Reconfigurable Single-Feed Antenna With Switchable Polarization

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Abstract: A new reconfigurable single-feed circular microstrip antenna with polarization diversity is proposed. The simple structure of this antenna contains a radiating circular patch, four switches (PIN diode), and a 50 Ω microstrip feed line. It can be switched between four different states: two states for linear polarization (LP), one state for left hand circular polarization (LHCP) and one for right hand circular polarization (RHCP). Simulation and experimental results show that the proposed antenna demonstrates a good impedance bandwidth, and axial ratio in the circularly polarized states.

Keywords: Circular polarization, linear polarization, microstrip antenna, PIN diode, reconfigurable polarization.

1. Introduction

Now a days, there is a great tendency to intensify the development of reconfigurable antennas besides enjoying a very rich and diverse history of innovation and design. Application areas that drive the development of reconfigurable antennas include multifunction wireless devices, multiple-input multiple-output (MIMO) systems, and ultra wide band systems anti-jamming secure communication to accommodate the ever demanding requirements of such systems. The advantages of Reconfigurable microstrip antennas for frequency agility and polarization diversity are their frequency reuse for doubling the system capability and a high degree of polarization control for optimizing the system performance. It is achieved through intentional redistribution of the currents, or equivalently, the electromagnetic fields on the antenna’s effective aperture [1]. The reconfigurable antenna with polarization agility offer an impressive enrichment in receiving the communication signal which includes an exceptional ability of multipath fading reduction.

The microstrip antennas with polarization diversity and characteristics of them have been reported [2]–[3]. The antennas studied in [4] and [5] use the dual-fed for reconfigurability while antenna with simple feeding network is one of the main factors in wireless communication systems. Several reconfigurable antennas with polarization diversity between linear and circular polarization [6] and two circular polarizations (i.e., LHCP and RHCP) [4] - [8] have been discussed in past literature. Furthermore, many of them employ slots for reconfigurability.

Designing a novel single-feed circular microstrip antenna with reconfigurable polarization capability for all polarization states with stubs instead of slots is the main motivation in this paper. The propounded antenna utilizes an arc line on the top of the circular microstrip patch. To switch the polarization states, four PIN diodes are used. Simulations by using HFSS and measurements show good matching performance for all polarization states.

2. Antenna design

Fig. 1 depicts the geometry of the proposed circular microstrip antenna with reconfigurable polarization capability. The proposed antenna is printed on a 1.6 mm thick FR4 epoxy substrate of relative permittivity 4.4. The ground plane dimensions are 100 × 100 mm².

Inserting two paths with λg/4, approximately in antenna’s feed line leads to have an appropriate impedance matching for four states.
Controlling the polarization state of the designed antenna is possible with inserting four PIN diodes close to the edge of the stubs. The proposed antenna has two main polarized states; linear polarization (LP) and circular polarization (CP). The characteristics of this antenna are divided into four cases depending on the bias of the PIN diodes, as depicted in Fig. 2.

When all the four PIN diodes on the circular patch are biased in either the “on-state” (Ant. 1) or the “off-state” (Ant. 2) simultaneously, in order to guarantee the physically and electrically symmetric shape of the circular microstrip patch, the antenna radiates linearly polarized waves. As all of the diodes are in the “on-state,” they act as electrically short circuits and the other hand, When they are in the “off-state,” they act as electrically open circuits. The operating frequency of the Ant. 1 is different than the Ant. 2.

To radiate circularly polarized waves, both of the diodes (either diodes (1 and 3) or (2 and 4)) should be in the “on-state” while the others should be in the “off-state.” While diodes 1, and are in “on-state” (the short circuit case), and diodes 2, and 4 in “off-state” (the open circuit case), this configuration is referred to as Ant.3.

In this case, the arc-shape stub in Ant.2 changes to similar to an L-shape. Therefore, the CP can be accomplished. If diodes 1 and 3 are in the “on-state,” it leads to RHCP in Ant. 3. In contrast, if diodes (2, 4) in the “on-state,” the shape of the stub changes and it leads to LHCP in Ant. 4.

### 3. Results

The simulations of proposed antenna were studied by using HFSS version 13. A perfect open-circuit was supposed for the PIN diodes in the “off-state.” When the diodes are in the “on-state,” they were simulated as through lines by using metal tape. Details of the design parameters are summarized in Table 1.

<table>
<thead>
<tr>
<th>Wf (mm)</th>
<th>Lf (mm)</th>
<th>α (deg)</th>
<th>a (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.059</td>
<td>17.11</td>
<td>58</td>
<td>18.35</td>
</tr>
<tr>
<td>g (mm)</td>
<td>Ws (mm)</td>
<td>Wm (mm)</td>
<td>Lm (mm)</td>
</tr>
<tr>
<td>1.6</td>
<td>1.5</td>
<td>1</td>
<td>18.35</td>
</tr>
</tbody>
</table>
The return loss of the proposed antenna for all states has been measured. Fig. 3 shows the S-parameters of the antenna for linear polarization, which illustrates a proper result. What displayed in this figure are the results of the simulated and measured of proposed antenna, with all the four diodes are “on-state” (Ant. 1) and all the four diodes are “off-state” (Ant. 2). According to these outcomes, it is identified that the different physical antenna sizes (area) for Ant. 1 is slightly larger than for Ant. 2. In the other words, the operating frequency of the first configuration is slightly lower than that of the second one. (See Fig. 3). The difference between the simulated and measured results for Ant.1 is due to the use of wire instead of perfect short circuit.

Fig. 4 shows the return loss of the antenna for circular polarization, too. Good impedance matching in resonance frequency is specified.

The axial ratio is the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components of equal amplitude (and 90 degrees out of phase). Because the components are equal magnitude, the axial ratio is 1 (or 0 dB). In addition, the axial ratio tends to degrade away from the main beam of an antenna, so the axial ratio may be indicated in a spec sheet (data sheet) for an antenna as follows: "Axial Ratio: <3 dB for +30 degrees from mainbeam". This indicates that the deviation from circular polarization is less than 3 dB over the specified angular range. Fig. 5 shows the simulated axial ratio of the proposed antenna for CP and fig. 6 shows the simulated gain of the antenna for LP states, which is 2.5 dB. Table 2 gives the measured and simulated return loss, bandwidth, the axial ratio BW and gain of the antenna too.

The simulated impedance matching bandwidth, when RHC mode is 25.1%, while LHCP mode is 29.16%.

Also it is about 23% for linear polarization. It is noted that because of radiating two resonant modes for circular polarized case simultaneously, and only one resonant mode radiates for linear polarized, the bandwidth for CP is larger than that of LP.

The simulated radiation patterns are depicted in Fig. 7 for CP states. In accord with these results, evidently the antenna has a good agreement in the main beam of copolarization and cross-polarization. The simulated frequencies for the radiation patterns in the CP states were selected at the minimum axial ratio in the operating bandwidth. Results show that broadside radiation patterns with good LHCP, and RHCP characteristics obtained at the resonant frequency.
TABLE II
Return loss, Bandwidth, Axial ratio BW and Gain results of four different antenna configuration

<table>
<thead>
<tr>
<th></th>
<th>Diode 1</th>
<th>Diode 2</th>
<th>Diode 3</th>
<th>Diode 4</th>
<th>Bw[%] Sim.</th>
<th>Bw[%] Mea.</th>
<th>Axial ratio BW[%]</th>
<th>Gain[dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant. 1</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>1.86</td>
<td>2.72</td>
<td>-</td>
<td>2.4</td>
</tr>
<tr>
<td>Ant. 2</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>2.21</td>
<td>2.67</td>
<td>-</td>
<td>2.69</td>
</tr>
<tr>
<td>Ant. 3</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
<td>On</td>
<td>2.08</td>
<td>2.18</td>
<td>2.48</td>
<td>2.5</td>
</tr>
<tr>
<td>Ant. 4</td>
<td>On</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
<td>2.91</td>
<td>2.68</td>
<td>2.48</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Fig. 7. Simulated radiation patterns of the proposed antenna for circular polarization at (a) Ant. 3 and (b) Ant. 4.

4. Conclusion
This paper investigates a reconfigurable single-feed antenna with polarization diversity suitable for wireless local area network (WLAN) application. Unlike the conventional switchable polarizations studied in another literature, the proposed antenna was designed with stubs on top of the antenna and can be switched by the PIN diodes for two frequency modes in linear polarization, as well as for LHCP and RHCP in circular polarization. All of the simulated results agree to confirm the validity of our used models.

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References