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CIRCULARLY POLARIZED PATCH ANTENNA WITH A STACKED SLOT-RING

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Abstract—A probe-fed circularly polarized microstrip patch antenna is presented. By stacking a sot-ring a proper distance above the patch, traveling current along the periphery of the slot-ring is formed. The axial-ratio bandwidth is optimized by varying the size of the slot-ring and the size of the ground plane. Through this simple method, 3-dB axial-ratio bandwidth of 9.8% centered at 915 MHz is achieved for RFID use.

1. INTRODUCTION

Circularly polarized (CP) antennas are frequently used in wireless environment to overcome the misalignment between the transmitter and the receiver. The probe-fed circularly polarized microstrip patch antenna has intensively been studied in the literature. The main disadvantage of the antenna is that it has a very narrow axial-ratio bandwidth [1, 2]. Therefore, methods to widen the axial-ratio bandwidth are continuously under investigation. The axial-ratio (AR) bandwidth is based on AR < 3. In [3], a single-layer patch embedded with a U-shaped slot has an axial-ratio bandwidth of 4%. The height of the antenna is 0.085λ. In [4, 5], a single-layer corner-truncated patch is fed by an L-shaped probe to achieve over 14% axial-ratio bandwidth. Besides the single-layer antennas, more research works are focused on stacked antennas [6–9]. Axial-ratio bandwidths of 11% and 13.5% are realized respectively in [6, 7] by stacking a parasitic patch to the driven patch. The antenna in [8] is a probe-fed dual-band circularly polarized antenna. The axial-ratio bandwidth is 3.3% and 6.3% respectively in the low-band and in the high-band. In [9], a metal-ring is stacked above

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the patch to widen the axial-ratio bandwidth of a probe-fed patch. The total height of the antenna is about 0.09λ, which is lower than 0.1–0.2λ in [4–7]. In this paper, the stacked metal-ring in [9] is replaced by a stacked slot-ring. It is investigated that the axial-ratio bandwidth of the probe-fed patch can also be increased by optimizing the relative position between the patch and the slot-ring. The antenna occupies a volume of $102 \times 93 \times 34.8\,\text{mm}^3$ in comparison with $124 \times 117 \times 33.2\,\text{mm}^3$ in [9] (both ground planes are excluded). The size of the ground plane of both antennas is dimensioned with $160 \times 160\,\text{mm}^2$.

2. ANALYSIS

Figure 1 shows the structure of the proposed antenna. It contains a probe-fed microstrip patch and a stacked rectangular slot-ring. Referred to the origin at the center of the patch, the patch is fed at (39 mm, 29 mm, 0 mm). The slot-ring is on the plane of $z = H2$

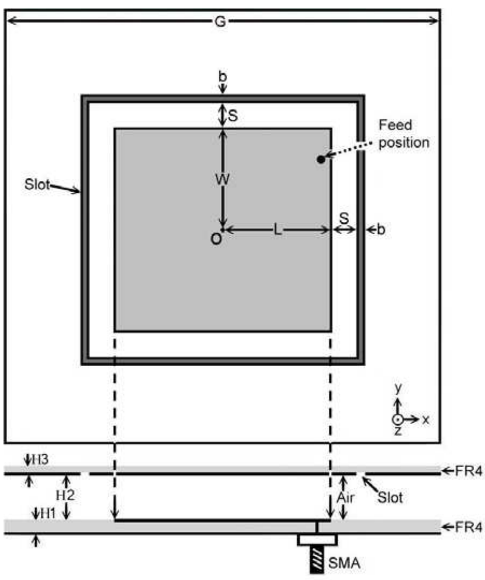

Figure 1. Structure of the proposed antenna.

Table 1. Geometrical parameters of the antenna (unit: mm).

L	W	S	b	G	$H1$	$H2$	$H3$	Feed point
43	38.5	6	2	160	3.2	30	1.6	(39, 29, 0)

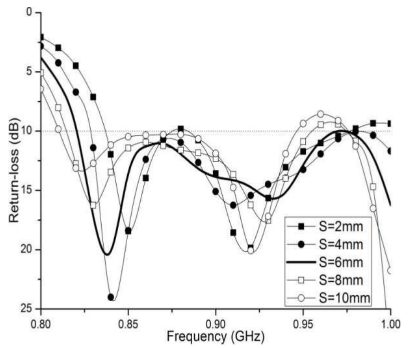

Figure 2. Return-loss of the antenna by tuning "S".

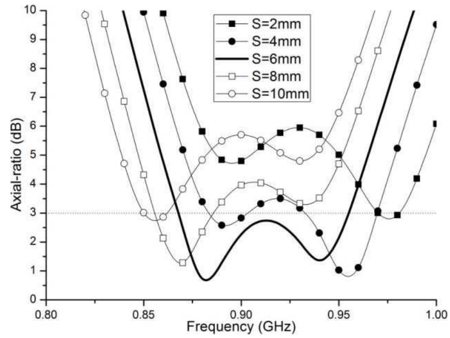

Figure 3. Axial-ratio of the antenna by tuning "S".

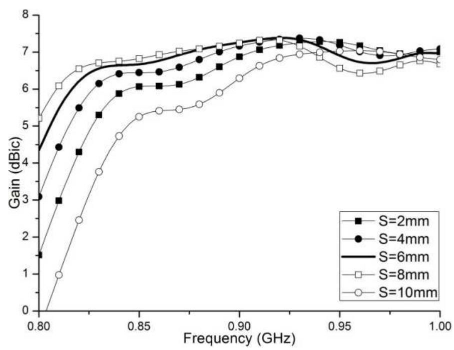

Figure 4. Gain of the antenna by tuning "S".

and the ground plane is on the plane of $z = -H1$. Without the slot-ring, it is expected that the single-layer patch with main parameters shown in Table 1 is operated on a very narrow axial-ratio bandwidth. The return-loss bandwidth is also narrow resulting in a simulated overlapped bandwidth of 1% centered at 900 MHz. To increase the overlapped bandwidth, a slot-ring is stacked above the patch. The slot-ring has a uniform width of $b = 2$ mm. "S" denotes the spacing between the outer periphery of the patch and the inner periphery of the slot-ring when they are projected into the same plane. Figures 2, 3, and 4 respectively show the return-loss, the axial-ratio, and the boresight-gain responses of the antenna with different values of S. With $S = 6$ mm, it is shown that the axial-ratio value is lower than 3 dB from 870 MHz to 960 MHz. Within this frequency range, the return-loss is greater than 10 dB and the boresight-gain is greater than

6.5 dBic. The current distribution surrounding the slot-ring is shown in Figure 5. The arrow in each sub-graph indicates the location where there is a referenced minimum current density. It is shown that the current flows in a clockwise direction, yielding a left-hand circularly

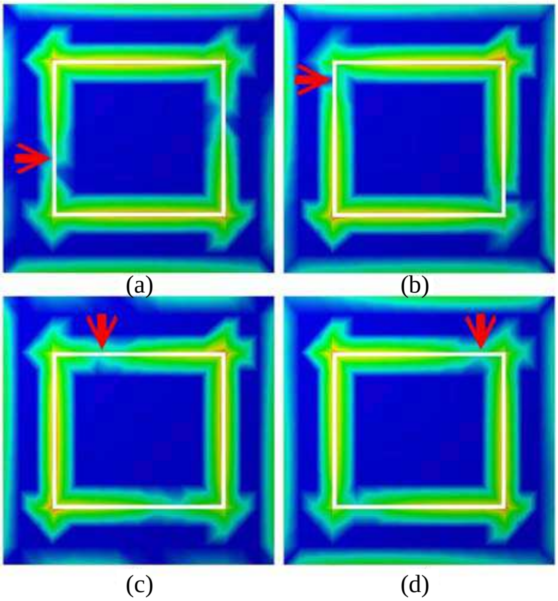

Figure 5. Current distribution surrounding the slot-ring of the proposed antenna at different time, (a) $t = 0$, (b) $t = T/8$, (c) $t = 2T/8$, and (d) $t = 3T/8$, where T is the period.

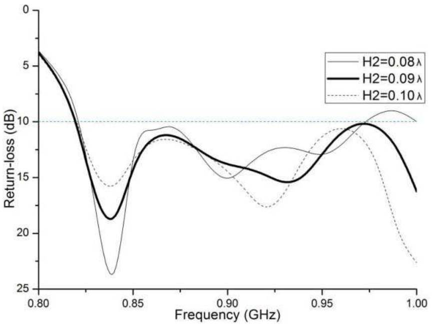

Figure 6. The effect of the stacked height ($H2$) on the return-loss of the antenna.

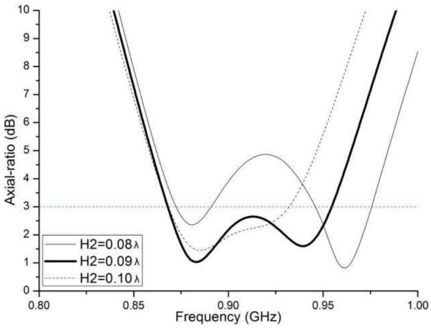

Figure 7. The effect of the stacked height ($H2$) on the axial-ratio of the antenna.

polarized wave in the upper-half space. It is investigated that the isolated patch also radiates a left-hand circularly polarized wave in the upper-half space.

The influence of the thickness of the air-layer on the performance of the antenna is shown in Figures 6, 7, and 8 respectively for the return-loss, the axial-ratio, and the bore-sight gain. Apparently, the thickness influences little on the return-loss bandwidths from 830 MHz to 970 MHz. The best optimized thickness to get the widest axial-ratio bandwidth is about 0.09λ at 900 MHz in free space. The simulated axial-ratio bandwidth can cover the range from 870 MHz to 960 MHz with good impedance match. The overlapped bandwidth is 9.8% centered at 915 MHz.

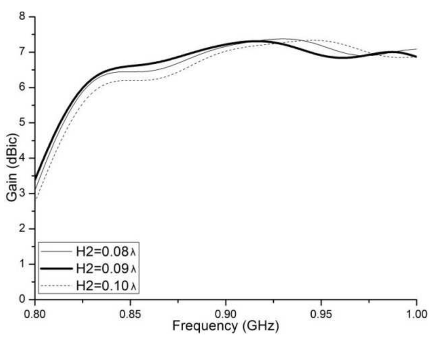

Figure 8. The effect of the stacked height ($H2$) on bore-sight gain of the antenna.

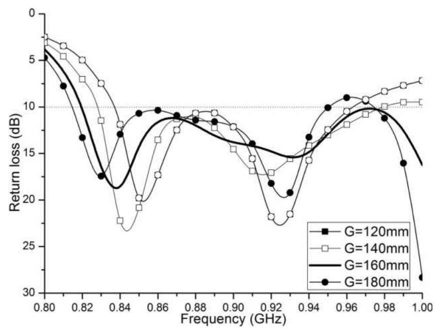

Figure 9. The effect of the size of the ground plane on the return-loss of the antenna.

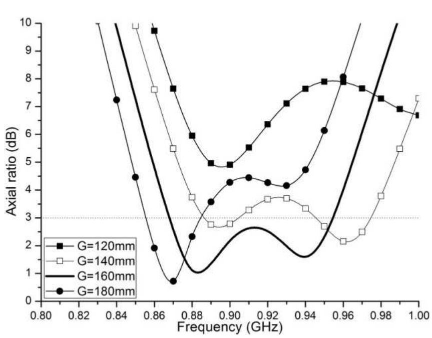

Figure 10. The effect of the size of the ground plane on the axial-ratio of the antenna.

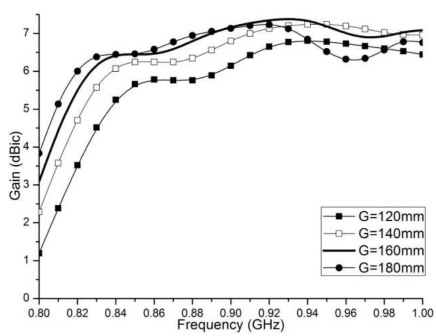

Figure 11. The effect of the size of the ground plane on the bore-sight gain of the antenna.

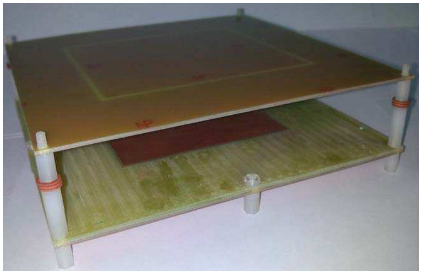

Figure 12. A picture of the assembly of the antenna.

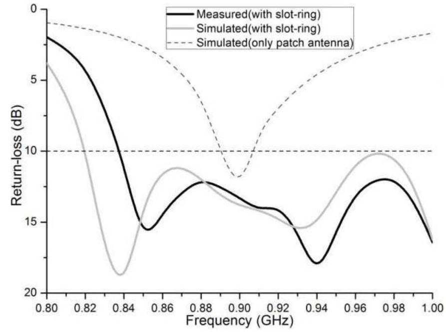

Figure 13. Simulated and measured return-loss of the antenna.

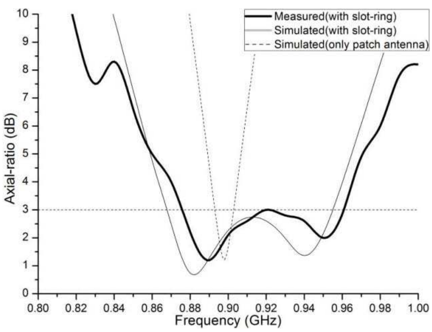

Figure 14. Simulated and measured axial-ratio of the antenna.

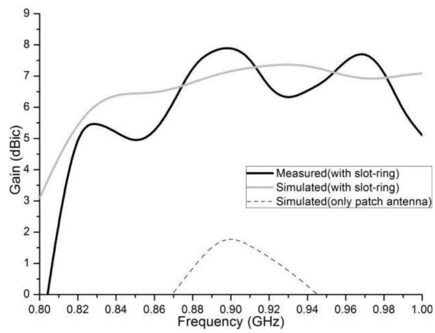

Figure 15. Simulated and measured bore-sight gain of the antenna.

Another factor that may influence the performance of the antenna is the size of the ground plane, which is made equal to the size of the substrate. The influence of the size of the ground plane on the performance of the antenna is shown in Figures 9, 10, and 11, respectively for the return-loss, axial-ratio, and bore-sight gain. With $G = 160\,\text{mm}$, the widest axial-ratio bandwidth can be achieved.

3. EXPERIMENTS

Based on the analysis by the IE3D software, the antenna is designed with the main parameters shown in Table 1. A picture of the assembly of the antenna is shown in Figure 12. The simulated and measured results of the return-loss, the axial-ratio, and the bore-sight gain of

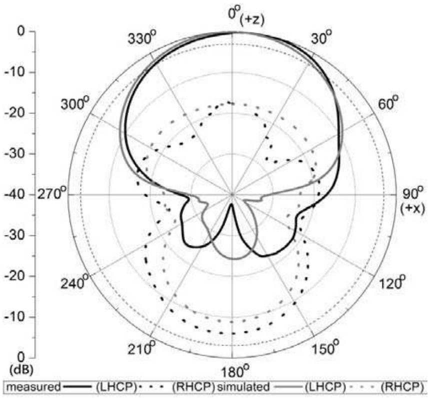

Figure 16. Measured and simulated LHCP and RHCP radiation patterns in the XZ-plane at 900 MHz.

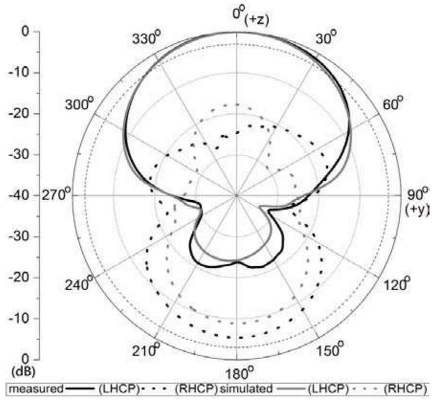

Figure 17. Measured and simulated LHCP and RHCP radiation patterns in the YZ-plane at 900 MHz.

the antenna are respectively shown in Figures 13, 14, and 15. The simulated results of the return-loss and the axial-ratio of the isolated circularly polarized patch are also displayed in Figures 13 and 14. It is expected that the isolated patch radiates the CP wave within a very narrow axial-ratio bandwidth about 1.6% centered at 900 MHz. With the stacked slot-ring, both the simulated and measured results of the return-loss and axial-ratio bandwidths are found largely increased. The measured 3-dB axial-ratio bandwidth is from 875 MHz to 965 MHz. The measured 10-dB return-loss is wide enough to cover the above range. In Figure 15, the measured gain increases from 1.75 dBic for the isolated patch to 8 dBic for the proposed antenna at 900 MHz.

The simulated and measured XZ-plane radiation patterns of the antenna are shown in Figure 16. In Figure 17, the patterns in the YZ-plane are shown. It is confirmed that the antenna radiates a LHCP wave in the upper half space and a RHCP wave in the lower half space.

4. CONCLUSION

In the past, patch and metal-ring have been demonstrated as useful parasitic elements to be stacked above a probe-fed driven patch to increase the axial-ratio bandwidth. In this paper, it is demonstrated that a stacked slot-ring can also be employed for the same purpose. The slot-ring is placed outside the periphery of the driven patch. An optimum spacing between the patch and the slot-ring can be found to widen the axial-ratio bandwidth. In [9], a metal-ring instead of the slot-ring is adopted. Since less copper is removed from the surface of a metal-clad substrate using an engraving machine in fabricating a slot-ring than a metal-ring, the former one is easier to fabricate. The measured axial-ratio bandwidth is 9.8% centered at 915 MHz with a maximum gain of 7.8 dBic. In [9], measured axial-ratio bandwidth is 7.7% centered at 905 MHz with a maximum gain of 7.1 dBic. The new design is more suitable for RFID application.

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