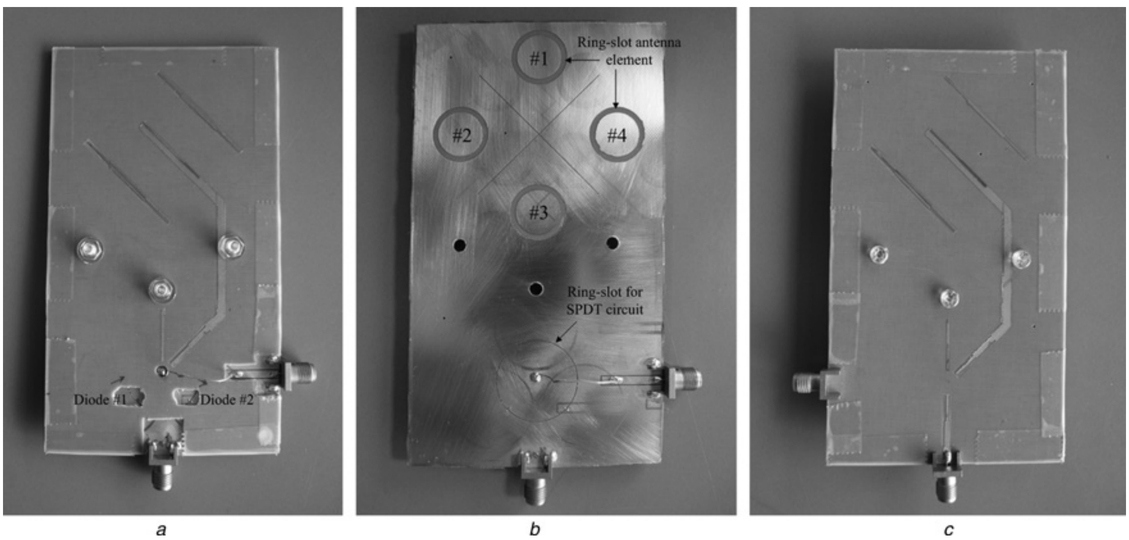

Figure 10 *Photos of the proposed ring-slot array antenna*

a Top view (layer-1)
b Ring-slot array (layer-2)
c Bottom view (layer-3)

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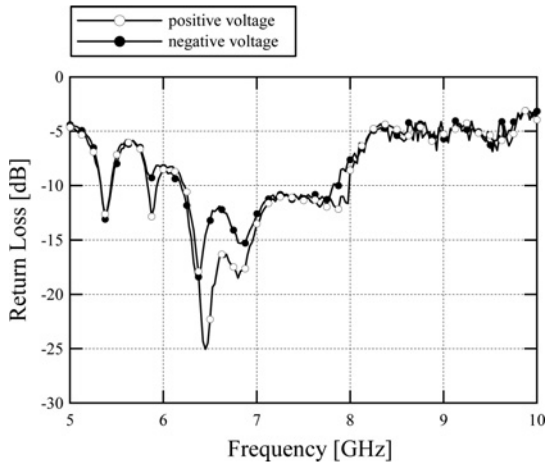

Figure 11 *Measured return loss of proposed linear polarisation switchable ring-slot array antenna*

isolation performance S_{31} is better than 20 dB over the frequency range of 6.5–8.6 GHz. A better insertion loss S_{21} is obtained in the same band. Fig. 9 shows the measured results. The isolation performance S_{31} is better than 20 dB over the frequency range of 6.5–7.65 GHz. The insertion loss S_{21} is less than 3 dB in the same band. For the opposite polarity of the bias voltage, the same result is obtained. Comparing the experimental data with the simulation data, the discrepancy is mainly due to the effect of the diode characteristics. In the simulation, the ON state diode is replaced by a conductor line.

According to these results, a wide band SPDT switch circuit has been achieved. Better circuit performance can be realised by further matching of the impedances of the microstrip lines and ring-slot on the SPDT switch.

3.3 Experimental results of the linear polarisation switchable ring-slot array antenna

The integrated orthogonal linear polarisation switchable array antenna of the ring-slot array antenna and the SPDT switch

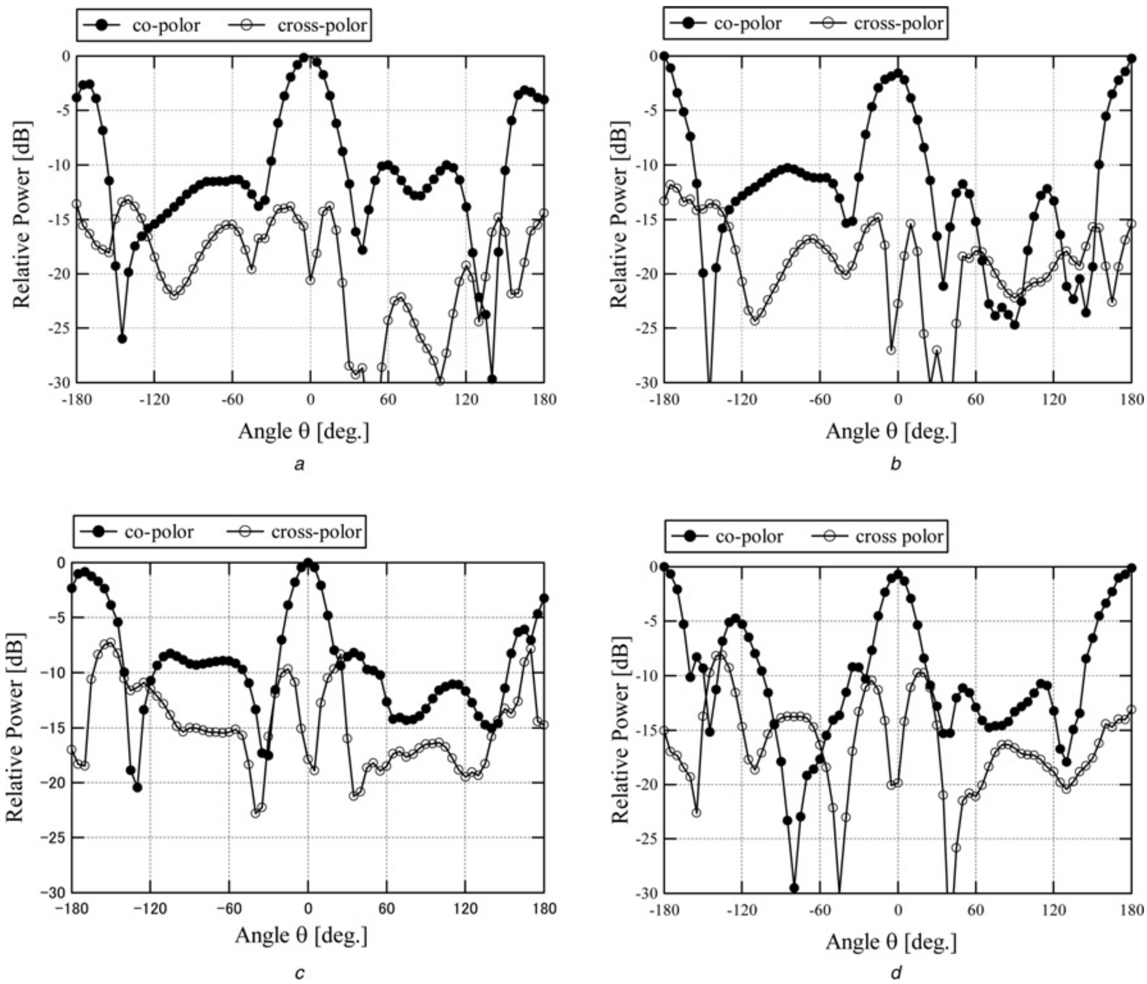

Figure 12 *Measured radiation patterns of proposed polarisation switching ring-slot array antenna at 7 GHz*

a *E*-plane, $\phi = +45^{\circ}$, diode #2 is ON
b *E*-plane, $\phi = -45^{\circ}$, diode #1 is ON
c *H*-plane, $\phi = +45^{\circ}$, diode #2 is ON
d *H*-plane, $\phi = -45^{\circ}$, diode #1 is ON

circuit has been fabricated and measured. The fabricated antenna is shown in Fig. 10. The size of the ground plane is 70 mm × 120 mm.

Fig. 11 shows the return loss of the array antenna. A return loss better than 10 dB is obtained in a frequency range of 6.3–7.8 GHz for both the positive bias and the negative bias.

The far fields of the array antenna are measured using a linear polarisation horn antenna. The horn antenna is set at a distance of 2 m from the array antenna. The array antenna is located on a turntable. Radiation patterns of the proposed ring-slot array antenna are shown in Fig. 12. The measurement frequency is 7 GHz. When a positive voltage is applied to the array antenna, diode 2 is ON and diode 1 is OFF. The main polarisation angle ϕ of the antenna is tilted to $+45^\circ$. The radiation patterns are shown in Figs. 12*a* and *c*. When the polarity of the bias voltage is reversed, diode 1 is ON and diode 2 is OFF. The main polarisation angle ϕ of the antenna is -45° as shown in Figs. 12*b* and *d*.

The radiation patterns of the two orthogonal linear polarisations are almost identical. In addition, the cross-polarisation level is about -20 dB at the bore-sight for both $\phi = +45^\circ$ linear polarisation and $\phi = -45^\circ$ linear polarisation. The better cross-polarisation suppression of the array antenna is obtained because of the complementarity effect of the mirror-symmetry antenna structure [8] and the good isolation performance of the SPDT switch circuit.

4 Conclusions

In this paper, a novel linear polarisation switchable ring-slot array antenna is proposed and the characteristics of the antenna are experimentally investigated. The antenna can provide the switching function between the polarisation angle of $\phi = +45$ and -45°. The double-sided MIC technology is effectively applied to form the array antenna. By the use of the combining effect of a microstrip-slot parallel power divider and a microstrip-slot series power divider, a very simple circuit configuration and good polarisation performance can be achieved. A 10 dB return loss bandwidth is obtained over the 6.3–7.8 GHz frequency range.

Extending this array antenna structure, a 16-element array or 32-element ring-slot array antenna with linear polarisation switching function can be easily realised as well. The proposed slot array antenna may find applications in various radars and polar-metric sensors. Moreover, much wider applications can be found if a reflector is added for a directional radiation pattern. Therefore the proposed array antenna is attractive for advanced wireless communication systems and other applications.

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