The Design of the X-Circular Polarized Microstrip Patch Antenna with Slanted Rectangular Slot by Using A Single Port At Frequency 2.4GHz

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Abstract: This paper presents the design and investigation of the single circular patch with slanted rectangular slot and the X-circular polarized microstrip patch antenna with slanted rectangular slot by using a single port at frequency 2.4GHz. It’s called “X” because the design structure of transmission line in X-form. The ±45° feed of transmission line using two stage quarter wave transformer impedance matching techniques. All the designs were simulated using Microwave CST software with dielectric constant, εr = 4.3, tan δ = 0.019 and the thickness FR-4 substrate, t= 1.6mm. The antenna radiated the circular polarization radiation at every patch. The X-circular polarized shows 90% efficiency at frequency 2.4GHz. The axial ratio bandwidth is 215.35MHz with the gain of 2.1dB.

Key words: Circular patch • Circular polarization • X-circular polarized

INTRODUCTION

In the development of wireless communication systems have been rapidly growing in recent years with increasing demand in the level of enhancement and performance. The advantages of microstrip antennas are light weight, low profile, easy to integrate with active circuit and easy to mount structures [1]. There are a few types of polarization such as linear polarization, circular polarization and x-polarization. To get a linear polarization are using a method of coupled patch [2], slot [3] and single feed method [4]. The circular polarization is the common polarization schemes used in current wireless communication systems such as radar and satellite systems. While, the advantages of the circular polarization are allowing for greater flexibility in orientation angle between transmitters and receivers compared to the linear polarization, better mobility, weather penetration, reduction in multipath reflections and other kinds of abilities of anti-interferences [1] [5].

There are some methods have been proposed by [6] [7] [8] to realize the circular polarization antenna. In [6] is using a double layer method to get broad bandwidth and they used a Wilkinson power divider to get the circular polarization radiation. In [7] also using a double layer method, a ring slot and a parasitic patch to broad the bandwidth around 5% to 45% by adjusting the distance between the wide slot and the parasitic patch. In [8] is cutting a symmetrical slit in a diagonal direction into the square patch to obtain the circular polarized radiation. However, the x-polarization proposed in [9] where the dual polarization transmits through a single port and printed array microstrip antenna at ±45° feed of transmission line using a quarter wave transformer impedance matching techniques. However, the bandwidth achieved is 100MHz and the gain obtained is 7.9dB. Commonly to obtain circularly polarized radiation, the author using a dual feed antenna. The single feed configuration reduced the fabrication complexity, antenna weight and RF losses reported in [10].
From the literature review, there is no circular polarized antenna design in X-form for MIMO application at 2.4GHz. In this paper, the proposed antenna is designed at 2.4GHz frequency and able to produce the circular polarization radiation in the X-form. The circular polarization is obtained by connecting the single circular patch with +45° rectangular slots to the X-transmission lines. The main advantage of using circular polarization is that regardless of receiver orientation, it will always receive a component of the signal due to the resulting wave with an angular variation reported in [11]. Design details of the antenna together with the measured and the simulated results are provided in Antenna Design section and Results and Discussion section respectively. Finally, a conclusion is presented in the Conclusion section.

**MATERIALS AND METHODS**

Figure 1 shows the geometry of a single circular patch with +45 rectangular slot microstrip patch antenna. In general, an approximate original value for the radius of circular patch is given by equation as follows [12] [13].

\[
f_r = \frac{1.841 \times c}{2 \pi \epsilon_{r_{eff}}}
\]

\[
r_{eff} = a \left( 1 + \frac{2h}{\pi a \epsilon_r} \left[ \ln \left( \frac{\pi a}{2h} \right) + 1.7726 \right] \right)
\]

where \(f_r\) is the resonant frequency, \(c\) is the velocity of light, \(r_{eff}\) is the effective radius, \(\epsilon_r\) is the effective dielectric constant, \(a\) is the actual radius and \(h\) is the dielectric height. The antenna consists of dielectric substrate FR4 with thickness \(h=1.6\)mm, relative permittivity, \(\epsilon_r=4.4\), loss tangent, \(\tan \delta=0.019\). The patch and ground are placed at the top and bottom of substrate respectively. The slanted +45° rectangular slot is placed at the center of the circular patch and it consists the length of the slot, \(L_s=15.6\)mm and width of slot, \(W_s=1.2\)mm. A 50Ω SMA port is used as a feeding structure and connected to the feeding line consists length of feedline, \(L_f=16\)mm and width of feedline, \(W_f=3\)mm. The fabricated circular polarization antenna from an optimized design of the simulation is shown in Fig. 1 (b). By adjusting \(L_s\) and \(W_s\), it helps to improve the results of S11, gain and axial ratio. This has resulted circular polarization, where the axial ratio is less than 3dB.

After completing designed the single circular patch with +45° rectangular slot, next is designed the X-circular polarized microstrip patch antenna shown in Fig. 2. The 4 elements of the single circular patch with +45 degree rectangular rotated at 45°, 135°, 225° and 315°. All circular patches are connected with 4 different transmission lines. Then, all the transmission lines are combined and connected with 50Ω SMA coaxial probe at the center of the antenna. In order to improve the transmission line between feed probe and circular patch, the double stage quarter wavelength binomial transformer is implemented. Diameter of patch, \(D\) is 32mm, length, \(L_s\) and width, \(W_s\) of 50Ω feedline is 43.7mm and 3mm respectively. Length of slot, \(L\), and width of the slot, \(W\) is same with Section A. The width of 1st stage quarter wavelength \(W_{m1}\) is 1.1mm, the width of 2nd stage quarter wavelength \(W_{m2}\) is 2.27mm and \(W\) is 1.3mm. The length of
Fig. 2: (a) The X-circular polarized microstrip patch antenna structure, (b) fabricated antenna

$L_1$, $L_{m1}$, and $L_{m2}$ is 16mm. The material of the patch and the ground is copper (0.035mm). This has resulted circular polarization, where the axial ratio is less than 3dB.

**RESULTS AND DISCUSSION**

Table 1 and Figure 3 exhibits the study of the angle position of rectangular slot. The graph shows that the axial ratio is less than -3dB for an angle of 45° and 90°, which can produce the circular polarized wave. When the angle at position 45 degrees, the return loss is less than -30dB and the higher gain was produced. The maximum gain obtained at 45° is 6.35dB.

<table>
<thead>
<tr>
<th>Aslot (degree)</th>
<th>RL (dB)</th>
<th>3dB AR (dB)</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1.45</td>
<td>5.25</td>
<td>1.37</td>
</tr>
<tr>
<td>45</td>
<td>-37.99</td>
<td>2.58</td>
<td>6.35</td>
</tr>
<tr>
<td>90</td>
<td>-5.70</td>
<td>0.36</td>
<td>4.81</td>
</tr>
<tr>
<td>135</td>
<td>-2.07</td>
<td>3.69</td>
<td>2.97</td>
</tr>
</tbody>
</table>

Figure 4 shows the return loss results of simulation and measurement. The return loss result for simulation and measurement at frequency 2.4 GHz are -22dB and -16.8dB respectively. The measurement result shows the shifting of resonant frequency to 2.47GHz.

Figure 5 show the simulated gain is 6.79dB and the directivity is 7.56dBi at frequency 2.4GHz. The total efficiency at 2.4GHz is 1.75dB. Figure 6 presents the surface current distribution of the x-circular polarized antenna for simulation part. Apparently, the current is mostly distributed at the rectangular slot during the 0° phase and 90° phase. The rectangular slot is essential in order to ensure the surface current is rotating along the edge of the circular patch. The surface current movements illustrate that this antenna is a circular polarized antenna.

The impedance bandwidth is narrower than the axial ratio bandwidth as usual for microstrip antenna. The simulated axial ratio is presented in Figure 7. The obtained circular polarized bandwidth of 3dB axial ratio for 2.4GHz is 215.35MHz.
Fig. 5: 3D radiation pattern at frequency 2.4GHz

Fig. 6: Surface current distribution at frequency 2.4GHz

Fig. 7: The simulated axial ratio at frequency 2.4GHz

Fig. 8: Simulation and measurement of radiation pattern (H-field)
Figure 8 shows the simulation and measurement radiation pattern for H-field and E-field. The main lobe magnitude of simulated for the H-field is 6.8dB at 25°. The main lobe magnitude of measured for the H-field is -63.28dB at 260°.

Figure 9 shows the simulation and measurement radiation pattern for E-field. The main lobe magnitude of simulated for the E-field is 6.8dB at 25°. The main lobe magnitude of measured for the E-field is -59.09dB at 187°.

Table 2 shows the summary table of the single circular patch with slanted rectangular slot and the x-circular polarized microstrip patch antenna. There are consisting of return loss, bandwidth, gain, directivity, total efficiency and 3dB axial ratio bandwidth.

### CONCLUSION

The design of the single circular patch with +45° rectangular slot and x-circular polarized with the slanted rectangular slot antenna at frequency 2.4GHz have been presented with all antennas parameters of simulated and measured results. The antenna is simulated using Microwave CST software. The x-circular polarized can generate 4 circular radiations with a good total efficiency and 3dB axial ratio bandwidth. Further investigation can be done on the function of this antenna to the polarization diversity effect on wireless MIMO application.

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### REFERENCES