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T-STRIP FED PATCH ANTENNA WITH RECONFIGURABLE POLARIZATION

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Abstract—In this paper, right handed circular polarization (RHCP), left handed circular polarization (LHCP) and linear polarization (LP) reconfigurable antenna is proposed by reconfigured fabrication. The proposed antenna comprising of two square patches, a T-stripline, and a finite ground plane is designed for HiperLAN2 5 GHz operation. The patches are symmetrically placed along the vertical portion of T-strip and coupling fed by the strip. The planar structure is in LP sense while CP sense is achieved as the structure bent. For the bent structure, the vertical and horizontal portions of T-strip not only respectively feed the coplanar patch but also provide a 90° phase difference between the feeds. Two orthogonal E-fields with quadrature are excited to achieve CP sense. Moreover, the switching between RHCP and LHCP is easily achieved by folding the structure along opposite vertical edge of T-strip. Instead of electrically controlling switches, the polarization reconfiguration can be manually constructed.

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1. INTRODUCTION

For the rapidly growing wireless communication systems, microstrip antennas have been widely developed owing to their attractive features of low profile, light weight and easy integration with RF circuitry [1]. Generally, antenna operation in linear polarization is suitable for land-mobile communication. In addition, a circular polarization (CP) antenna is suitable for some mobile wireless communications because of its insensitivity to signal orientations and polarization [2, 3]. To achieve CP radiation with single feed, an L-strip [4] and a cross-slot [5] can provide orthogonal proximity feeding. Usually, the feeding module which levels at the radiating element is a considered problem. Another key factor of 90° phase difference can be obtained by adapting strip/slot length. In addition, sequential quadrature feed network introduced by branched power dividers [6, 7] and an adapting perturbation in radiating element [8, 9] can work in CP sense.

Moreover, a polarization reconfigurable antenna has received considerable attention because it has potential to overcome the fading effect caused by multi-path and reduce the antenna amount coped with the unknown relative positions of transmitter/receiver [10]. To switch right handed circular polarization (RHCP) and left handed circular polarization (LHCP) at the same frequency, PIN diodes network [10, 11], high isolation RF switches [12], and electrical controlled-phase-source [13] with proposed bias circuits were used to alter feeding position or rotate the phase sequence for realizing the polarization reconfigurability. Besides, switching in LP and CP sense was studied. For single feed, RF MEMS switch [14] and PIN diodes [15] were employed between additional stub and the original LP radiator to switch in CP and LP. Most of the previous techniques for polarization reconfigurability need a complex fabrication process and additional cost of RF element.

Instead of electrically controlling switches, this article presents a simple method for polarization reconfigurable antenna. The design consisting of two square patches and a T-strip feed is for HiperLAN2 5 GHz operation. By coupling feed from the T-strip, the planar structure is in LP sense. As the structure is bent along the vertical edge of the T-strip, the vertical and horizontal portions of T-strip not only respectively feed the coplanar patch but also provide a 90° phase difference between the feeds. Two perpendicular field components with quadrature are excited. The feature indicates the proposed antenna with bent structure can be in CP sense. Moreover, the switching between RHCP and LHCP is easily obtained by bending along opposite T-strip edge. The diverse fabrications can be manually constructed as the antenna is arranged into a folded wireless terminal. Also, automatic fabrication can be proceeded by motored machine. In this article, both the measured and simulated results for the constructed prototypes are presented and discussed.

2. ANTENNA DESIGN

The schemas of the proposed antenna in LP, RHCP, and LHCP senses are shown in Figures 1(a), (b), and (c), respectively. As shown in Figure 1(a), a finite ground plane with dimension of $L \times W$

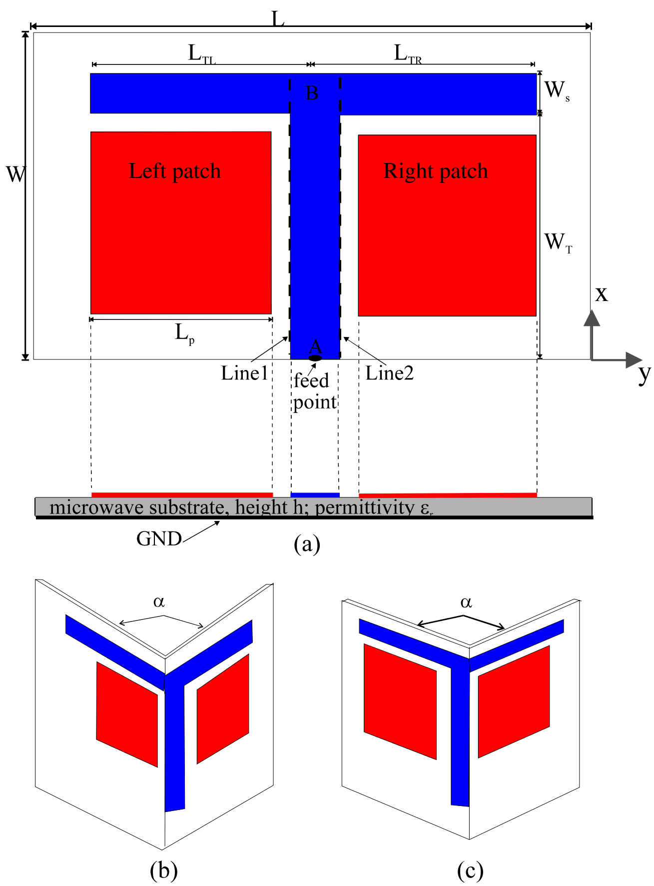

Figure 1. Configuration of the proposed antenna in sense of (a) linear polarization, (b) right-handed circular polarization, and (c) left-handed circular polarization.

was printed on a microwave substrate with thickness h and relative permittivity ε_r. On the opposite substrate layer, two square patches with side-length of L_p and a T-strip were printed. For the T-strip, the horizontal portion with length L_T ($L_{TL} + L_{TR}$) and vertical portions with length W_T were in the same strip width W_s. The patches were symmetrically placed along the vertical-strip and separated from the T-strip with a gap g. Such fabrication introduces a coupling feed from T-strip to both patches for LP operation. On the other hand, the prototype in CP sense was constructed by bending the original structure along the vertical edge of T-strip. The patches were clipped in an included angle α. The RHCP and LHCP senses are respectively achieved by bending the structure along line 1 and line 2. For real application, the planar/bent fabrications can be manually constructed by complete/incomplete opening the cover as the proposed antenna arranging into a folded wireless terminal. Also, the diversity fabrications can be automatically proceeded by motored machine.

In this study, the design principles are: 1. strip width W_s is optimally selected for impedance matching with 50-Ω coaxial cable; 2. gap g is optimally selected for desirable coupling feed and enough space for folding fabrication, 3. patch length $L_p = \frac{\lambda_g}{2}$; $\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{\mathit{eff}}}}$; $\varepsilon_{\mathit{eff}} = \frac{\varepsilon_r+1}{2}$; λ_g is the guided wavelength at center frequency of operating band; 4. For CP sense, the vertical T-strip length (W_T) is about one quarter wavelength at center frequency of CP bandwidth to provide a 90° phase difference between point A and B; 5. For CP sense, the vertical portion and horizontal portion of T-strip respectively feed the coplanar patch to provide a pair of orthogonal E-fields; 6. The bent fabrication should keep the patches back-to-back placed for CP sense.

Table 1. The corresponding data and parameter of the proposed prototypes Here, OP BW and CP BW are respectively determined by AR ≤ 3 and $S_{11} \leq -10$. L_{TL} is selected for optimum CP bandwidth. Other parameters were constant as $L_p = 12.5$ mm, $W_T = 15$ mm, $W_s = 2$ mm, $g = 0.5$ mm, $L_{TR} = 15.5$ mm.

Parameters	L_{TL} mm	α degree	OP BW GHz; %	CP BW GHz, %; GHz
Ref.	15.5	180	4.96–5.46, 9.6	–
Ant. 1	13.5	45	5.11–5.71, 11.1	5.17–5.38, 4.0
Ant. 2	14.5	90	5.09–5.71, 11.5	5.13–5.38, 4.8
Ant. 3	15	135	5.11–5.70, 10.5	5.11–5.39, 5.3

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

For experiments, frequency responses in the included angle α were considered first. The whole structure occupies a space of $40 \times 25 \times 1.6$ $(L \times W \times h)\,\text{mm}^3$. Here, an FR4 substrate ($\varepsilon_r = 4.4$), which is inexpensive and common for PCB circuitry, was used. Because the antenna parameters almost have the same effect on RHCP and LHCP antenna, we only chose LHCP antenna shown in Figure 1(c) as the studied prototype. Figures 2(a) and (b) respectively shows the measured and simulated S_{11} in frequency for $\alpha = 180°$ (Ref.; same prototype as Figure 1(a)), 45° (Ant. 1), 90° (Ant. 2), and 135° (Ant. 3). The other parameters were $L_p = 12.5\,\text{mm}$, $W_T = 15\,\text{mm}$, $W_s = 2\,\text{mm}$, $g = 0.5\,\text{mm}$, $L_{TR} = 15.5\,\text{mm}$. Note that W_T was selected to provide a pair of quadrature feeds for CP sense. However, the phase shift caused by W_T is sensitive to frequency. It seems that the horizontal portion of T-strip has effect on equivalent strip length and current amplitude. In other word, L_{TL} has the function of fine tuning to broaden CP bandwidth. The corresponding measured data and parameter are presented in Table 1. As shown in Figure 2, the simulated results agree with the measured Both results indicate that two neighbor modes excited by the patches are combined together to form a bandwidth of 9.6% ($4.96 \sim 5.46\,\text{GHz}$) for the planar prototype (Ref.). Because of the terminating effect caused by the horizontal feeding strip, patch length L_p is shorter than $\lambda_g/2$ at center operating frequency of 5.2 GHz. For the bending structures, separated feeding strip shortens effective feeding path and shifts whole operating band toward upper frequency. Also, different feeding mechanism more separates the relative resonance modes. The impedance bandwidth (OP BW) determined by 10 dB return loss is consequently increased from 9.6% up to 11.5%.

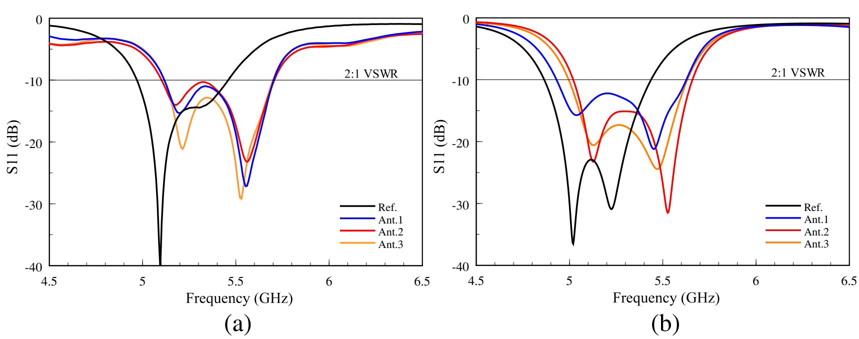

Figure 2. S_{11} in frequency of four studied prototypes. (a) Measurement; (b) Simulation. The simulations performed with the commercial microwave software of Ansoft HFSS 10.0.

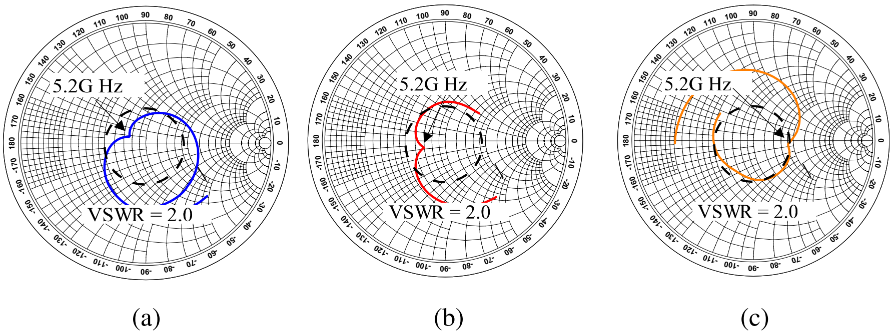

Figure 3. Measured Smith chart at center operating frequency for (a) Ant. 1, (b) Ant. 2, and (c) Ant. 3.

The input impedance in frequency is studied in smith chart. In Figures 3(a), (b), and (c), an apex at about 5.2 GHz (f_c) are seen for Ant. 1 $\sim$ 3. It indicates two importance features: broad bandwidth and two degenerated modes. The later usually occurred for CP sense. Moreover, surface current distributions on patches and T-strip of the Ant. 3 in phase are studied. Ant. 1 and Ant. 2 have similar features and are unshown here. For clear comparison, the Ref. is also studied and shown in Figure 4(a). It indicates that current nulls occur at both patch's radiating edges and surface current mainly coupled from the vertical portion of T-strip. The features indicate that the half-wavelength mode of each patch is successfully excited in LP sense. Note that the current distribution of the Ref. antenna is independent of phase. Figures 4(b) $\sim$ (e), present the Ant. 3 in phase of 0°, 90°, 180°, and 270°. The experimental results verify that the bent fabrication introduces a pair of orthogonal E-fields in almost quadrature on two radiating patches first. The arrows shows a clockwise rotating E-field within a period. The feature indicates the LHCP sense.

The radiation characteristics are studied. Figure 5 shows the measured linear spinning patterns at center operating frequency for Ant. 1 $\sim$ 3. From the experimental results, ripple level close by broadside is less than 3.0 dB for both planes. It indicates a CP sense is achieved for all bent prototypes. In this design, the effect of nonidentity amplitudes of two orthogonal fields limits 3-dB CP beamwidth and degrades the CP performances. For practical applications, the drawback can be solved by suitable strategy such as adding an amplifier or a regenerator to compensate the path loss. In addition, it is seen that the 3-dB CP beam in y-z plane is altered with included angle. Simulated axial-ratio in degree θ is shown Figure 6 for clear indication. The experimental results shows that the 3-dB CP beams respectively centers around $\theta = +20°$, $0°$, and $-30°$ for Ant. 1 ($\alpha = 45°$), Ant. 2 ($\alpha = 90°$), and Ant. 3 ($\alpha = 135°$). Similar features are observed in the measured results shown in Figure 5. This feature suggests that the proposed antenna not only has characteristic of polarization reconfiguration but also CP beam shift.

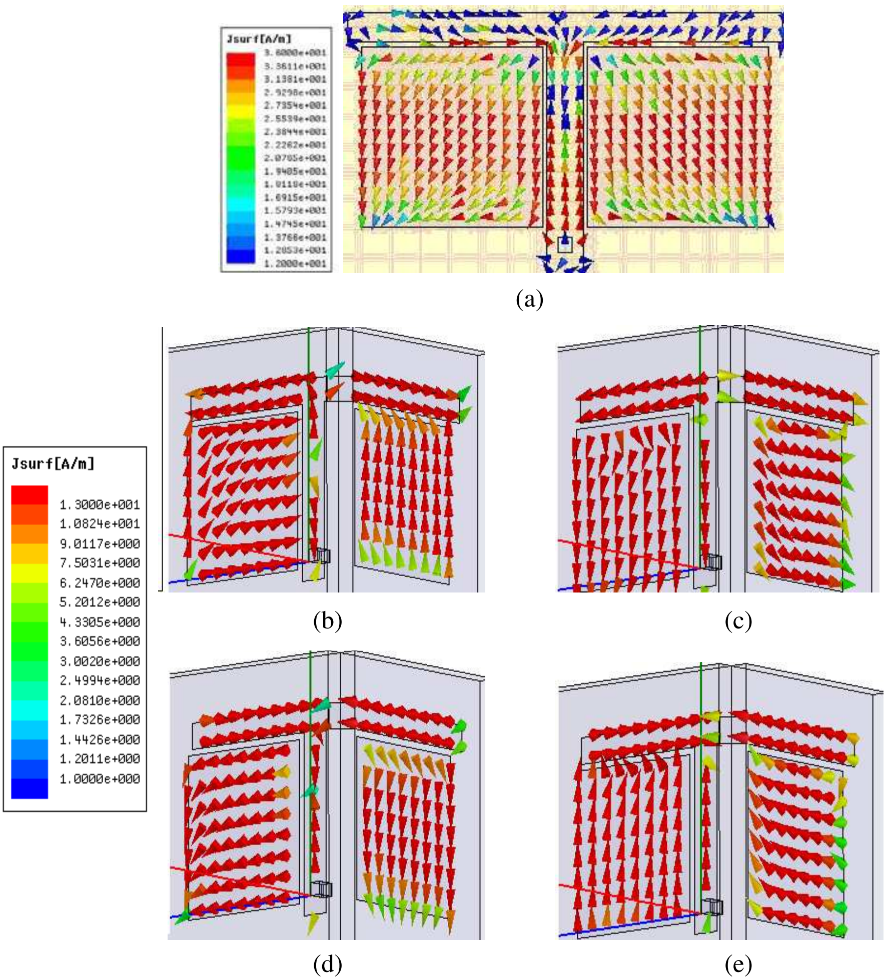

Figure 4. (a) Simulated surface currents on patches and T-strip at 5.2 GHz for Ref.. Simulated surface currents on patches and T-strip at 5.2 GHz for Ant. 3 in phase of (b) 0, (c) 90°, (d) 180°, and (e) 270.

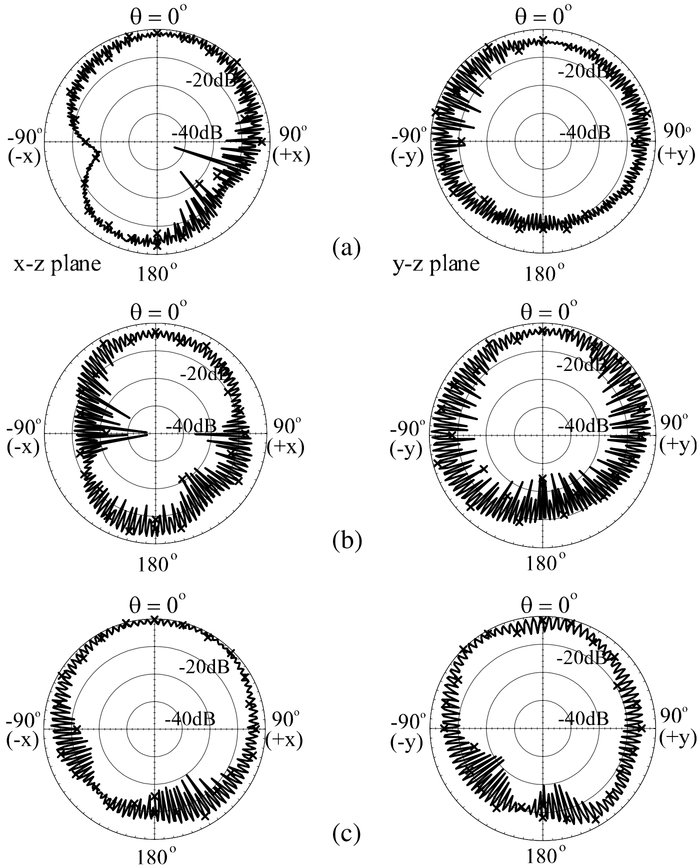

Figure 5. Measured linear spinning patterns at f_c for (a) Ant. 1, (b) Ant. 2, and (c) Ant. 3.

Figure 7(a) shows the axial ratio in frequency with varied α. The detail data about CP bandwidth determined by 3-dB axial-ratio is also seen in Table 1. For all bent prototypes, the CP bandwidth ranges within $4.0 \sim 5.3\%$, which is better than $1 \sim 2\%$ of the conventional single feed CP patch antenna. Moreover, the optimum axial-ratio is about 1 dB for the proposed CP antennas. It suggests a good CP performance can be expected in the design. As the experimental results showing, CP BW and OP BW are almost independent of α. The characteristics suggest that the CP sense of the proposed antenna is insusceptible to the included degree. It makes the CP prototype easily constructed. Figure 7(b) shows the axial ratio in frequency with varied L_{TL} within $13.5 \sim 18$ mm. Although the desirable quadrature between the orthogonal E-fields is mainly introduced by vertical portion of T-strip, the phase shift caused by W_T is sensitive to frequency. It seems that the horizontal portion of T-strip has effect on equivalent strip length and current amplitude. Therefore, L_{TL} has the function of fine tuning to broaden CP bandwidth. Figure 8 shows the antenna gains for LP- and CP-prototypes. In addition to 3 dB degradation caused by the spitted operating mode for CP sense, slight gain variation in frequency is obtained.

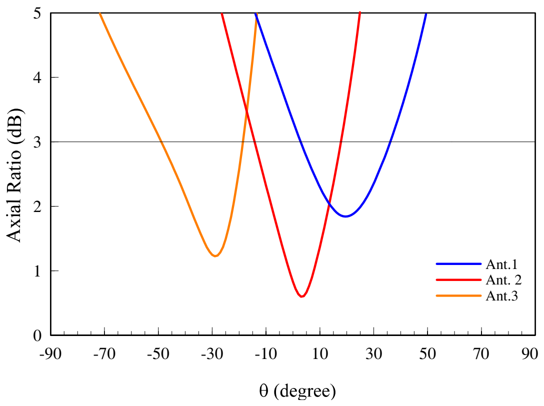

Figure 6. AR against θ degree in y-z plane of the proposed CP antenna at f_c.

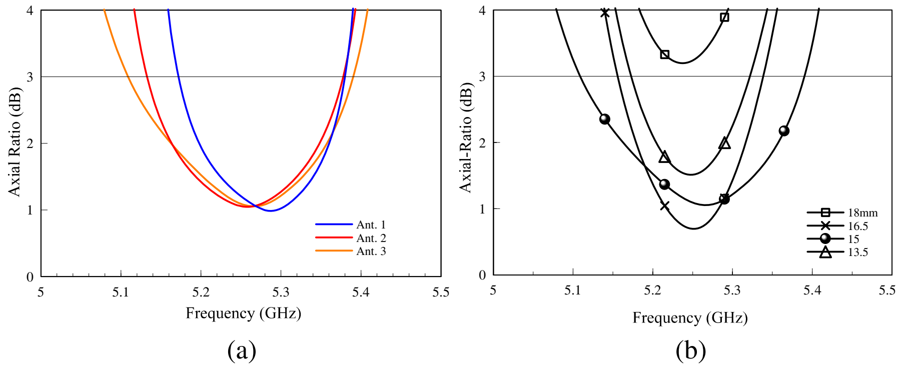

Figure 7. Simulated Axial Ratio in frequency with varied (a) α, and (b) L_{LT}.

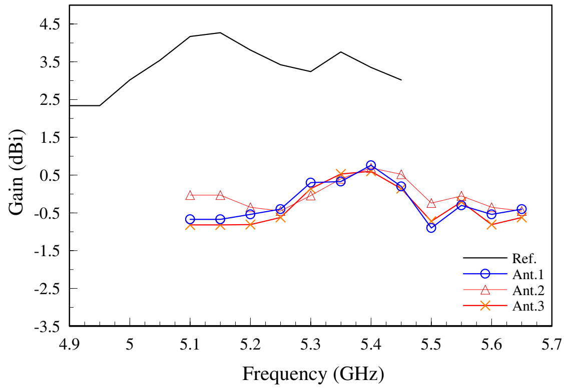

Figure 8. Measured antenna gain for Ref., Ant. 1, Ant. 2, and Ant. 3 in frequency.

4. CONCLUSIONS

A reconfigurable T-strip-single fed antenna has been developed. The prototypes for LP, RHCP, and LHCP switching directly proceeded by bending fabrication without additional switching circuitry are demonstrated. Moreover, a prototype whose polarization can be switched among LP and CP modes has been successfully implemented and studied. Although inherent path loss caused by nonidentity feeding mechanism imperfects the CP performance, simple compensating strategy can be applied to resolve the shortcoming. The easy polarization sense switching indicates that the proposed antenna has highlighted potential for wireless systems requiring polarization diversity.

REFERENCES

1. Wong, K. L., *Compact and Broadband Microstrip Antennas*, 69–86, Wiley, New York, 2002.
2. Klaus, F., *RFID Handbook*, Wiley, New York, 2003.
3. Lee, C., W. K. Han, I. Park, and H. Choo, "Design of a double-layered spiral antenna for radio frequency identification applications," *IET Microwaves, Antennas & Propagation*, Vol. 4, No. 1, 121–127, 2010.
4. Row, J. S. and S. W. Wu, "Circularly-polarized wide slot antenna loaded with a parasitic patch," *IEEE Trans. on Antennas and Propaga.*, Vol. 56, 2826–2832, 2008.

5. Huang, C. Y., J. Y. Wu, and K. L. Wong, "Cross-slot-coupled microstrip antenna and dielectric resonator antenna for circular polarization," *IEEE Trans. on Antennas and Propaga.*, Vol. 47, 605–609, 1999.
6. Huang, J., "A technique for and array to generate circular polarization with linearly polarized elements," *IEEE Trans. on Antennas and Propaga.*, Vol. 34, 1113–1124, 1986.
7. Lau, P.-Y., K. K.-O. Yung, and E. K.-N. Yung, "A low cost printed CP patch antenna for RFID smart bookshelf in library," *IEEE Trans. on Industrial Electronics*, Vol. 57, No. 5, 1583–1589, May 2010.
8. Kasabegoudar, V. G. and J. K. Vinoy, "A broadband suspended microstrip antenna for circular polarization," *Progress In Electromagnetics Research*, Vol. 90, 353–368, 2009.
9. Li, J. F., B. H. Sun, H. J. Zhou, and Q. Z. Liu, "Miniaturized circularly-polarized antenna using tapered meander-line structure," *Progress In Electromagnetics Research*, Vol. 78, 321–328, 2008
10. Aissat, H., L. Cirio, M. Grzeskowiak, J. M. Laheurte, and O. Picon, "Reconfigurable circularly polarized antenna for short-range communication systems" *IEEE Trans. on Microwave Theory and Tech.*, Vol. 54, 2856–2863, 2006.
11. Yoon, W. S., S. M. Han, J. W Baik, S. Pyo, J. Lee, and Y. S Kim, "Crossed dipole antenna with switchable circular polarisation sense," *Electron. Lett.*, Vol. 45, 717–718, 2009.
12. Wei, W. B., Q. Z. Liu, Y. Z. Yin, and H. J. Zhou, "Reconfigurable microstrip patch antenna with switchable polarization," *Progress In Electromagnetics Research*, Vol. 75, 63–68, 2007
13. Wan, K. C. and Q. Xue, "A novel reconfigurable wideband circularly polarized transmitter implemented by indirect-controlled-phased-source," *IEEE Antennas and Wireless Propaga Lett.*, Vol. 6, 604–607, 2007.
14. Jung, T. J., I. J. Hyun J. M. Kim C. W. Baek, and S. Lim, "Polarization reconfigurable antenna on RF-MEMS packaging platform," *Asia Pacific Microwave Conf.*, 579–582, 2009.
15. Chen, R. H. and J. S. Row, "Single-fed microstrip patch antenna with switchable polarization," *IEEE Trans. on Antennas and Propaga.*, 922–826, 2008.