Circularly Polarized Proximity-Fed Microstrip Antenna with Switchable Polarization Ability

Ally Yahaya Simba[1], Manabu Yamamoto[1], Toshio Nojima[1] and Kiyohiko Itoh[2]

[1] Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, 060-0814, Japan
E-mail: yamamoto@ice.eng.hokudai.ac.jp

[2] Tomakomai National College of Technology
Nishikioka 443, Tomakomai, 059-1275, Japan

1. Introduction

Antenna systems that utilize polarization diversity have stimulated significant research interest lately due to the development of modern wireless communication systems. Microstrip antennas are particularly attractive because of their low profile, light weight and easy fabrication [1]. They have been employed in systems such as wireless local area network (WLAN), satellite communication systems, as a modulation scheme in microwave tagging systems and several other applications [2]. Various antenna structures having capability of switching the sense of polarization have been proposed [2,3]. In many of these antennas, it is the patch that is reconfigured to obtain the required two orthogonal modes with equal amplitude and thus requiring many PIN diodes for their operations. For example, two diodes are required in [2], and four diodes in [3] for single antenna, with the number of diodes doubling for any added patch if an array configuration is to be employed.

Based on these considerations, we present a novel circularly polarized proximity-fed microstrip antenna (CP-PMA) with polarization switching ability. This antenna consists of a truncated-corners square patch coupled in close proximity to a microstrip line. It uses the reconfigured feed line for its operation, thus requiring fewer PIN diodes even in array configuration [4,5]. The technique of truncating corners of a square patch to obtain single-feed circular polarization is well known [6]. But it's only recently that a truncated square patch with switchable polarization has been reported [7]. However, just like in [2,3], it requires four diodes for the switching operation.

The proposed CP-PMA is investigated using the FDTD technique and experiment at 5GHz band.

2. Antenna Structure

Fig. 1 shows the configuration of the proposed CP-PMA where all dimensions are in millimeters. A 50Ω microstrip line with a width of 2.0mm is printed on the same plane of PTFE substrate (thickness: 0.8mm, permittivity: 2.6) with the microstrip patch antenna. The dimensions of the patch antenna are chosen such that the antenna resonates at 5.0GHz. A small square of side length 1.2mm is truncated from the opposite corners of the patch to provide the perturbation, necessary to produce the orthogonal modes required for the generation of circular polarization. The patch is arranged in proximity to the feed line and is excited with electromagnetic coupling through a 0.8mm gap width. The feedline is extended beyond the edge of the patch. In order to control the termination of the

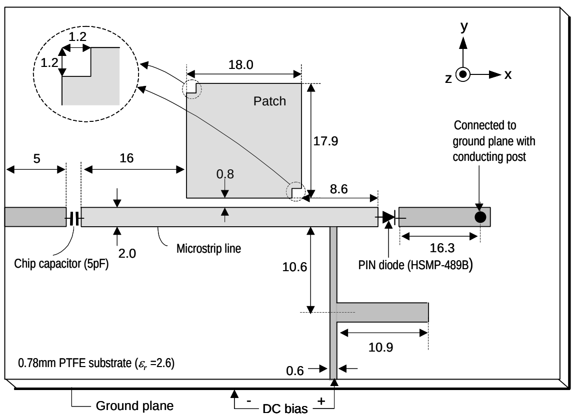


Fig.1: Geometry of CP-PMA.

ISBN: 89-86522-79-9 94460©KEES

feedline, a PIN diode is inserted between the end of the line and a 16.3mm stub whose end is connected to the ground plane by a conducting post. The stub is required to compensate the parasitic reactance of the PIN diode. The length of the stub can be determined by using an equivalent circuit shown in Fig. 2. The following equations can be derived from the equivalent circuit.

$$Z_d = j\omega L_d + \frac{R_d}{1 + j\omega C_d R_d} \quad , \quad Z_s = R_c \frac{Z_p + jR_c an\beta L_f'}{R_c + jZ_p \tan \beta L_f'}$$

$$Z_p = j\omega L_p \,, \quad Z_{in} = Z_D + Z_S$$

where R_s, C_d and L_d are series resistance, capacitance and inductance of PIN diode, respectively. L_p is an inductance of the conducting post. The values for these parameters are obtained from data sheet of Agilent technology HSMP-489B [8], which is employed in the following study. In order to compensate the parasitic reactance of the PIN diode, the stub length should be designed such that imaginary part of Z_{in}, which is an impedance looking into the series circuit of the PIN diode and the stub, becomes 0.

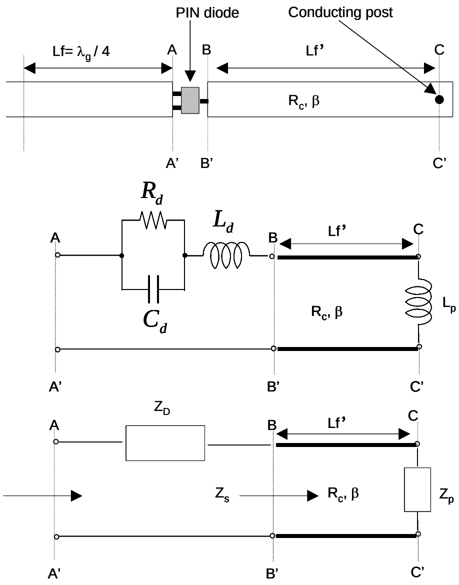


Fig. 2: Equivalent circuit switching circuit.

To control the status of the diode, a bias circuit is required. In the CP-PMA antenna, is realized using 50 and 100Ω λ_g / 4 microstrip lines. 5pF chip capacitor is introduced in the vicinity of the feed line to isolate the DC bias while maintaining the continuity of the RF signal. The gaps in the input of the feed line and between the feed line and stub are chosen to be 1mm so that the diode and chip capacitor can easily be soldered.

The operational mechanism of the CP-PMA is similar to that of the linearly polarized PMA [5]. However, in the CP-PMA, the short-terminated feed line (bias on) case will produce the right hand circular polarization (RHCP) due to the truncation of the patch opposite corners, where as open-circuited feed line (bias off) will result in to the left hand circular polarization (LHCP). Actually, these two cases equivalently correspond to the singly fed patch with perturbations where the feed location exists on the *x*- and *y*-directed centerlines, respectively [1].

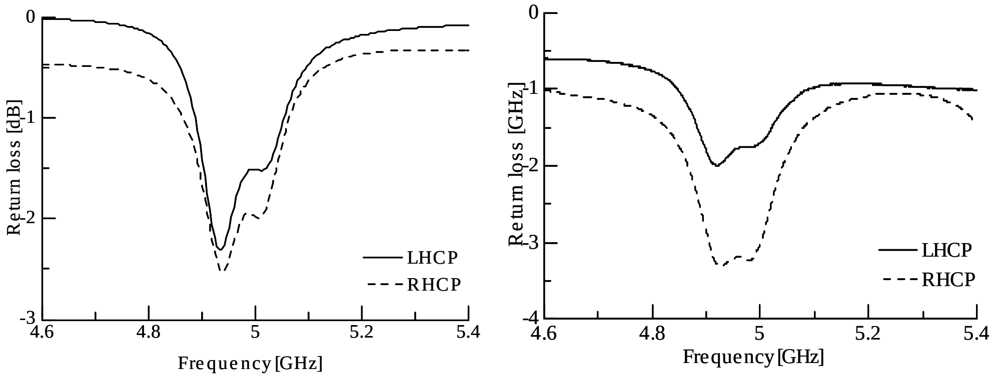
3. Numerical Results

Characteristics of the CP-PMA have been investigated by non-uniform mesh FDTD analysis [9]. In the analysis, the PIN diode was modeled with an equivalent circuit presented by the manufacturer [8].

Fig. 3a shows the simulated return loss of the CP-PMA. Lower return loss observed is due to the wider gap width between the feed line and the patch. The return loss improves when smaller gap width is employed, however, feed line coupling makes the patch appear electrically longer in its *y*-dimension. This causes the minimum axial ratios of the LHCP and RHCP to occur at different frequencies. The investigation of the way to improve the return loss is underway. The technique, which employs a very small shunt short-circuit stub positioned at the feedline first voltage minimum from the patch edge, was found to improve the return loss of the antenna to about 10dB bandwidth of 2-3% when employed to the separately built CP-PMA for LHCP or RHCP. This method, a similar one of which has been employed elsewhere [10], has insignificant effect to the axial ratio or antenna radiation pattern.

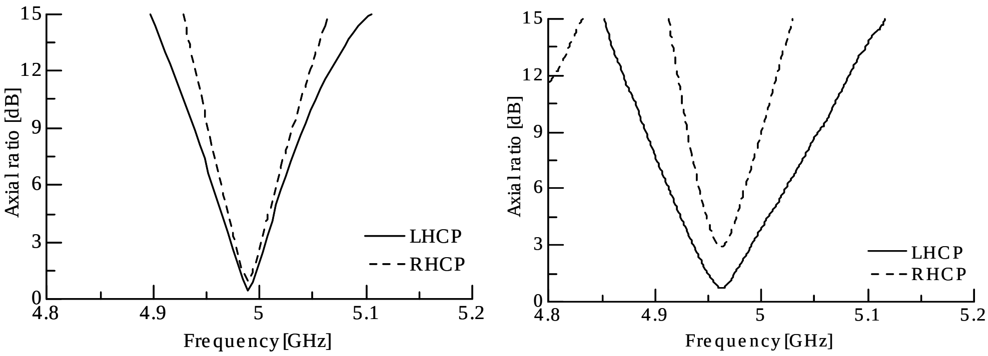
Fig.4(a) shows the simulated axial ratio of the CP-PMA. The minimum broadside-axial ratios of 0.5 and 0.9dB were obtained at the frequency of 4.99GHz for both LHCP and RHCP, respectively. The difference in bandwidths may be attributed to the difference in the dimension of the sides of the patch.

The simulated radiation patterns in the *xz*-plane, calculated at the frequency of minimum axial ratio are shown in Fig. 5(a). The co-polarization for LH and RHCP are denoted by $|E_L|$ and $|E_R|$, respectively. Radiation patterns with 84 and 78 degrees beamwidths are produced for LHCP and RHCP case, respectively. Similar patterns have been observed in the *yz*-plane.



(a) FDTD result (b) Experimental result

Fig. 4: Frequency response of return loss of CP-PMA.



(a) FDTD result (b) Experimental result

Fig. 5: Frequency response of axial ratio of CP-PMA.

4. Experimental Results

In order to confirm the numerical considerations, the CP-PMA was fabricated and measured at 5GHz band. In the experiment, the stub length of 18.5mm was found to produce best result. Note that, this length is different to the one used in the analysis i.e. 16.3mm. This may be due to the difference in characteristics between the ideal diode modeled in the FDTD investigation and the actual one used in the experiment. However, beside this difference, all other dimensions of the fabricated antenna are the same as those used in the analysis. To short-circuit the end of the feed line, a bias current of 20mA was supplied to the PIN diode using a constant-current circuit. The axial ratios were obtained from a phase less measurement of the linear polarization [11].

Fig. 3(b) shows the measured return loss of the CP-PMA. The curves are similar to those obtained by analysis depicted in Fig. 3a. Axial ratios measured in the broadside direction are plotted in Fig. 4(b). The frequency of minimum axial ratio for both LHCP and RHCP cases is 4.96GHz, which is 30MHz lower from simulated one. Poor axial ratio observed in the RHCP may be attributed to the behavior of the PIN diode in the bias on state. Measured radiation pattern for both sense of the polarizations are shown in Fig. 5(b). They are calculated at the frequency of minimum axial ratios, with only *xz*-plane indicated. Similarities with simulated patterns are observed, despite the difference in frequency of measure. Lower cross-polarization levels in the broadside direction confirm the effective performance of the proposed antenna.

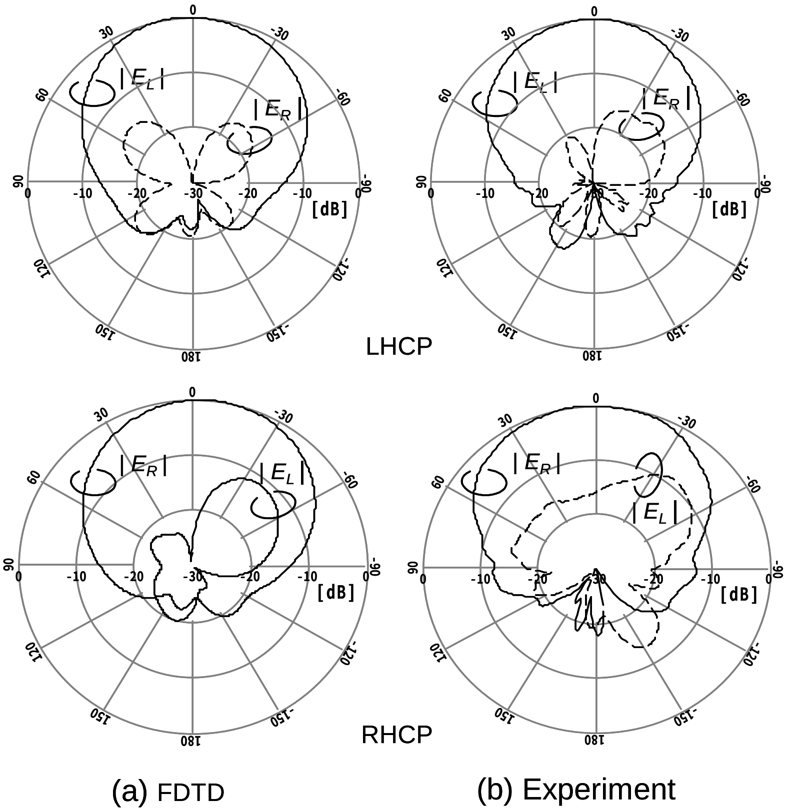


Fig. 5: Radiation pattern of CP-PMA observed in *xz*-plane.

5. Conclusions

A novel circularly polarized-proximity fed microstrip antenna (CP-PMA) with polarization switching ability was proposed. This antenna uses PIN diode to reconfigure the feed line for its switching operation. Both analysis and measurement were presented to confirm the performance of the proposed configuration.

Acknowledgement

This work has been supported by Grant-in-Aid for Research 16760284 from the Japan Society for the Promotion of Science.

References

[1] H. F. Lee and W. Chen:, Advance in Microtrip and printed antennas, John Wiley & Sons, New York, 1997.
[2] F. Yang et al:, IEEE Microw. and Wireless Comp. Lett., Vol. 2, No.3, pp.96-98, March. 2002.
[3] M. K. Fries et al:, IEEE Micr. and Wireless Comp. Lett., Vol. 13, No.11, pp.490-492, Nov. 2003.
[4] T. Tokunaga et al:, Electronics Letters, Vol. 33, No. 22, pp., October. 2003.
[5] M.Yamamoto et al;, Proceedings of ISAP-2004, pp.413-416, August. 2004.
[6] W. -S Chen et al:, IEEE Trans. Antennas Propagat., Vol.49, No. 3, pp. 340-342, March. 2001.
[7] Y. J. Sung et al:, IEEE Micr. and Wireless Comp. Lett., Vol. 14, No.11, pp.534-536, Nov. 2004.
[8] Agilent Technologies HSMP-389x and HSMP-489x series RF PIN switch diodes data sheet.
[9] H. Jiang and H. Arai:, IEICE Trans. Commun., Vol.E83-B, No.7, Jul. 2000.
[10] K. L. Chun et al:, IEEE Trans. Antennas Propagat., Vol.51, No. 12, pp. 3239-3248, Dec. 2003.
[11] P. Hallbjorner:, IEE Proc.Microw. Antennas Propagat., Vol. 150, no. 1, pp.28-33, Feb. 2003.