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# A Polarization Reconfigurable Microstrip Antenna Employing Dual-Perturbation Technique

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**Abstract**—This study presents a polarization reconfigurable antenna with frequency diversity function. The antenna incorporates a novel positive and negative perturbation technique to achieve different polarization sense. A square shape slot is loaded on the ground plane to excite circular polarization by creating a negative perturbation. An L-shape segment is integrated to the patch using a switching diode. This segment creates a positive perturbation to eliminate the negative perturbation created by the defected ground slot, and the antenna excites linear polarization. Frequency diversity is achieved by exciting different polarization senses at different frequencies. A 3-dB axial ratio bandwidth of 1.41% is obtained for circular polarization radiation while the 10-dB impedance bandwidth during linear polarization is 1.8%. The antenna shows good radiation performances with high gain at both polarization states, and the performances are confirmed experimentally.

## 1. INTRODUCTION

Reconfigurable antennas are attractive for many RF wireless communication applications as antenna characteristics can be changed by using a single antenna. Polarization reconfigurable antennas with frequency diversity are promising for terrestrial digital broadcasting which is sometimes known as Mobile TV. In this technology, a mobile user terminal such as a mobile phone receives signals from a geostationary satellite using circular polarization (CP) and terrestrial gap-filler using linear polarization (LP) [1].

Several polarization reconfigurable antennas have been demonstrated in [2–5]. In [2], a patch antenna with switchable slot (PASS) concept has been used to implement a CP reconfigurable microstrip antenna with dual-frequency operation. A similar PASS concept combining corner truncation technique has been used in [3] to realize LP and CP switching at different frequencies. A slot-perturbation using different shapes on the patch has been demonstrated in [4, 5] to obtain CP reconfigurability. However, these two antennas show a moderate gain in a range of 2–3.5 dBic. A polarization reconfigurable antenna with diversity function has been discussed in [6]. Polarization and frequency diversities are achieved in this antenna by using a switching diode which is integrated between a corner truncated patch and the corner segment larger than the truncated corner portion of the patch. In [7], a corner-truncated patch antenna with a better gain performances allowing polarization switching in which four independently biased PIN diodes are used to produce LP or CP has been demonstrated. Furthermore, ground defected antennas have been studied in [8–11] to present the benefits of this kind of antennas. A gain enhanced CP equilateral-triangular microstrip antenna using a slotted ground plane [8] and a square patch with an arrow-shaped slotted ground plane [9] have been discussed. On the other hand, in [10, 11], defected ground plane concept has been implemented for polarization diversity by integrating switching diodes though the gain of these antennas is below 4 dBic.

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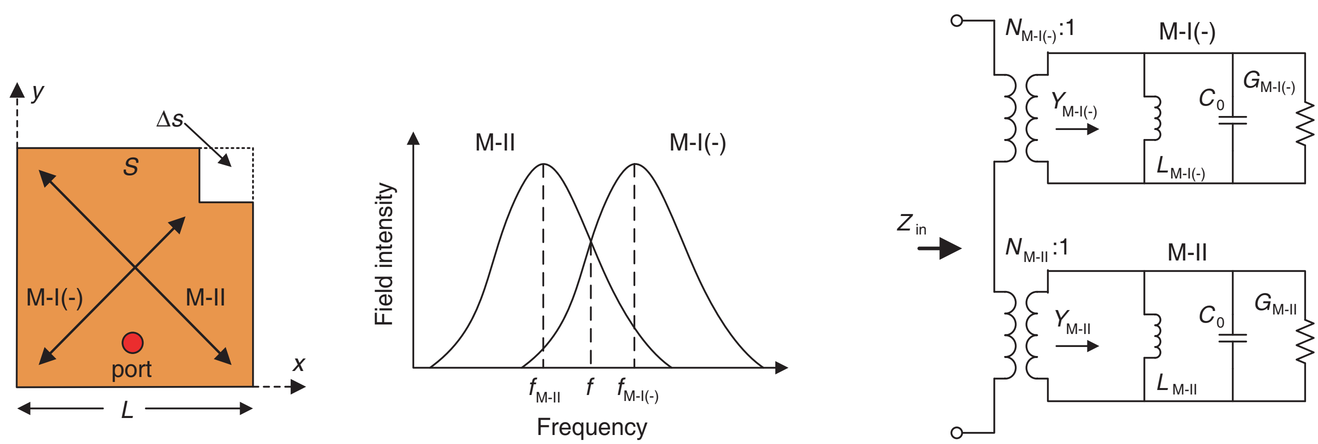
In this paper, a novel technique to design polarization reconfigurable antennas using two types of perturbations is presented. A square slotted ground plane and an L-shape microstrip segment are used simultaneously to obtain polarization reconfigurability. The square slot on the ground creates a negative perturbation. The negative perturbation can be eliminated by a positive perturbation that is made by adding an L-shape microstrip segment to the patch using a switching diode. The polarization sense can be alternated between CP and LP at different frequencies by changing the state of a diode. The antenna structure is very simple and compact. Moreover, the benefit of the proposed antenna is to use a single switching diode to achieve polarization and frequency diversities that helps to attain better gain than other conventional polarization reconfigurable antennas using multiple switching diodes discussed previously. In addition, this antenna is suitable to enhance polarization reconfigurability by integrating active components on the ground slot with simple bias circuit arrangement on the ground plane as the polarization reconfigurability achieved by defected ground perturbation is free from radiation performance degradation that is caused in the case of the patch side perturbation segment and bias networks [10]. The proposed antenna is attractive for wireless and satellite communication applications such as terrestrial digital broadcasting.

## 2. GENERALIZED CONCEPT OF THE PERTURBATION TECHNIQUE

Perturbation technique is one of the main techniques to excite circular polarization. Perturbation can be introduced on the patch by either adding or removing a corner segment of the patch. So, this type of antennas can be classified into two types depending on the perturbation type. If the perturbation is created by removing a portion of the patch, it is called negative perturbation.

Figure 1 illustrates the mechanism of the negatively perturbed antennas. In [12, 13], an equivalent circuit of a rectangular microstrip antenna after negative perturbation as shown in Figure 1(c) has been presented considering the effect of the perturbation segment on the cavity model field and its eigenvalue. The equivalent circuit contains two ideal transformers with turn ratios $N_{\text{M-I}(-)}$ and $N_{\text{M-II}}$, whereas $Y_{\text{M-I}(-)}$ and $Y_{\text{M-II}}$ are the input admittances corresponding to the orthogonally polarized M-I(−) and M-II modes. Radiation, dielectric and copper losses are represented by the equivalent conductances $G_{\text{M-I}(-)}$ and $G_{\text{M-II}}$. Detail parameters can be derived from [12].




(a) (b) (c)

**Figure 1.** Negatively perturbed circularly polarized antenna. (a) Configuration. (b) Frequency response. (c) Equivalent circuit.

Considering fundamental configuration of the antenna presented in Figure 1(a), the resonant frequency of the square patch before perturbation can be obtained using the following equation

$$f_r = c/2\overline{L}\sqrt{\varepsilon_r} \tag{1}$$

where $c$ and $\overline{L}$ are the velocity of light and the effective side length including the fringing effect.

After introducing a perturbation, perturbation segment $\Delta s$ creates two modes M-I(−) and M-II. If the shifts of the frequencies are $f_{\text{M-I}(-)}$ and $f_{\text{M-II}}$ corresponding to M-I(−) and M-II, the frequencies can be expressed as

$$f_{\mathrm{M-I}(-)} = f_r + \Delta f_{\mathrm{M-I}(-)} = f_r[1 - 2(\Delta s/S)] \quad (2)$$

$$f_{\mathrm{M-II}} = f_r + \Delta f_{\mathrm{M-II}} = f_r \quad (3)$$

Optimum frequency $f$ for the axial ratio can be obtained from Eqs. (2) and (3) as follows:

$$f = (f_{\mathrm{M-I}(-)} + f_{\mathrm{M-II}})/2 = f_r(1 - \Delta s/S) \quad (4)$$

where $f_{\text{M-I}(-)}$ of mode M-I(−) is created due to the perturbation segment $\Delta s$ that reduces the diagonal electrical length along the perturbation segment. As a result, it creates a negative perturbation on the patch. On the other hand, the other diagonal electrical length remains same. So, the frequency $f_{\text{M-II}}$ is the same as $f_r$.

Figure 2 presents a microstrip antenna with positive perturbation. A positive perturbation is created by adding a corner segment of $\Delta s$. In this case, when a segment is added to the patch, the diagonal electrical length for mode M-I(+) is longer than the diagonal electrical length of mode M-II. Therefore, the frequency $f_{\text{M-I}(+)}$ obtained by Eq. (5) is shifted to a lower frequency than the frequency of $f_{\text{M-II}}$ for mode M-II as shown in Figure 2(b).

$$f_{\mathrm{M-I}(+)} = f_r - \Delta f_{\mathrm{M-I}(+)} = f_r[1 + 2(\Delta s/S)] \quad (5)$$

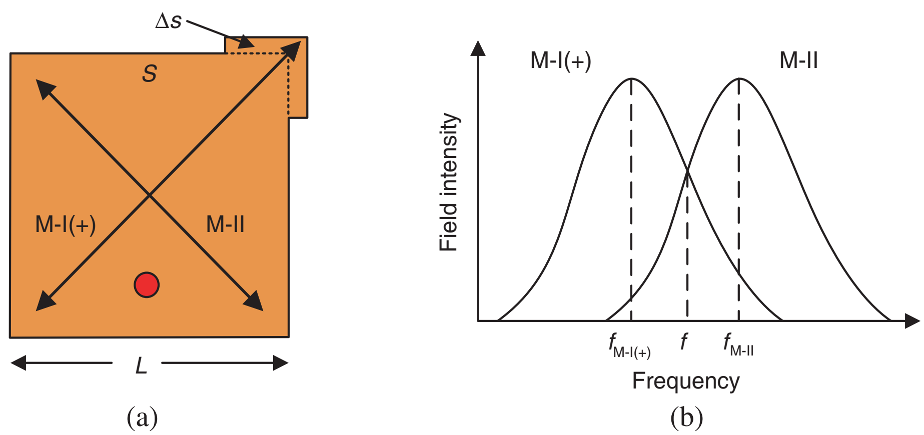



**Figure 2.** Microstrip antenna with positive perturbation. (a) Configuration. (b) Frequency response.

Based on the above discussion, it can be determined that the effect of one kind of perturbation can be eliminated by applying the opposite perturbation. Figure 3 shows that original characteristics of an unperturbed patch antenna can be restored using modified configuration by applying dual-perturbation technique. When $\Delta s_2$ is attuned properly to eliminate the effect of $\Delta s_1$ by fulfilling the condition of $\Delta s_1 = \Delta s_2$, the frequencies along the two diagonal modes will be indistinct. It can be explained with the help of Eqs. (2) and (5).

$$f_{\mathrm{M-I}} = (f_{\mathrm{M-I}(-)} + f_{\mathrm{M-I}(+)})/2 = f_r \quad (6)$$

In this case, the frequencies are equal to $f_r$. Therefore, the characteristics of the antenna will be identical to the antenna without perturbation.

Figures 4(a)–4(c) present the simulated impedance characteristics for the patch with and without perturbations to verify the proposed concept and the derived formulas. The patch size is kept same for all conditions during simulation. Figure 4(a) illustrates impedance characteristics of the patch before and after applying dual-perturbation. According to this figure, the unperturbed patch resonates at a frequency around 9.8 GHz. When a negative perturbation is introduced in the patch as shown in Figure 3, and two modes, M-I(−) and M-II, are excited as the two tips are observed in the Figure 4(b). Frequency of M-II is still at around 9.8 GHz, and M-I(−) resonates at a higher frequency, $f_{\mathrm{M-I}(-)}$ due

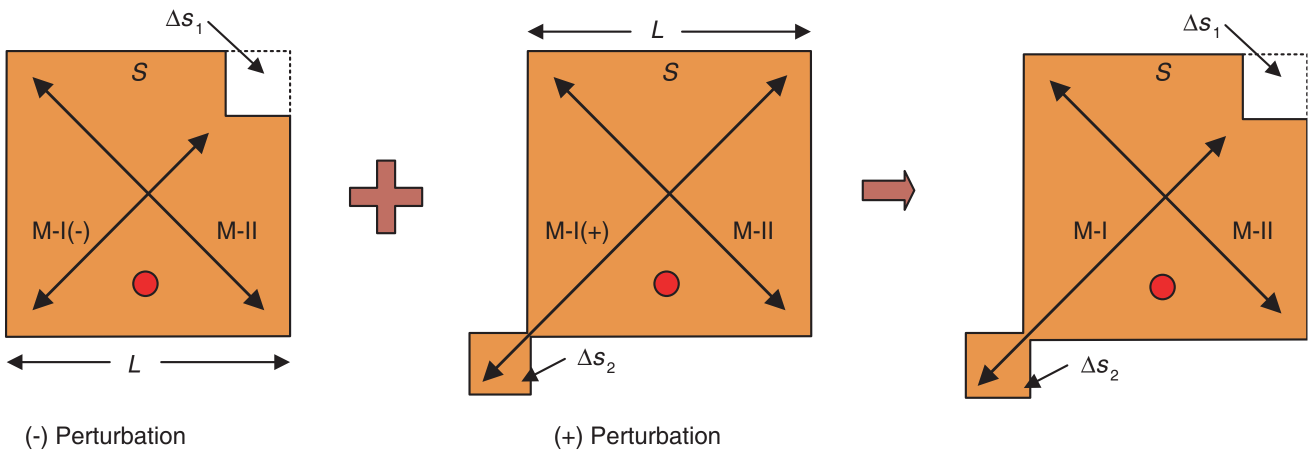



**Figure 3.** Microstrip antenna with dual-perturbation.

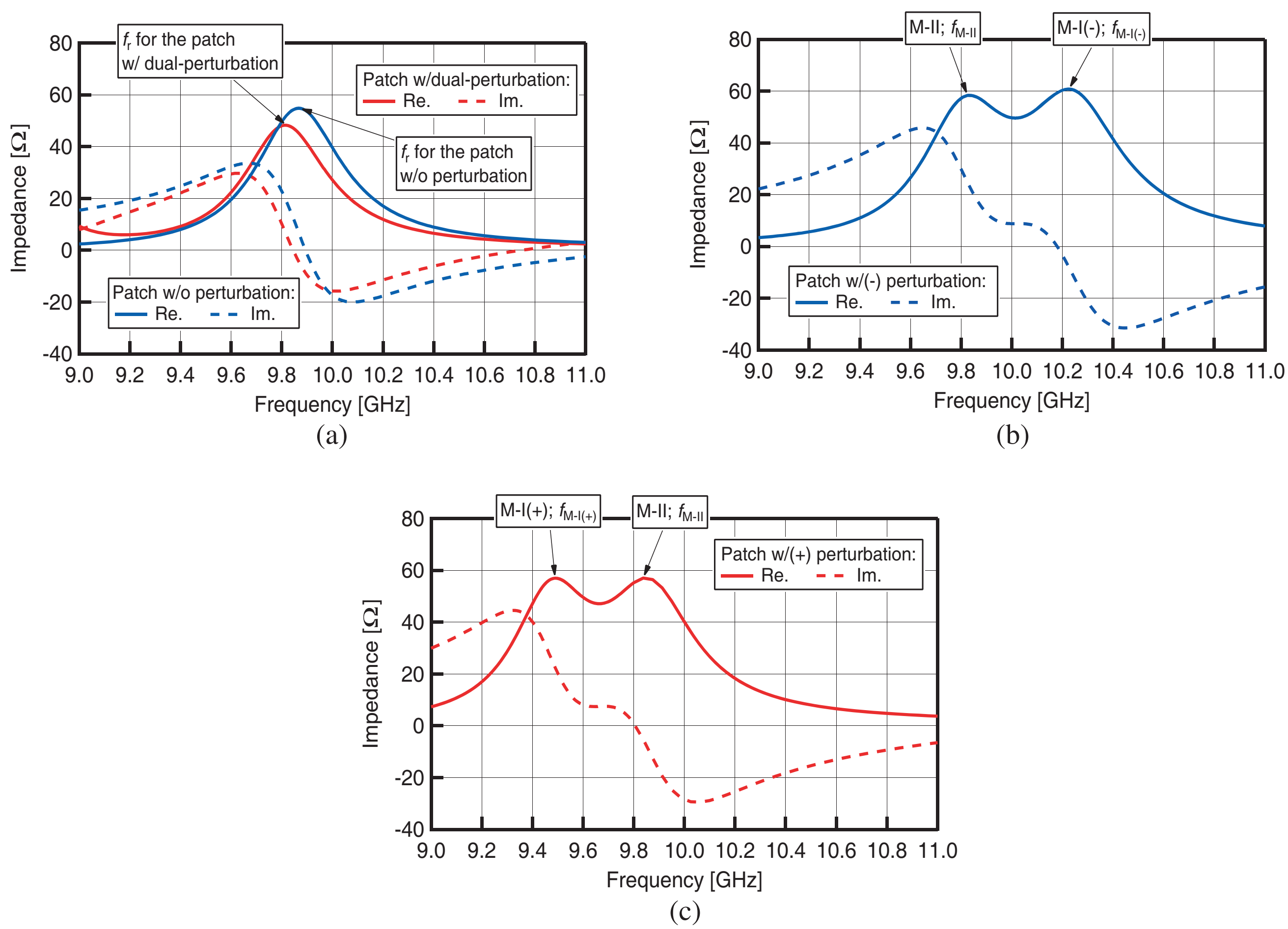



**Figure 4.** Simulated impedance characteristics of the antennas shown in Figure 3. (a) Impedance characteristics for the patch without perturbation and with dual-perturbation. (b) Impedance characteristics for the patch with a negative perturbation. (c) Impedance characteristics for the patch with a positive perturbation.

to the shorter diagonal length according to Eq. (2). On the other hand, according to Figure 4(c), $f_{\text{M-I}(+)}$ of M-I(+) is shifted to a lower frequency without changing the frequency ($f_{\text{M-II}}$) for M-II when a positive perturbation is caused in the patch due to the extended square corner segment. When both types of perturbation are applied to the patch with a proper adjustment of the perturbation segments, the resonance frequency of the patch with dual-perturbations is restored at the same frequency of the unperturbed patch as shown in the simulated impedance characteristics of Figure 4(a). Thus, these simulation results also confirm the basic concept of the proposed dual-perturbation technique.

## 3. STRUCTURE AND OPERATIONAL MECHANISM

Figure 5 shows the layout of the proposed reconfigurable antenna. A square slot having a side length of $d_1$ and slot width of $w_1$ on the ground plane just below one of the top corners of the square patch is embedded to create a perturbation in the patch. On the other hand, an L-shape microstrip segment with a dimension of $d_2 \times w_2$ is placed at the opposite diagonal corner of the square slot. The microstrip segment is separated from the patch by a narrow gap of $g$, and a PIN diode (D) is integrated between the segment and the patch for switching. Therefore, depending on the switching states of the diode, polarization sense can be changed. A bias network whose one end is connected to the ground through a via hole is used to apply the dc bias voltage properly. The bias network is designed using a high impedance microstrip line wherein each segment is quarter wavelength. When a negative dc voltage is applied to the patch, the diode becomes OFF. As a result, the square slot on the ground creates a perturbation, and the polarization of the antenna is CP. However, when the diode is in ON condition due to the positive dc bias voltage, the L-shape segment that introduces a positive perturbation is connected to the patch to eliminate the negative perturbation caused by the square slot on the ground.

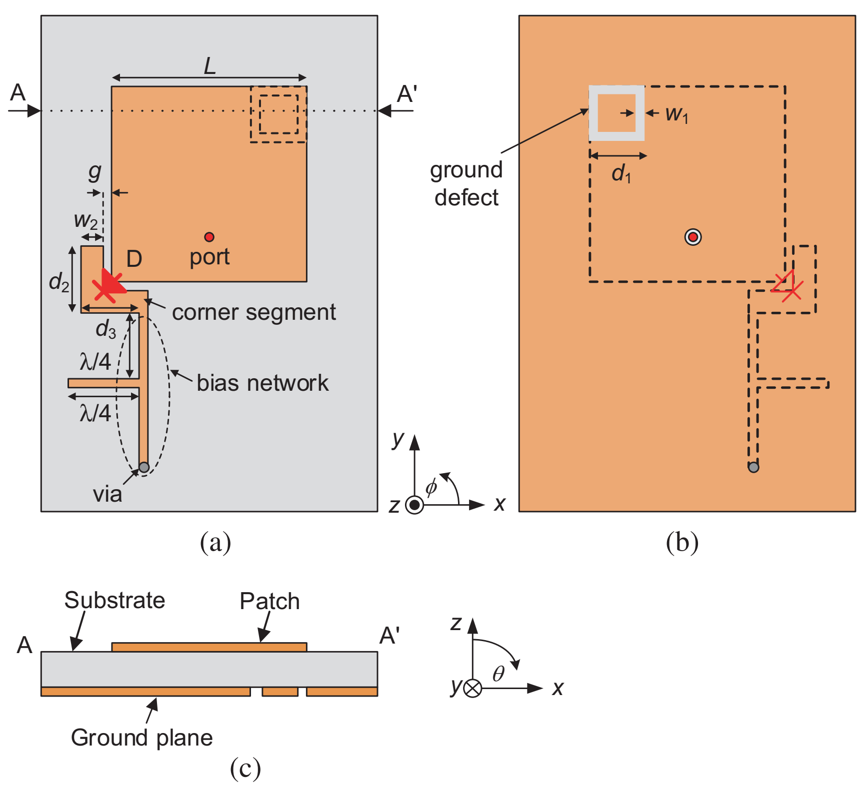



**Figure 5.** Schematic layout and cross sectional view (AA′) of the proposed antenna. Dimensions are: $L = 9.54$ mm, $d_1 = 3.1$ mm, $d_2 = 2.6$ mm, $d_3 = 2.4$ mm, $w_1 = w_2 = g = 0.2$ mm. $\lambda$ is the wavelength for microstrip line at the design frequency of 10 GHz. (a) Top view. (b) Bottom view. (c) Cross section (AA′).

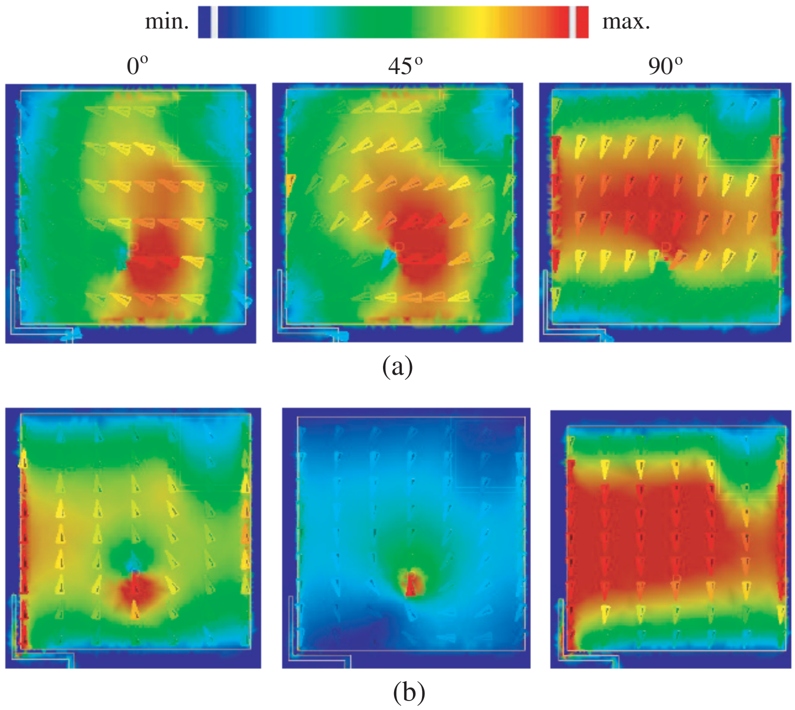



**Figure 6.** Current distribution of the proposed antenna. (a) D = OFF [RHCP and $f = 9.76$ GHz]. (b) D = ON [LP and $f = 9.73$ GHz].

Therefore, LP is obtained.

Figure 6 illustrates the current distribution for different switching conditions of the diode. A counterclockwise rotation is observed during OFF state diode condition. Therefore, CP sense is right-handed CP (RHCP). However, the L-shape microstrip segment affects the field distribution while it is attached to the patch by turning the diode ON. The segment helps to orient the field vertically. As a result, LP can be obtained.

## 4. ANTENNA PERFORMANCES

Figure 7 shows photographs of the fabricated X-band antenna. The design and performances of the proposed antenna have been examined using Keysight Technologies' EMPro. The antenna is etched on a 0.8-mm thick Teflon glass fiber substrate ($\epsilon_r = 2.15$). Switching between LP and CP is achieved by

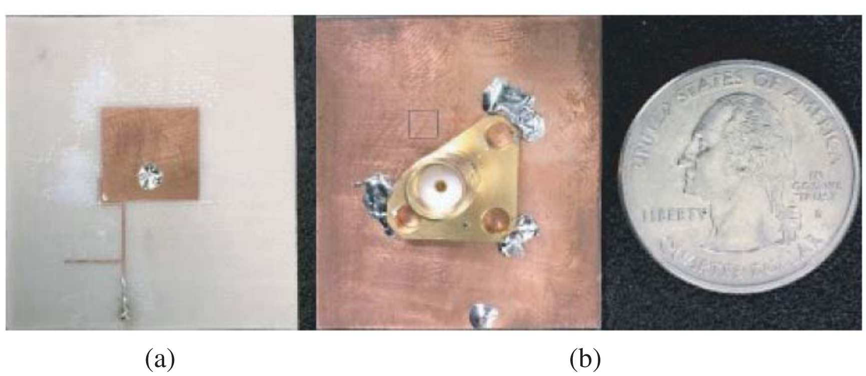



**Figure 7.** Photographs of the fabricated X-band antenna (28.6 mm × 32.3 mm). (a) Top plane. (b) Ground plane.

integrating a PIN diode (MBP1036-B11). During simulation, a 2.5-Ω resistor and a 0.04-pF capacitor are used as an equivalent circuit to realize ON and OFF states of the diode, respectively. On the contrary, the performances of the antenna during measurement are investigated by applying +1 V and −0.6 V for turning ON and OFF the diode, respectively.

Figure 8 presents the measured and simulated reflection coefficients of the antenna for different dc bias conditions. The measured 10-dB impedance bandwidths of the antenna are 1.8% and 5.32% for LP and CP, respectively.

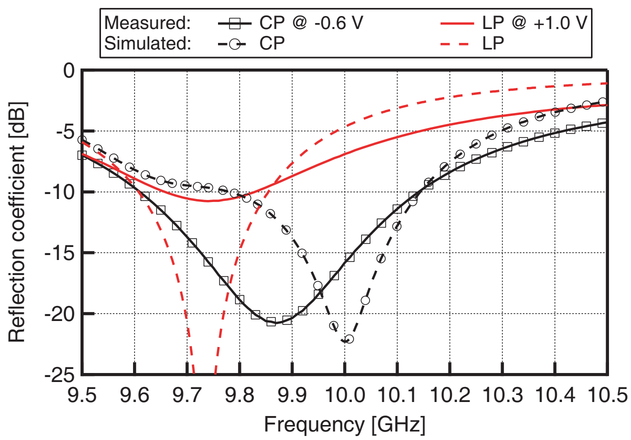



**Figure 8.** Reflection coefficient of the proposed antenna.

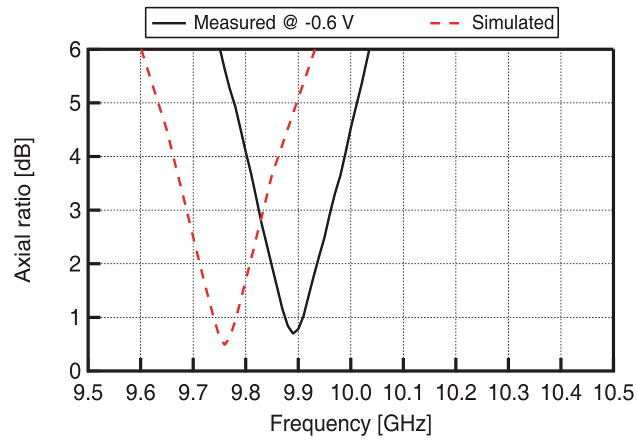



**Figure 9.** Axial ratio of the proposed antenna.

Figure 9 shows the axial ratio (AR) performance of the antenna. A 3-dB AR bandwidth of 1.41% is achieved with a minimum AR value of 0.70 dB at 9.89 GHz. Figures 8 and 9 confirm that the antenna for LP and CP operation can be used for a frequency band of 9.655–9.83 GHz and 9.83–9.97 GHz, respectively. A mismatch is observed between measured and simulated performances of the antenna. The use of the diode equivalent circuit during simulation is the main reason for this inconsistency as the parasitic components which are not considered during simulation have an effect on the measured performances.

Figure 10 shows the CP radiation pattern of the proposed antenna while the diode becomes OFF. In this condition, the sense of polarization is RHCP. An RHCP gain of 6.33 dBic is obtained at 0°, and the CP cross-polarization component is better than 25 dB.

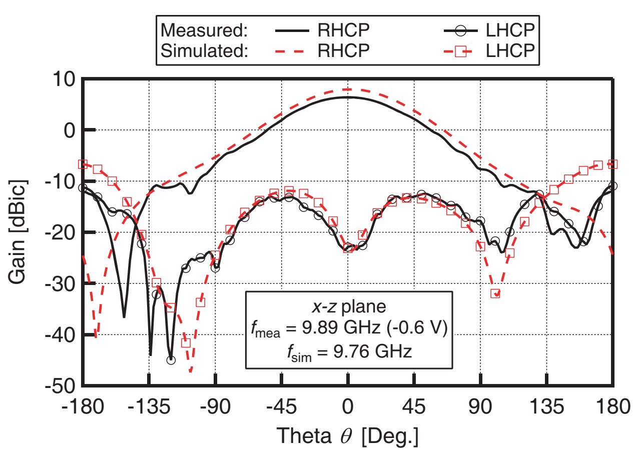



**Figure 10.** CP radiation pattern of the antenna.

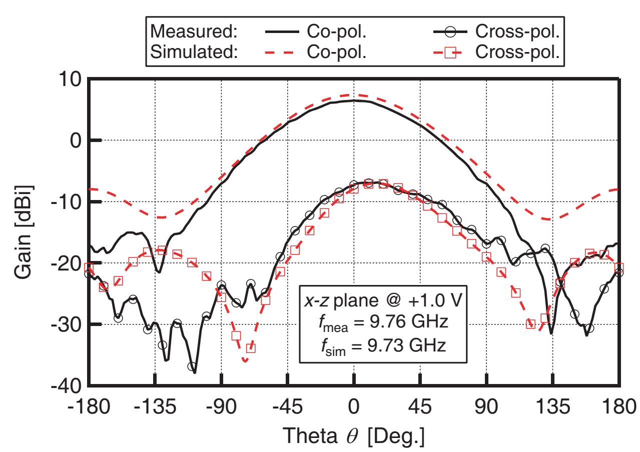



**Figure 11.** LP radiation pattern of the antenna for $x$-$z$ plane.

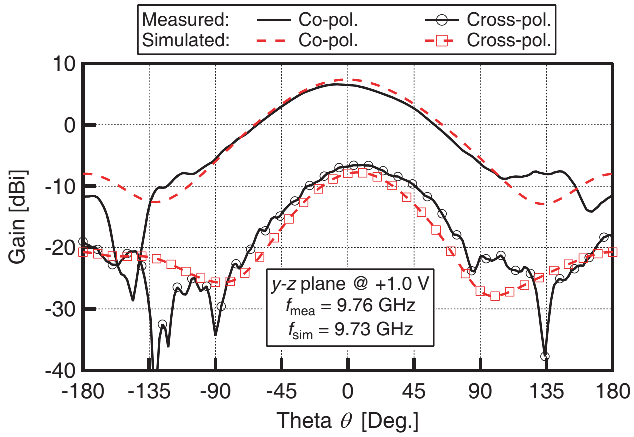



**Figure 12.** LP radiation pattern of the antenna for $y$-$z$ plane.

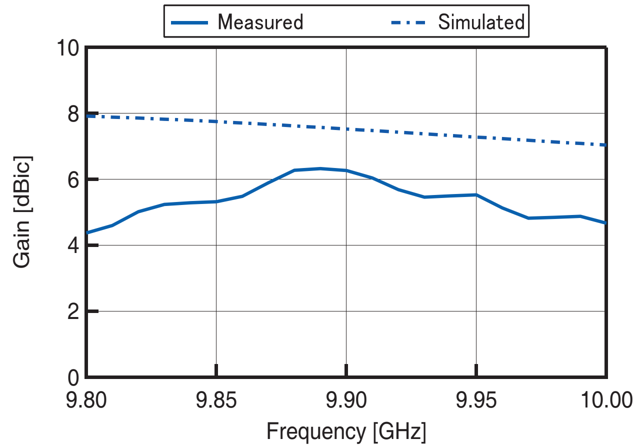



**Figure 13.** Gain of the antenna w.r.t. frequency for OFF state diode condition.

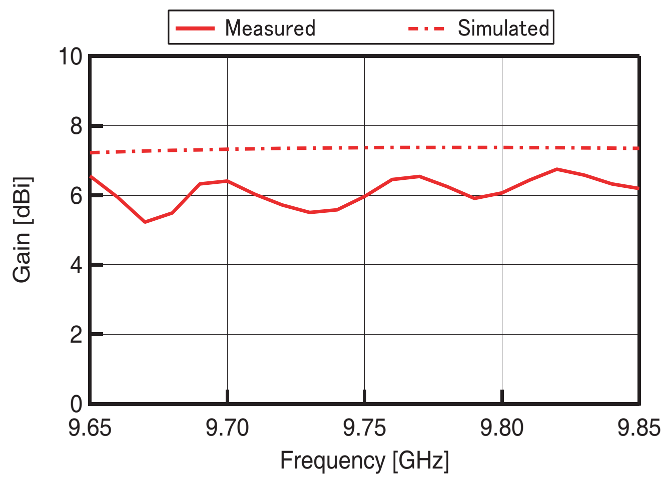



**Figure 14.** Gain of the antenna w.r.t. frequency for ON state diode condition.

Figures 11 and 12 present the gain performances of the antenna for $x$-$z$ and $y$-$z$ planes, respectively when the state of the diode is ON. During ON state diode, the polarization sense is LP. The maximum gain of the antenna is around 6.45 dBi at both planes, and the cross-polarization level is better than 13 dB. It is evident from the figures that the proposed antenna shows better gain performance at both diode conditions than that of conventional perturbation type microstrip antennas though the cross polarization level suppression is not good enough. It is due to the nonlinear effect of the diode. To verify the effect of the diode, the antenna is simulated after replacing the diode by a 0.2 mm microstrip line to consider the ideal short circuit condition. In this condition, the cross polarization suppression is improved, and it is better than 30 dB. This improvement indicates that LP can be achieved perfectly by cancelling out the effect of negative perturbation by creating the positive perturbation according to the proposed concept described in this paper.

Figure 13 shows gain response of the proposed antenna with respect to frequency. The gain is more than 5 dBic over the whole AR bandwidth during CP radiation. On the other hand, Figure 14 illustrates the antenna gain corresponding to frequency for ON state diode condition. In this condition of the antenna, more than 5 dBi gain is achieved for the entire 10-dB impedance bandwidth of LP radiation.

A comparison between the proposed work and previous polarization reconfigurable antennas is

**Table 1.** Comparison of the proposed antenna with previously reported antennas.

| Antennas | patch size (mm) | LP | | CP | | |
|---|---|---|---|---|---|---|
| | | Imp. BW ($< -10$ dB) | Gain (dBi) | Imp. BW ($< -10$ dB) | AR BW ($< 3$ dB) | Gain (dBic) |
| [3] | 25.4 | 60 MHz, - 2.62–2.68 GHz | 2.5 | 95 MHz, - 2.585–2.68 GHz | 30 MHz, - 2.63–2.66 GHz | 3.2 |
| [7] | 45.3 | -, 1.84% | 5.3 | -, 2.5% | -, 1.5% | 5.3 |
| [9] | 29.6 | 41 MHz, 1.71% 2.376–2.417 GHz | 1.42 | 99 MHz, 4.07% | 27 MHz, 1.12% | 3.36 |
| This work | 9.54 | 175 MHz, 1.8% 9.655–9.83 GHz | 6.45 | 530 MHz, 5.32% 9.61–10.14 GHz | 140 MHz, 1.41% 9.822–9.962 GHz | 6.33 |

presented in Table 1. It is clear from the table that the proposed antenna has the advantages of good impedance bandwidth, 3-dB AR bandwidth, and higher gain at both polarizations. The polarization reconfigurability of the proposed antenna is achieved by integrating a single diode while other antennas of Table 1 are realized by using 3–4 diodes. Therefore, lower diode loss leads to higher gain of the proposed antenna.

## 5. CONCLUSION

This paper demonstrates a ground defected microstrip antenna with a switchable polarization sense. A diode integrated L-shape corner segment has been used to realize LP operation. A properly designed L-shape segment effectively eliminates the perturbation caused by the square slot on the ground. On the other hand, the ground defected square slot without the L-shape segment excites RHCP. Thus, the proposed concept using different types of perturbations can be used in a variety of reconfigurable antennas.

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