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A Coplanar Waveguide Fed Rectangular Reconfigurable Patch Antenna with Switchable Strips for Polarization Diversity

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ABSTRACT

A compact single feed rectangular patch antenna with reconfigurable circular polarization has been proposed in this paper. The basic antenna structure is a rectangular patch of dimensions 10 mm x 15 mm printed on a thin FR4 substrate of thickness 3 mm. Two rectangular strips are connected through switches at sideways of the main patch to get polarization diversity. The polarization of the proposed antenna can be reconfigured between left hand circular polarization (LHCP) and right hand circular polarization (RHCP) by the current path, which is changed by operating the switches in ON and OFF modes. The antenna is designed and simulated using IE3D MoM based electromagnetic simulator. The simulated results show good return loss, radiation pattern, axial ratio and acceptable gain at the operating frequency. The antenna has around 15 % effective impedance bandwidth over 4.0 GHz - 4.8 GHz frequency band at a maximum gain of 3.0 dBi with polarization diversity.

Keywords: Reconfigurable antenna, polarization diversity, circular polarization, patch antenna, coplanar waveguide feed

1. INTRODUCTION

In the history of development of wireless communication systems, reconfigurable antennas have been thought of having a key role in today's radio electronic systems. From the mid-1990s until the present there has been an increasingly rapid advance in the area of reconfigurable antennas. Miniaturization always indicates scientific progress. So efforts are directed towards reducing the antenna size. So far several studies were made to design a single antenna which is used for single application, but today's wireless environment need a single antenna serving different applications (switch between different frequency bands) and should have the capability of switching between different operating modes, polarizations, appropriate radiation patterns which helps in miniaturizing entire size of the device. The above mentioned purpose is fulfilled by the use of reconfigurable antennas. To configure means to organize elements of something in a particular form or figure. Hence, by definition reconfigurable antenna means the antenna that can intentionally and reversibly change the distribution or character of its performance-governing electromagnetic fields[1]. This reconfiguration can be achieved through dynamic redistribution of the antenna's aperture currents which can be achieved through different mechanisms such as switching, material tuning and structural modifications.The switching mechanism uses solid state switches such as PIN diodes, FETs and RF MEMS switches. The later type switches have many advantages than solid state switches[2-4]. The reconfigurable antennas are capable of operating at multi band frequencies, with or without polarization diversity, adaptive beam forming by automatically changing to the appropriate radiation pattern, minimize interference or jamming, estimating direction of arrival.

One of the many advantages of circularly polarized antennas is good receiving sensitivity which makes it useful in mobile applications. The other advantages are low fading when used in WLANs, increased security that can be used in military wireless systems and in RFID systems[5].

Circular polarization (CP) can be achieved by using a symmetrical patch which can be excited by two identical orthogonal modes. It can also be achieved by feeding two orthogonal identical patch antennas in quadrature. A single feed quasi symmetrical patch antenna that supports two degenerated modes also operates in circular polarization. Previously, many researches[6-9]have shown that there are several types of patch antennas with polarization diversity but these antennas have more than one feeding element and parasitic structures, and in some cases they also have several layers below the main radiating patch which makes the design more complex and asymmetric.

The main aim of this paper is to achieve CP diversity by using geometrically symmetrical shaped antenna with small size and less complexity. Such types of antennas are useful in array type of structures, especially in planar array configuration. Hence we propose a simple and compact rectangular patch with single coplanar waveguide (CPW) feed that produces circular polarization diversity. So far, CP antennas are designed with conventional micro strip feeding structures but this paper proposes CPW feed because of its many advantages such as; reduction in radiation loss, improved bandwidth, easy surface mounting of active and passive devices, reduced cross talk effects between adjacent lines because of ground plane between any two adjacent lines, simplified fabrication[10].

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2. RECONFIGURABLE ANTENNA DESIGN

Figure 1 shows the geometry of the proposed reconfigurable antenna. The antenna is designed on a low cost FR4 substrate which is 3 mm thick and having dielectric constant, $\varepsilon_r = 4.3$. The other dimensions of the antenna in mm are listed in Table 1. The basic antenna consists of a rectangular patch whose length L and width W for the given frequency of operation 'f_r' are mentioned below.

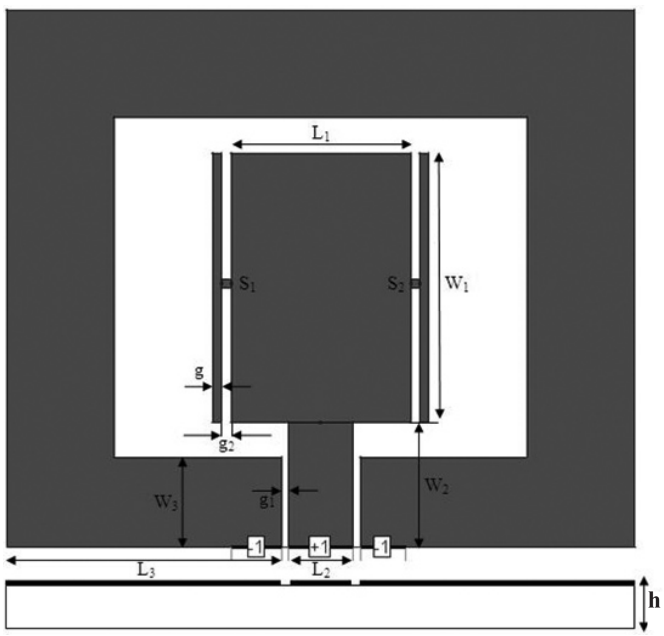

Figure 1. Structural geometry of the proposed antenna.

Table 1. Dimensions of the proposed antenna in mm

Patch Length, L_1	10
Patch Width, W_1	15
Strip dimension, g	0.5
CPW feed length, L_2	3.6
CPW feed width, W_2	7.0
Gap spacing, g_1	0.4
Strip spacing, g_2	0.5
Ground length, L_3	15.3
Ground width, W_3	6.0

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

where c = 3e8 m/s and the effective dielectric constant is given by

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (2)$$

where 'h' is the thickness of the substrate. The extended length ΔL of the patch is given by

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)}\right] \quad (3)$$

The effective length of the patch for the given resonant frequency is given by

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} = L + 2\Delta L \quad (4)$$

Hence the actual length of the patch is

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (5)$$

The optimized dimensions of the patch for the operating frequency of 4.8 GHz are 10 mm x 15 mm. The overall dimensions of the antenna are 35 mm x 30 mm which include patch and CPW ground.

The structure of this antenna is modified to get circular polarization. The two orthogonal nearly degenerated resonant modes for CP in single feed CPW patch antenna are obtained by exciting two rectangular strips on both sides of the patch. Two switches are introduced in the structure namely S_1 and S_2. Switch S_1 connects left rectangular strip to the patch, and S_2 connects the right rectangular strip. The two switches are realized in the simulation as short copper paths between the main patch and the strips. Presence of the short is treated as ON and the absence of the short as OFF. Different switch configurations which make the proposed antenna to operate in different CP diversity cases are shown in Table 2.

Table 2. Switch configurations for the proposed antenna

Case	S_1	S_2
Case 1	ON	ON
Case2	ON	OFF
Case 3	OFF	ON
Case 4	OFF	OFF

3. RESULTS

The return loss curve of the basic patch antenna of 10 mm x 15 mm is shown in Fig. 2. The antenna operates at 4.8 GHz with a return loss of -21 dB.

For reconfigurable operation, in case 1, when both the switches are in ON state, the antenna exhibits linear polarization because of the symmetry in the antenna structure. In case 2, when S_1 is ON and S_2 is OFF, due to the quasi symmetric structural configuration two orthogonal degenerate modes are generated which makes the antenna to excite in circular polarization. Thus when the antenna is reconfigured from case 1 to case 2, the polarization switches from linear to circular. The current distributions of the reconfigurable antenna in case 2 are shown in Fig. 3. This figure clearly shows the rotation of current vector in the clockwise direction at the position of switch S_1 at time instances t=0, t=T/4, t=T/2 and t=3T/4. This implies antenna operates in LHCP. Similarly in case 3 i.e. when S_1 is OFF and S_2 is ON, it exhibits RHCP. In case 4, the antenna radiates through center rectangular patch in linear polarization.

The return loss curves of the proposed antenna in all the cases are shown in Fig. 4. It shows that antenna in case 1 operates at a frequency of 4.23 GHz. When both S_1 and S_2 are ON, the electrical length of the antenna is larger than the other cases and say l_H. In Case 2 and Case 3 the return loss curves are same (because of same electrical length say l), and resonates at slightly higher frequency of 4.47 GHz and 5.76 GHz when compared to case 1. Return loss of -29 dB is obtained at 4.47 GHz and -22 dB at 5.76 GHz. In case 4, when both S_1 and S_2 are OFF the electrical length of the antenna (l_L) is smaller and the operating frequency would be higher than the above cases. The antenna operates at a frequency of 4.66GHz with reduced return loss and gain compared to above cases because of mutual coupling that exists between central patch and side strips.

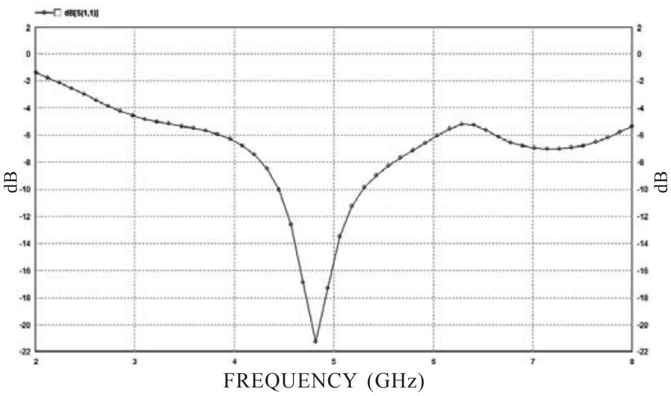

Figure 2. Return loss curve of the basic rectangular patch antenna.

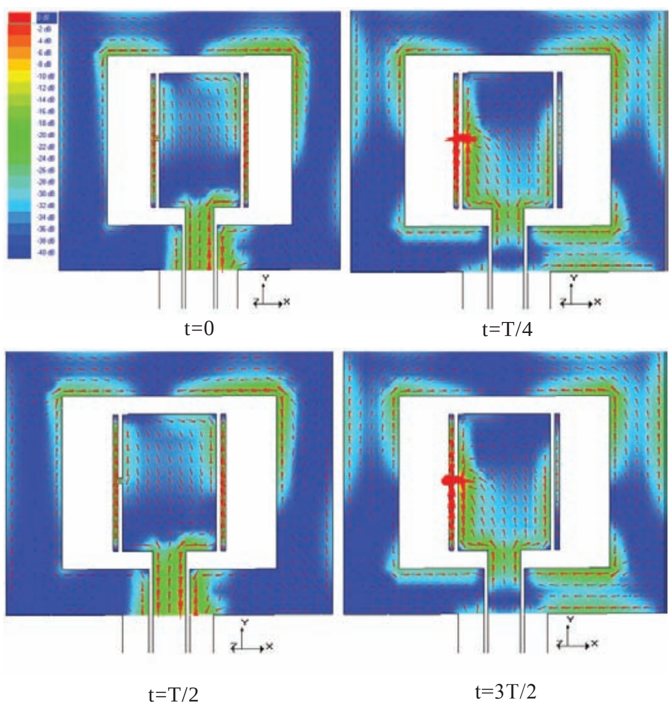

Figure 3. Surface electric current distribution in Case 2.

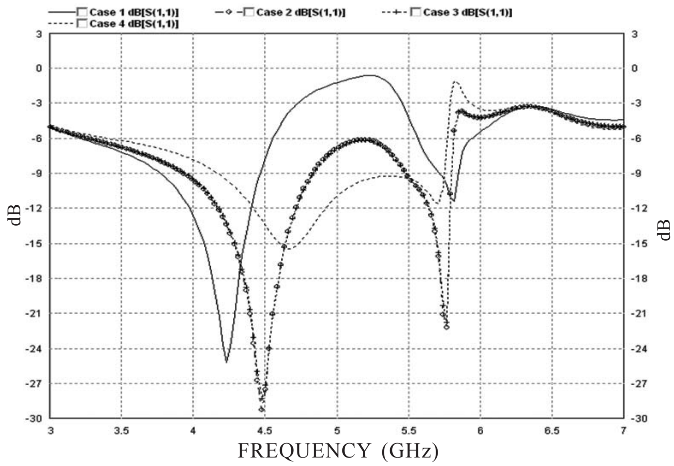

Figure 4. Return loss curves of the proposed reconfigurable antenna in all modes.

A reconfigurable antenna with polarization diversity must have the same operating frequency with varied polarization. The proposed reconfigurable antenna satisfies this condition with the same operating frequency in both RHCP and LHCP. The radiation pattern curves of the reconfigurable antenna in all cases i.e., E_φ polarization patterns in the elevation cuts (*y–z* plane and *x–z* plane) at their corresponding resonant frequencies are shown in Fig. 5. The radiation efficiency is found to be more than 70% in both LHCP and RHCP.

The axial ratio of the proposed reconfigurable antenna in all states is less than -3dB over the entire operating frequency band. The gain of the antenna is also above 2 dBi for all the reconfigurable states. The different parameters of the proposed antenna are shown and compared in Table 3. The effective impedance bandwidth (-10dB return loss) of more than 15% is achieved. The impedance value at resonant frequencies is around 51Ω which is close to ideal value 50 Ω.A commercial Method of Moments based IE3D CAD tool was used for simulation.

Table 3. Results

Antenna parameters	Case 1	Case 2	Case 3	Case 4
Operating frequency	4.23 GHz	4.47 GHz, 5.76 GHz	4.47 GHz, 5.76 GHz	4.66 GHz
Return loss	-25 dB	-29.2 dB, -22.1 dB	-28.3 dB, -21.3 dB	-15.4 dB
Bandwidth	580 MHz (13.7%)	738 MHz (16.5%), 252 MHz (4.3%)	738 MHz (16.5%), 252 MHz (4.3%)	840 MHz (18%)
Antenna Gain	2.65 dBi	3 dBi, 5 dBi	3 dBi, 5 dBi	2 dBi
VSWR	1.11	1.07, 1.16	1.08, 1.19	1.42
Polarization	LP	LHCP	RHCP	LP

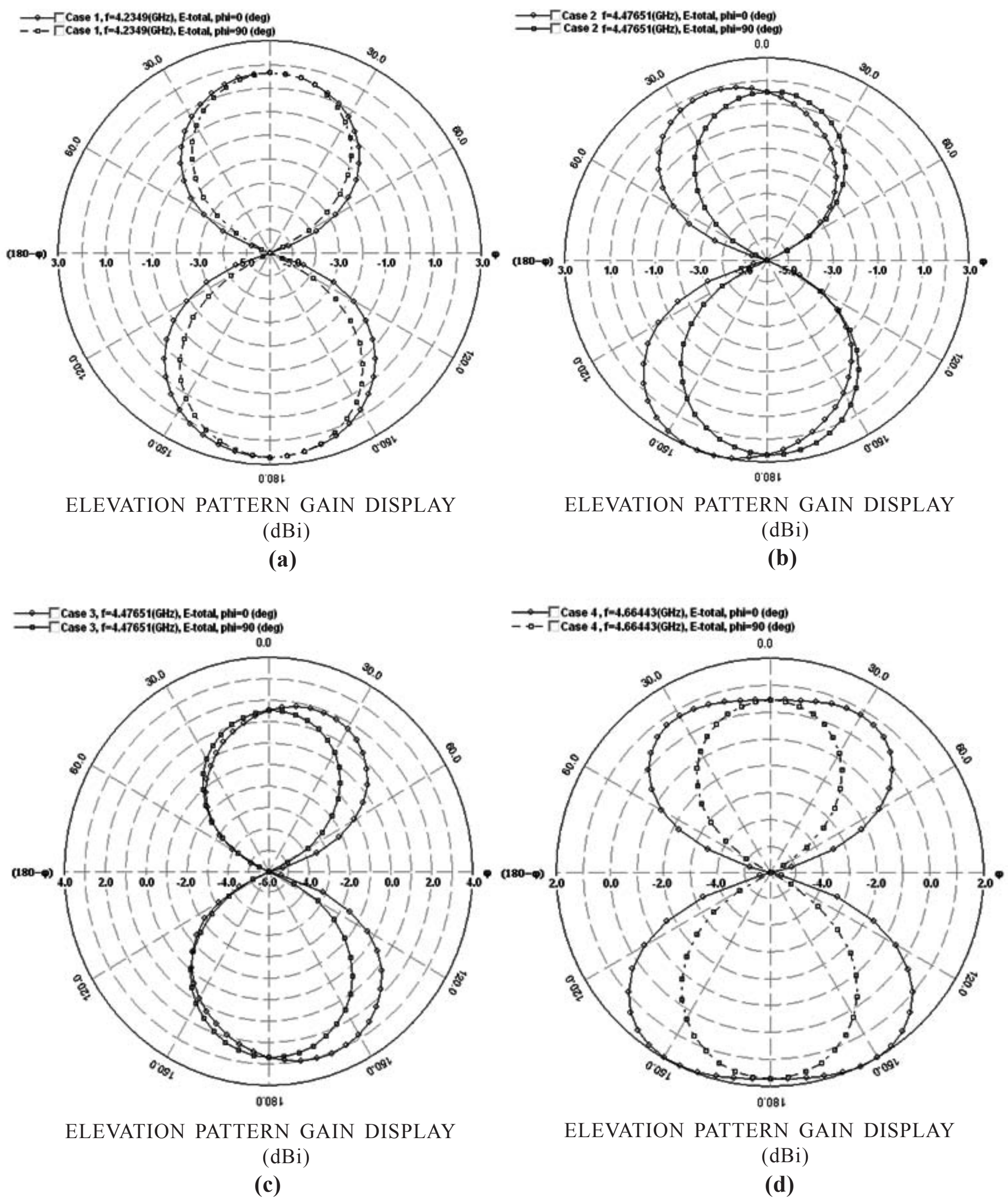

Figure 5. E_φ polarization patterns of the proposed reconfigurable antenna in elevation cut for (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

4. CONCLUSIONS

This paper gives an account of achieving circular polarization agility using a simple and compact rectangular shaped patch antenna with CPW feed. The miniaturized size of the antenna is 35 mm x 30 mm. The use of CPW feed to improve the overall impedance bandwidth has been demonstrated using single layer and single feeding element to achieve circular polarization. The mode of CP is changed by the use of only one of the two switches at a time. For different polarizations the proposed antenna operates at the same frequency and it is suitable for wireless communication applications.

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