Reconfigurable Circular Microstrip Patch Antenna with Polarization and Pattern diversity using PIN Diodes for WLAN

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Abstract: A novel single feed reconfigurable circular microstrip patch antenna with polarization and pattern diversity using PIN diodes has been proposed. Reconfiguration is achieved by exciting the antenna with $\text{TM}_{11}$, $\text{TM}_{21}$ mode using six PIN diodes. Using the different configurations of diode, polarization diversity that is linear polarization and circular polarization and pattern diversity like conical pattern and omni directional pattern can be obtained. When all diodes are in OFF state, antenna excites two orthogonal modes simultaneously with equal and 90\degree out of phase, giving circular polarization with broadside radiation pattern. Whereas when all diodes are in ON state antenna radiates $\text{TM}_{21}$ mode giving conical radiation pattern with linear polarization. When only one diode D6 is OFF, antenna radiates monopole like radiation pattern with linear polarization. Whereas when diode D1 is ON antenna radiates broadside radiation pattern with linear polarization.

Keywords: Reconfigurable Antenna, Polarization diversity, Pattern diversity, PIN diode.

1. Introduction

The space available in electronic devices for antenna installation is very limited, and it is difficult to install multiple antennas at a single terminal. Additionally, there are also the issues like degradation of the internal circuitry, and mutual coupling of antenna signal. Such problems can be avoided by using reconfigurable antenna. The motivation for implementing reconfigurable properties in an antenna in general is straightforward – the acquisitions of new capabilities that eliminate the need for multiple antennas and/or that provide additional degrees of operational freedom that expand system performance [1]. This is the main heading of the paper. Reconfigurability can be implemented in many ways like space, frequency, polarization, and pattern. Polarization reconfigurable antennas are capable of switching between different polarizations modes. Polarization mode like horizontal, vertical and circular can be used to reduce polarization mismatch losses that are multipath fading in portable devices. Pattern diversity antenna are implemented to avoid the interference and to provide large coverage area and can switch between different patterns like broadside, conical, omnidirectional. Microstrip antennas are particularly good candidates for achieving reconfigurability. It is because of its well-defined ground planes and planar structures. Planar structures present clear opportunities for integration of a number of popular reconfigurable mechanisms (including switches and tunable materials) and their associated control circuitry. Additionally, since most microstrip antennas operate
in resonance and their operation is well modeled and well understood, an informed designer can manipulate the antenna structure and composition in different ways to achieve a variety of reconfigurable properties.

2. Related Works

As the requirement towards the development of multifunction wireless and satellite communications systems, reconfigurable antennas must fulfill the demands with multiple frequency operation that is frequency reconfigurability and/or multiple polarization and/or pattern diversity capabilities. Different methods can be implemented to achieve the different type of reconfigurability using microstrip antenna. Polarization diversity is achieved by using lattice structure and five PIN diodes [2]. A magneto-electric antenna is able to radiate four state of polarization [3]. By using modified mushroom structure; dual-band dual-mode polarization is proposed [4]. But, reconfigurations of antenna using PIN diodes have always been an attractive choice for the researchers. Especially in the field where cheap, low profile, light weight and easy to fabricate structures are desired such as in Wireless or Mobile communication. By using four PIN diodes and array of antenna polarization as well as conical beam pattern is achieved [5-6]. By using different configurations of diodes and different antenna structures, various polarizations are achieved [6-10]. The literature review indicates that the reconfiguration is only achieved using complex antenna structures or by using complex feed network. If both the polarization and pattern diversity is to be achieved in a single antenna structure the design becomes more complex. This motivates us for designing the simple structure for circular reconfigurable antenna. Also, the effect of PIN diode on the resonating frequency is required to be studied further. In this paper reconfigurable microstrip antenna with polarization and pattern diversity using PIN diode have been proposed. In order to radiate the circular polarization it is necessary to excite two orthogonal modes simultaneously with equal and 90° out of phase. This can be achieved by slightly perturbing a patch at appropriate location with particular area [11]. Microstrip antenna radiates the conical pattern if it is excited with the higher modes [12]. That is by increasing the size of the antenna different patterns can be radiated. HFSS 11 software is used to simulate the antenna and ‘Antenna measurement system’ is used to test the radiation patterns of fabricated antenna. The antenna structure is designed and fabricated. The results of simulation and results of actually fabricated antenna are studied and compared. The paper is organized as follows. Section III of this paper deals with the proposed methodology of antenna design. Section IV describes the antenna structure and other aspects for diversity. Section V discusses the results and finally section VI concludes the paper.

3. Methodology

The innovative circular antenna structure with a front view and back view are shown after fabrication in Figure 1 and Figure 2 respectively. Figure 1 and Figure 2 indicates the PIN diode and its biasing implementation on antenna respectively. Various design parameters of antenna are given below in Table 1 which includes the resonating frequency, dielectric constant, the dimensions of the substrate etc. The antenna is printed on the 1.6 mm thick FR4 substrate, which has a relative permittivity of 4.4 and loss tangent of 0.02. Circular microstrip patch antenna shown in Figure 3 indicates that two circular ring patch is used. The PIN diodes are placed along the circular patch to achieve polarization
and pattern reconfigurability. The polarization and pattern diversity can be achieved using the following configurations. The positions of the PIN diodes are shown as the diode switches SW1, SW2, SW3, SW4, SW5 and SW6. The four configurations are shown below for getting circular polarization, linear polarization, omnidirectional pattern, conical pattern. They are called as ANT1, ANT2, ANT3 and ANT4.

Table 1. Design parameters for Antenna

<table>
<thead>
<tr>
<th>Sr.</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frequency</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>2</td>
<td>Dielectric constant of substrate</td>
<td>FR4 (4.4)</td>
</tr>
<tr>
<td>3</td>
<td>Height of the substrate</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>4</td>
<td>Radius of Circular patch</td>
<td>17.1 mm</td>
</tr>
<tr>
<td>5</td>
<td>Slot length</td>
<td>8 mm</td>
</tr>
<tr>
<td>6</td>
<td>Slot width</td>
<td>3 mm</td>
</tr>
<tr>
<td>7</td>
<td>Outer radius of Inner Ring patch</td>
<td>23.8 mm</td>
</tr>
<tr>
<td>8</td>
<td>Inner radius of Inner Ring patch</td>
<td>17.5 mm</td>
</tr>
<tr>
<td>9</td>
<td>Outer radius of Outer Ring patch</td>
<td>28.9 mm</td>
</tr>
<tr>
<td>10</td>
<td>Inner radius of Outer Ring patch</td>
<td>24.5 mm</td>
</tr>
</tbody>
</table>

Figure 1: Fabricated Antenna Front Side
3.1 Configuration for circular polarization (ANT1)

In the first configuration all PIN diodes are in OFF state. This configuration is nothing but the inner circular patch antenna with rectangular slot on it. Due to this rectangular slot perturbation circular patch antenna radiates circularly polarized wave with broadside radiation pattern.

3.2 Configuration for linear polarization (ANT2)

When the perturbation slot is filled with ON state PIN diode switch (SW1), it radiates linearly polarized wave. Here the radiation is broadside.

3.3 Configuration for getting omnidirectional radiation pattern (ANT3)

Switching diode SW1, SW2, SW3, SW4 and SW5 to ON state, it will connect inner circular ring patch to the inner circular patch. This will increase the radius of the circular patch. The effective radius of the circular patch is 23.8 mm. In this configuration equivalent magnetic vector along the edges forms a magnetic loop, thus a monopole like radiation that is omnidirectional radiation pattern is generated.

3.4 Configuration for getting conical radiation pattern (ANT4)

By turning all diodes SW1, SW2, SW3, SW4, SW5 and SW6 in ON state, the outer circular ring patch gets connected to its inner circular ring patch and to the inner circular patch. Now the effective radius of the resulting circular patch is such that it excites $T_{21}$ mode. The antenna radiates conical pattern. The effective radius of the circular patch is now 28.98 mm.

4 Antenna Design

This section describes the designs of the dimensions of patch radius.
4.1 The calculation of the radius of the circular patch

Considering the resonating frequency of the antenna as 2.4 GHz, we have implemented it on 1.6 mm thick substrate of relative permittivity 4.4 with loss tangent 0.002. The radius of the circular patch is calculated, by the formula given by equation 1 [13],

\[
f_0 = \frac{1.8412 \cdot C}{2\pi a \sqrt{\varepsilon_r}}
\]  

(1)

Where,

\(a\) = Radius of the circular patch

\(f_0\) = Resonance frequency of Circular Microstrip Patch Antenna (CMPA).

\(C\) = Velocity of light in free space = \(3 \times 10^8\) m/s.

\(\varepsilon_r\) = Dielectric constant of the substrate = 4.4

Putting the values of the constants in above equation, the radius of the circular patches calculated as 17.1 mm.

4.2 Rectangular slot dimensions calculation

The rectangular slot dimensions are calculated according to the perturbation needed to excite circularly polarized wave. Single feed circular microstrip patch antenna generally radiates linear polarization. Hence, with no rectangular slot, the circular patch antenna will radiate linearly polarized wave. To excite it to radiate circular polarization, we have to generate two orthogonal patch modes with equal amplitude and in-phase quadrature. Equation 2 and 3 indicates the two orthogonal modes with equal magnitude and in-phase quadrature. To achieve two orthogonal modes, it is necessary to slightly perturb a patch at appropriate location with respect to the feed. Because of the proper perturbation segment, frequency response of the mode 2 will get detune such that at the operating frequency \(f_0\), the amplitude is same but phase will be 90° shifted with respect to mode 1,

\[
f_a = f_0 \left(1 + 0.4185 \frac{\Delta s}{s}\right) \quad (2)
\]

\[
f_b = f_0 \left(1 - 0.4185 \frac{\Delta s}{s}\right) \quad (3)
\]

\(f_0\) = Resonating frequency

\(\Delta s\) and \(f_0\) = Shift in resonating frequency

Percentage of perturbation segment,

\[
\left|\frac{\Delta s}{s}\right| = \frac{1}{X_{11}Q_0} \quad (4)
\]
First root of the derivative of the Bessel function of order one, $X_{11} = 1.84$ at fundamental $TM_{11}$ mode. 

Unloaded $Q$ factor of patch, $Q_0 = 14$ at $h=1.6$ mm.

$$\left| \frac{\Delta f}{f} \right| = 3\% \quad (5)$$

From equation 5, we can conclude that to radiate two orthogonal modes, antenna structure need to be perturbed by three percentages.

**4.3 Calculation of dimensions of the outer rings**

Dimensions of inner circular ring patch and outer circular ring patch are calculated to excite higher order modes. The fundamental mode $TM_{11}$ of the circular microstrip antenna radiates a broadside radiation pattern. The resonating frequency at mode $TM_{11}$ is given by equation 1. The higher order mode $TM_{21}$ radiates conical pattern with null at broadside especially 2 lobe pattern [11].

At $TM_{21}$ mode the resonating frequency of circular patch antenna is given by equation 6,

$$f_0 = \frac{3.05424 C}{2\pi a \sqrt{\varepsilon_r}} \quad (6)$$

$a$ = Radius of the circular patch 

$f_0$ = Resonance frequency of Circular microstrip patch Antenna = 2.4 GHz 

$C$ = Velocity of light in free space = $3 \times 10^8$ m/s. 

$\varepsilon_r$ = Dielectric constant of the substrate. = 4.4 

From equation 6, we can observe that to excite higher order mode $TM_{21}$, the radius of the patch should be 28.98mm.

Radius of the patch at $T_{11}$ mode found is $a = 17.1$ mm

Radius of the patch at $T_{21}$ mode found is, $a = 28.98$ mm

**5. Results and Discussion**

HFSS 11 software is used to simulate the antenna. It is tested on VNA (Vector Network Analyzer) to verify the resonating frequency and AMS (Antenna Measurement system) is used to test the radiation patterns of antenna. The four configurations of the proposed antenna are tested in the simulation environment first. When the reflection coefficient is lowest, the most of the energy is radiated and very less energy gets reflected. This indicates that the antenna resonates at this frequency. Figure 3
and Figure 4 indicate the result for simulated value of $S_{11}$ and axial ratio for all four configurations. It can be seen from the graph of $S_{11}$ that the value of $S_{11}$ is the lowest for the resonating frequency. The resonating frequencies obtained for all configurations namely ANT1, ANT2, ANT3 and ANT4 are 2.3625GHz, 2.3625GHz, 2.3875GHz and 2.4375GHz respectively. All these values of resonating frequencies in the simulation environment are found to be close to 2.4 GHz. It can be seen from the Figure 4 that the axial ratio for ANT1 is below 3dB giving circular polarization while it is higher than 3 dB for ANT2, ANT3 and ANT4.

![Figure 3: Simulated resonating frequency](image1)

![Figure 4: Simulated axial ratio](image2)

5.1 Results for Configuration ANT1

In the first configuration of antenna namely ANT1, rectangular slot on circular patch is open. We have used energy measurements and energy patterns for co and cross-polarization. Figure 5 indicates the co polarization and cross polarization pattern for this configuration. The observed experimental receiving power for co and cross polarized wave is -25 dB and -26 dB respectively. Here, two orthogonal modes get excited with equal amplitude and 90 degrees out of phase. This indicates that the antenna is radiating circularly polarized wave. The confirmatory test for circular polarization is
value of axial ratio. For a circular polarization mode ANT1, the axial ratio is close to 1 and for all other configurations, it is higher indicating linear polarization as shown in Figure 4.

![Figure 5: Experimental Co and Cross polarization ANT1](image)

5.2 Results for Configuration ANT2

Figure 6 shows the co polarization and cross polarization pattern for second configuration of antenna ANT2. Here, the switch SW1 is closed that is diode is in ON state. As the measured receiving power of co and cross polarized wave is -25 dB and -40 dB respectively, it indicates that the antenna is radiating linearly polarized wave. The axial ratio is much higher indicating linear polarization. The result obtained in this configuration gives linearly polarized wave just by switching only one diode on. Also the pattern is remaining same that is broadside radiation. So polarization diversity has achieved with less complex structure.

![Figure 6: Experimental Co and Cross polarization ANT2](image)
5.3 Results for Configuration ANT3

In this configuration the radius of circular patch has increased due to inclusion on inner ring patch. Due to which equivalent magnetic vector along the edges formed a magnetic loop, thus a monopole like radiation that is omni directional radiation pattern is generated. Figure 7 and Figure 8 are simulated and practical omni directional radiation patterns obtained.

![Simulated Omnidirectional Pattern ANT3](image)

**Figure 7: Simulated Omnidirectional Pattern ANT3**

![Radiation Pattern ANT3](image)

**Figure 8: Radiation Pattern ANT3**

5.4 Result of configuration ANT4

In this configuration due to increase in the radius of patch, $T_{21}$ mode is excited. Figure 9 and Figure 10 are simulated and practical radiation patterns obtained respectively. It is observed that the antenna is radiating conical pattern.
Table 2 indicates the practical result of antenna for four configurations. Table 3 summarizes the result for polarization and pattern diversity.

Table 2. Antenna configuration and result

<table>
<thead>
<tr>
<th>Antenna Config.</th>
<th>Biasing of PIN diode</th>
<th>Fr (GHz)</th>
<th>Radiation Pattern</th>
<th>Co-pol (dBm)</th>
<th>Cross-pol (dBm)</th>
<th>Axial Ratio (dB)</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All OFF (ANT1)</td>
<td>1.98</td>
<td>Broadside</td>
<td>-25</td>
<td>-26</td>
<td>0.91</td>
<td>Circular</td>
</tr>
<tr>
<td>2</td>
<td>D1 ON (ANT2)</td>
<td>1.96</td>
<td>Broadside</td>
<td>-26</td>
<td>-40</td>
<td>14</td>
<td>Linear</td>
</tr>
<tr>
<td>3</td>
<td>D1, D2, D3, D4, D5 ON (ANT3)</td>
<td>2.8</td>
<td>Omni directional</td>
<td>-43</td>
<td>-36</td>
<td>9</td>
<td>Linear</td>
</tr>
<tr>
<td>4</td>
<td>D1, D2, D3, D4, D5, D6 ON (ANT4)</td>
<td>2.8</td>
<td>Conical</td>
<td>-37</td>
<td>-45</td>
<td>8</td>
<td>Linear</td>
</tr>
</tbody>
</table>
Table 3. Antenna configuration for polarization and pattern diversity

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Polarization</th>
<th>Radiation Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>All diode OFF (ANT1)</td>
<td>Circular</td>
<td>Broadside</td>
</tr>
<tr>
<td>Switch 1 ON (ANT2)</td>
<td>Linear</td>
<td>Broadside</td>
</tr>
<tr>
<td>Switch 1,2,3,4,5 ON (ANT3)</td>
<td>Linear</td>
<td>Omnidirectional</td>
</tr>
<tr>
<td>Switch 1,2,3,4,5,6 ON (ANT4)</td>
<td>Linear</td>
<td>Conical</td>
</tr>
</tbody>
</table>

5.5 Effect of PIN diode capacitance and inductance on resonating frequency of antenna

PIN diode SMP 1322 is used as a switch having $L_s = 1.5 \text{ nH}$ during on state and $C_T = 1 \mu\text{F}$ during off state. It can be observed from Figure 3 that when all diodes are in off state (ANT1) or when only one diode SW1 is on (ANT2), the resonating frequency has shifted to 1.96 GHz. This shift is mainly due to the capacitance of five switches, where each switch capacitance lowers the frequency by 3.5% [14]. So the total shift observed is of 17.5 %, resonating antenna at 1.96 GHz. When all diodes are on (ANT4) or when five diodes are on (ANT3), inductance of each diode comes in parallel, increasing the resonating frequency to 2.8 GHz [15].

6. Conclusions

Reconfigurable Circular Microstrip Patch Antenna with Polarization and Pattern diversity using only six PIN diodes for WLAN communication is proposed. Polarization diversity is achieved as Circular polarization ($Ax = 0.91 \text{ dB}$) with broadside radiation pattern and Linear polarization ($Ax = 14 \text{ dB}$) with broadside radiation pattern. Pattern diversity is achieved as omnidirectional radiation pattern ($Ax = 9 \text{ dB}$) and conical radiation pattern ($Ax = 8 \text{ dB}$). As only six PIN diodes are used, the design is very simple giving four configurations with less cost.

References


