Adaptive Adjustment of Radiation Properties for Entire Range of Axial Ratio using a Parasitic Microstrip Polarizer

Sungjun Yoo*, Dongeun Lee**, Gangil Byun*** and Hosung Choo[†]

Abstract – This paper proposes the design of microstrip patch antennas for dual-band polarization adjustment. The antenna has a multi-layer structure for dual-band operation, and each layer contains a resonating patch with surrounding strips separated into two parts. The antenna polarization is adjusted by varying the separated positions of the strips, while fixing other design parameters. To demonstrate the feasibility, an antenna sample with right-hand circular polarization is fabricated, and its antenna characteristics are measured in a full anechoic chamber. The operating principle of polarization adjustment in the dual frequency bands is also verified by observing near electromagnetic fields and the magnetic surface current density around the antenna.

Keywords: Dual-band patch antennas, Polarization adjustment antennas, Microstrip antennas, GPS antennas

1. Introduction

In recent wireless communications systems, antennas are required to have multi-band characteristics with different polarization properties [1, 2]. However, the antenna polarization is easily distorted by multipath effects, such as wave scattering, blockage, and reflection, which cause an additional power loss due to the polarization mismatch [3]. Thus, there has been a lot of effort to control the antenna polarization using various approaches, for example, corner-truncated square patches [4-7] and position-changed feeding probes [8, 9]. However, these approaches are often limited to obtaining specific polarizations and do not provide in-depth considerations on tuning the polarization properties in the entire range of the axial ratio (AR). Although reconfigurable antenna structures can adjust the antenna polarization, they have been obstructive in practical applications because of its increased design complexity and the use of additional DC bias circuit [10-12].

In this paper, we propose the design of a multi-layer patch antenna for dual-band polarization adjustment. The proposed antenna consists of two patches, each of which is composed of a resonator and surrounding strips separated into two parts. The separated positions of these strips are varied to adjust dual-band polarization properties of the antenna over the entire AR range, which includes right-hand circular (RHC), left-hand circular (LHC), elliptical, and linear polarizations. The upper patch is fed by a

coaxial cable, and the lower patch is electromagnetic coupled to the upper patch. To demonstrate the feasibility of the dual-band polarization adjustment, we fabricate an antenna sample having the RHC polarization, and its antenna characteristics are measured in a full anechoic chamber. Then, operating principles of the proposed antenna are verified by calculating the electric and magnetic field distributions. In addition, a phase difference of the magnetic surface current density induced between the resonator and the strips is observed to compare its variation with the AR. The results prove that the proposed antenna is suitable for dual-band polarization adjustment without the use of any additional circuits.

2. Geometry of the Proposed Antenna

Fig. 1 shows the geometry of the proposed multi-layer patch antenna for dual-band polarization adjustment. Each layer contains a resonating patch with surrounding strips that are separated by d_1 and d_2, and their positions are adjusted by ϕ_{ar1} and ϕ_{ar2} to vary the polarization properties without significant frequency shifts [13]. The upper patch is fed by a coaxial cable, and its feeding positions is determined by l_f. The lower patch is then electromagnetically coupled to the upper patch through a high-dielectric CER10 substrate from Taconic ($\varepsilon_r = 10$, $\tan\delta = 0.035$), and their thicknesses are expressed as h_1 and h_2. The edge lengths of the two patches (w_1 and w_2) are designed to be about a half wavelength (λ_g) at each frequency band, and the gap distance (g_1 and g_2) and strip width (w_3 and w_4) are adjusted to induce strong electric fields within the gap for high magnetic surface current density. This is an important design factor for polarization adjustment because the AR of the antenna can be

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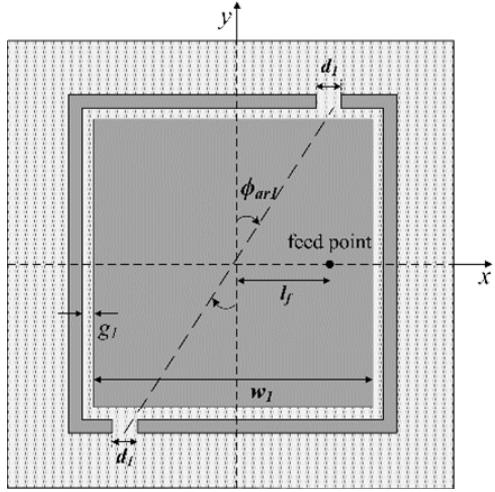
(a) Top view of upper patch
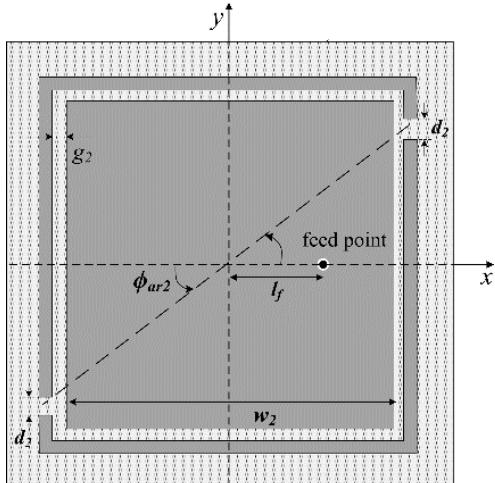
(b) Top view of lower patch
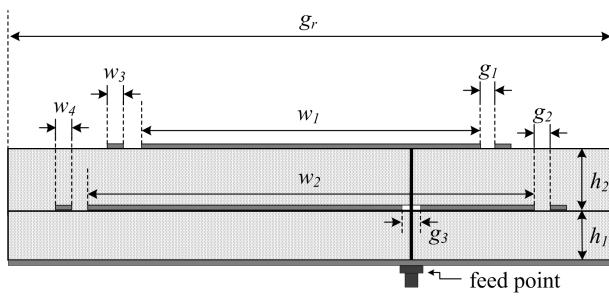
(c) Side view of the antenna

Fig. 1. Geometry of the proposed antenna

Table 1. Optimized values of the proposed antenna

Parameters	Optimized values
w_1	30.2 mm
w_2	35.6 mm
w_3	1.9 mm
w_4	2.7 mm
g_1	0.9 mm
g_2	1.3 mm
g_3	1.2 mm
d_1	0.5 mm
d_2	0.5 mm
l_f	10.6 mm
h_1	6.28 mm
h_2	6.28 mm
g_r	50 mm
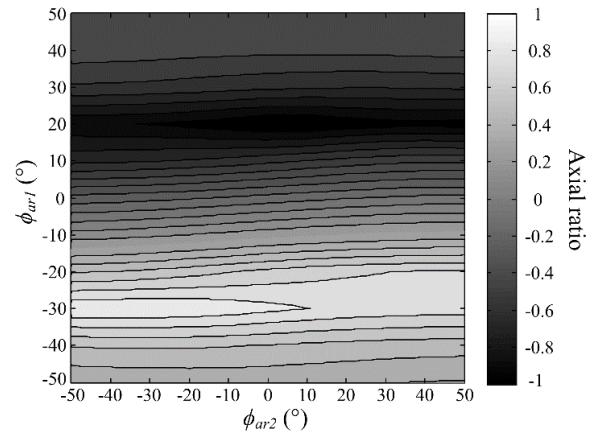
(a) Axial ratio at 1.575 GHz
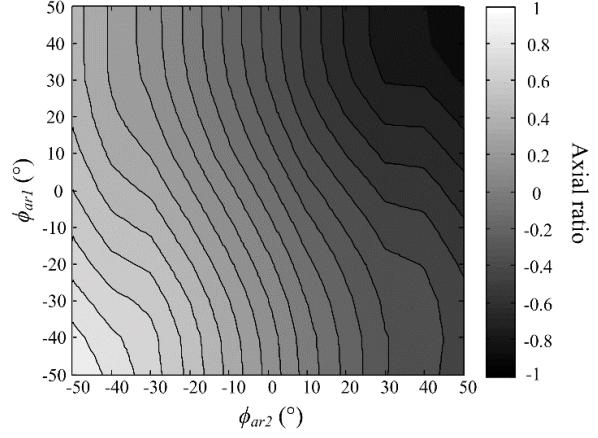
(b) Axial ratio at 1.227 GHz

Fig. 2. The values of the AR for the angle of the polarizer

controlled by varying the phase of the magnetic surface current density, which will be analysed in Section III.

Figs. 2(a) and (b) exhibit the variations of AR values at the bore-sight direction at 1.575 GHz and 1.227 GHz, respectively. In this observation, the values of ϕ_{ar1} and ϕ_{ar2} are adjusted from −50° to 50° at an interval of 10° while fixing those of other design parameters as specified in Table 1. At 1.575 GHz, the maximum AR value of 0.9 is observed at $\phi_{ar1} = -30°$ and $\phi_{ar2} = -50°$, and the minimum value of −0.97 is located at $\phi_{ar1} = 20°$ and $\phi_{ar2} = 0°$. At 1.227 GHz, the maximum value of 0.94 is found at $\phi_{ar1} = -50°$ and $\phi_{ar2} = -50°$, and the minimum value of −0.89 is placed at $\phi_{ar1} = 50°$ and $\phi_{ar2} = 50°$.

The results show that we can adjust the polarization properties in the entire AR range, which includes RHC,

LHC, linear, and elliptical polarizations. In addition, various combinations of different polarizations, e.g. linear with RHC polarizations, can also be achieved by separately varying the values of ϕ_{ar1} and ϕ_{ar2}.

3. Measurement and Analysis

To demonstrate the results, we fabricated a sample antenna with the RHC polarization ($\phi_{ar1} = -30°$, $\phi_{ar2} = -50°$), its antenna characteristics are measured in a full anechoic chamber. Fig. 3 shows a comparison of the measured and simulated reflection coefficients as a function of frequency. The simulated values are −11.9 dB at 1.575 GHz and −11.2 dB at 1.23 GHz, and the measured values are −10.5 dB and −15.4 dB at 1.6 GHz and 1.25 GHz, respectively.

The measured results are shifted by about 20 MHz toward the upper frequency band due to fabrication error of unintended air gaps between substrates, which is not included in our EM simulation. Fig. 4 shows the measured bore-sight gain in comparison with the simulated results.

The dotted and dash-dotted lines indicate the simulated RHC and LHC polarization gains, respectively, and the measured results are specified by the solid line (RHC), dashed line (LHC), and '+' markers. The antenna has

Fig. 5. Axial ratio of the proposed antenna
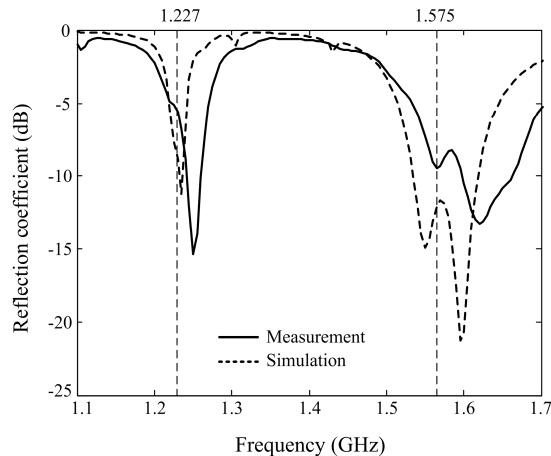
**Fig. 3.** Reflection coefficients of the proposed antenna
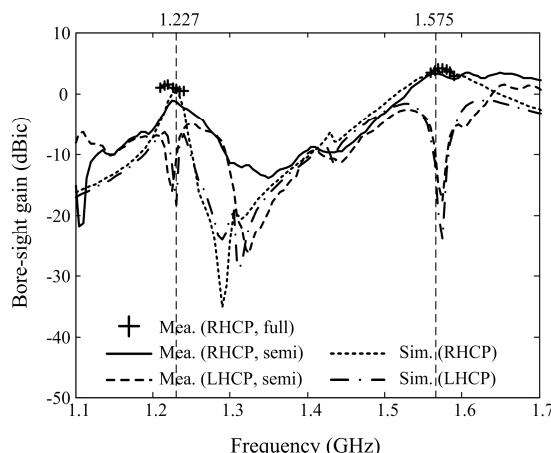
Fig. 4. Bore-sight gain of the proposed antenna
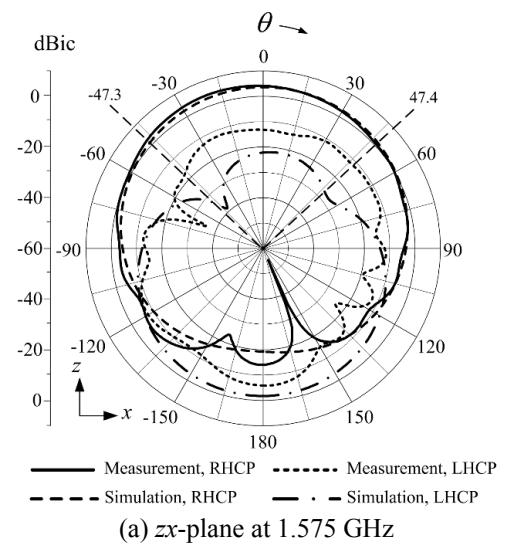
(a) *zx*-plane at 1.575 GHz
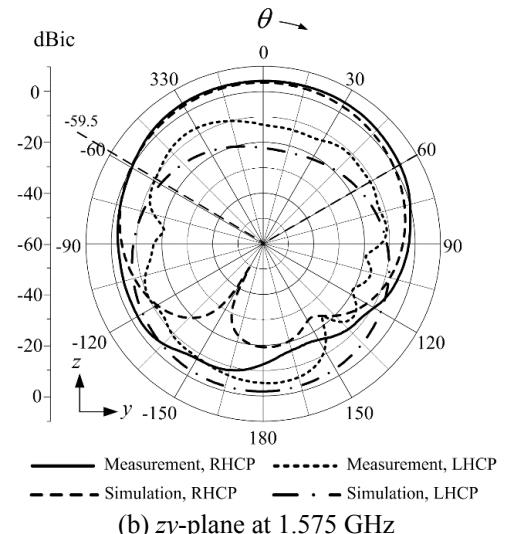
(b) *zy*-plane at 1.575 GHz

Fig. 6. Radiation patterns of the proposed antenna

measured values of 4 dBic and 0.9 dBic at 1.575 GHz and 1.227 GHz, respectively, and the gain in the GPS L2 band is relatively lower than the GPS L1 band due to the blockage effect in the bore-sight direction. The cross-polarization levels are −17.2 dB (1.575 GHz) and −15.3 dB (1.227 GHz).

Fig. 5 illustrates a comparison of the AR values in the bore-sight direction. The dashed line shows the simulated results, and '+' markers express the measured AR values. As can be seen, the antenna is circularly polarized with the measured AR values of 1.9 dB and 2.8 dB at 1.575 GHz and 1.227 GHz, which has a similar trend with the simulated values of 0.7 dB and 2.1 dB. These AR values are increased to 10.1 dB and 15.5 dB in the GPS L1 and L2 bands when the antenna becomes elliptically polarized ($\phi_{ar1} = -10°$, $\phi_{ar2} = 30°$), which demonstrates that the polarization properties can be adjusted by simply changing the shape of the strips. Figs. 6(a) and (b) show comparisons of the measured and simulated radiation patterns in *zx*- and

zy- planes at 1.575 GHz. The half power beam widths (HPBWs) of the antenna are 94.7° (*zx*-plane) and 119.5° (*zy*-plane), which are similar to the simulated value of 110° (*zx*- and *zy*-planes). Figs. 7(a) and (b) illustrate patterns at 1.227 GHz, and their HPBWs are 76.8° and 68.6° in *zx*- and *zy*-planes, respectively. We can verify that the fabricated antenna has circular polarization in the upper hemisphere with average cross-polarization levels of −14.7 dB (1.575 GHz) and −10.7 dB (1.227 GHz). The height difference h_2 also varies the AR properties; however, this AR variation is caused by an undesired frequency shift as shown in Fig. 8(a). On the other hand, ϕ_{ar1} allows for the adjustment of polarization properties in entire AR range from −1 to 1 without a significant frequency shift of less than 9 MHz, as presented in Fig. 8(b). Figs. 9(a) and (b) illustrate magnetic field distributions that are observed at 61 × 61 points on a cross section with a dimension of 60 mm × 27 mm, when input power is 1 W. As can be seen, the H-field is confined between the upper and lower patches with an average field strength of 15.1 A/m at 1.575 GHz, and a strong field is distributed between the lower patch and the ground with an average value of 24.5 A/m at 1.227 GHz.

Figs. 10(a) and (b) show top views of the E-field
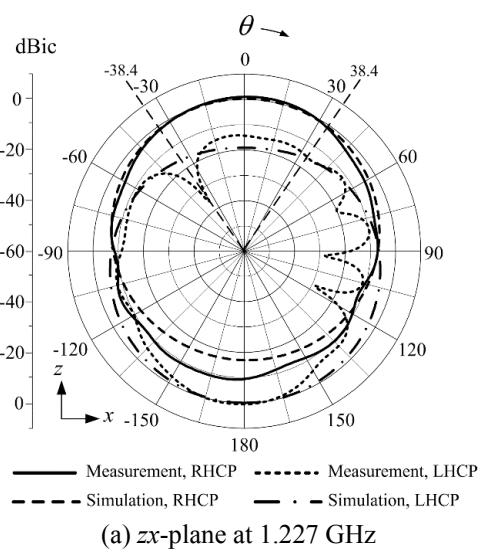

(a) *zx*-plane at 1.227 GHz
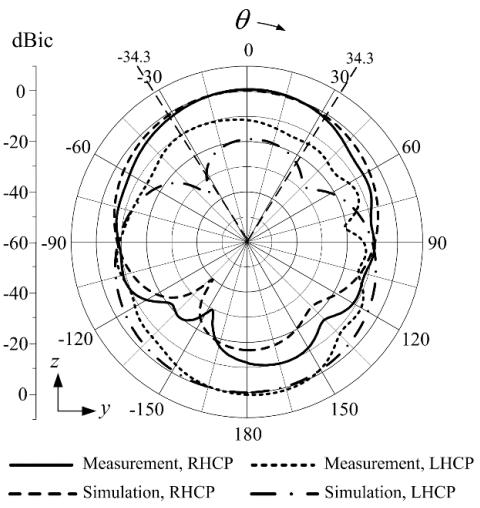
(b) *zy*-plane at 1.227 GHz

Fig. 7. Radiation patterns of the proposed antenna
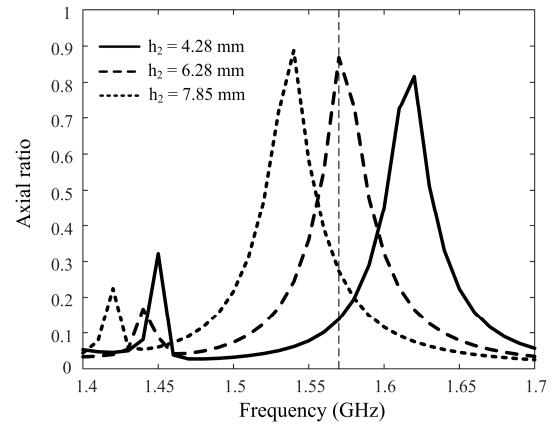
(a) Variation of AR according to h_2
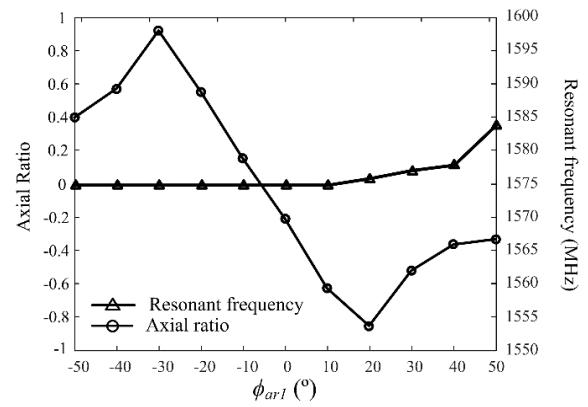
(b) AR and resonant frequency properties

Fig. 8. Variation of axial ratio

distributions at the upper and lower patches at 1.575 GHz and 1.227 GHz, respectively. As expected, strong electric fields are confined between the patch and the strips, which implies that high magnetic surface current density equivalently exists within the surface area of the gap. Since the shape of the parasitic strips affects the phase of the magnetic surface current density with little change in magnitude, only the polarization properties are adjusted without a significant frequency shift.

Figs. 11(a) and (b) show comparisons between the AR and the phase difference of the magnetic surface current density at 1.575 GHz and 1.227 GHz, respectively. We

(a) 1.575 GHz   (b) 1.227 GHz
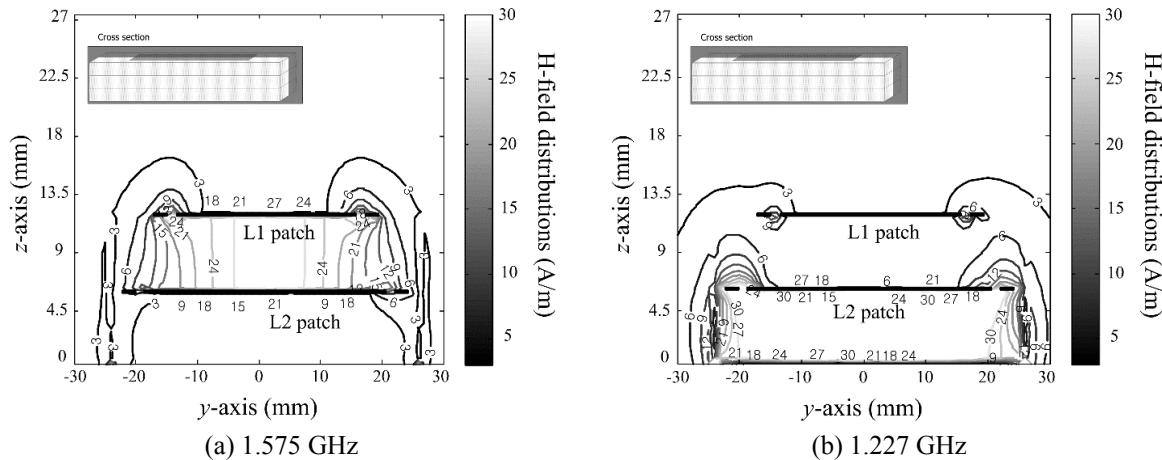
Fig. 9. H-field distribution of the proposed antenna

(a) 1.575 GHz   (b) 1.227 GHz
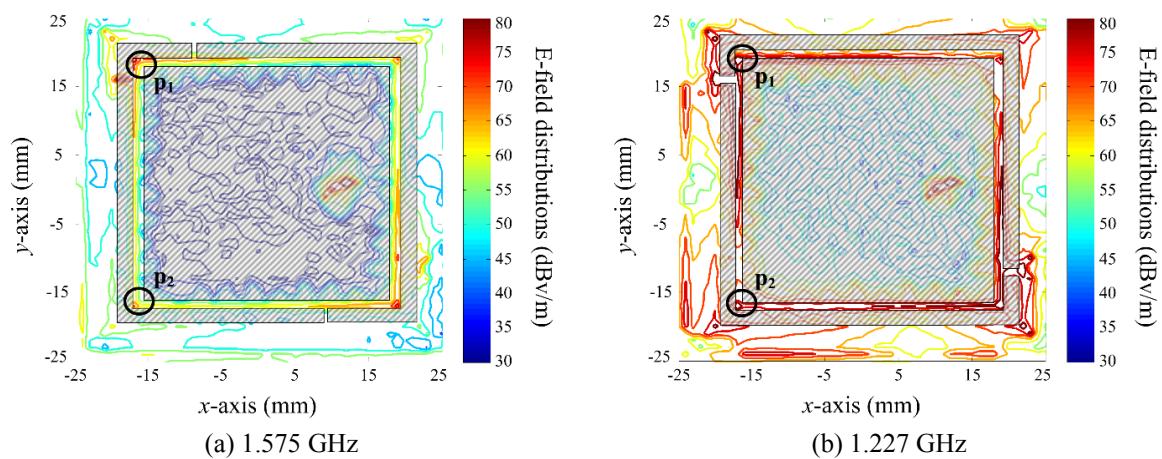
Fig. 10. E-field distribution of the proposed antenna

(a) 1.575 GHz   (b) 1.227 GHz
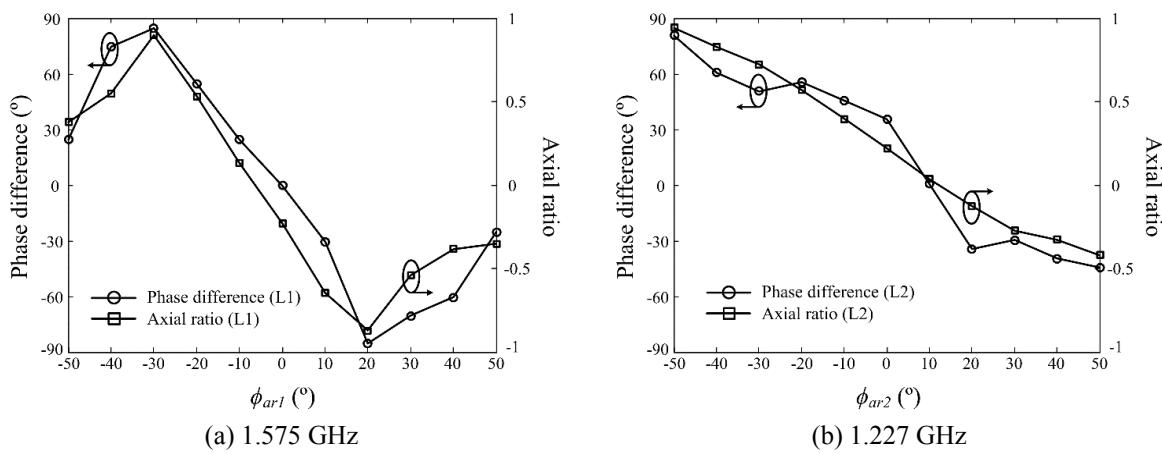
Fig. 11. Phase of magnetic surface current density and AR

calculated the phase difference using phase values at two points of p_1 and p_2, as specified in Fig. 10. The square and circular markers indicate the AR and the phase difference, respectively, and the angles of ϕ_{ar1} and ϕ_{ar2} are varied from −50° to 50°, while fixing other parameters as listed in Table 1. If we assume the center of the patch as 'O', the angle between $\overline{Op_1}$ and $\overline{Op_2}$ is 90°, geometrically. Thus, when the antenna has the right-hand circular polarization with AR = 0.9, the phase at p_1 should lead the phase at p_2 by 85°, while a 85° lag is needed for AR = −0.97. Zero phase difference is observed for the linear polarization. In our approach, we intentionally adjusted the phase difference between p_1 and p_2 from −90° to 90° by varying ϕ_{ar1} and ϕ_{ar2} to achieve the AR in the entire range from −1 to 1.

4. Conclusion

We have investigated the design of a multi-layer patch antenna for dual-band polarization adjustment. The proposed antenna consisted of two resonating patches with parasitic strips, and the antenna polarization is adjusted by rotating the separated positions of the strips. The feasibility of the polarization adjustment was verified by measuring antenna characteristics of the sample antenna with the RHC polarization. The measured bore-sight gains were 4 dBic and 0.9 dBic with the cross-polarization levels of −17.2 dB and −15.3 dB at 1.575 GHz and 1.227 GHz, respectively. The strong H-fields were confined between patches with average field strengths of 15.1 A/m at 1.575 GHz and 24.5 A/m at 1.227 GHz. We also verified that the phase difference has a similar trend with the AR, and the circular polarization can be achieved when the amplitude of the phase difference is close to 90°. The result demonstrated that the proposed antenna was suitable to adjust polarization properties in dual bands.

Acknowledgements

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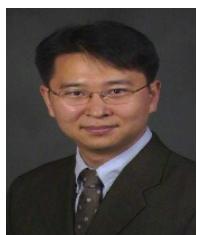
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