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Circularly Polarized Monopole Antenna Using CRLH TL Feed Network

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Abstract—A circularly polarized (CP) monopole antenna with the feed network designed based on using composite right/left-handed transmission line (CRLH TL) is proposed. The CP antenna consists of two monopole elements, a 90°-phase shifter implemented using a CRLH TL unit cell and a Wilkinson power divider. The two monopole elements are designed to operate at a frequency of about 2.3 GHz and placed in perpendicular to each other to generate two orthogonal electric fields. The power divider divides the input signal into two signals with equal amplitude and phase. One of the signals is fed to a monopole element via the phase shifter, while the other signal is fed directly to the other monopole element. The two signals at the corresponding monopole elements are therefore in phase quadrature, hence generating a CP signal. Simulation results show that the antenna has an impedance bandwidth (S11 < -10 dB) of 1.89-3.20 GHz and a wide axial-ratio bandwidth (AR < 3 dB) of 2.08-2.36 GHz.

Keywords— circularly polarized, CRLH, monopole, phase shifter, WLAN

I. INTRODUCTION

Circularly polarized (CP) antennas have many advantages such as mitigating polarization mismatching and avoiding multi-path interference for mobile communication systems. Due to the increasing demands for high-speed communications systems, impedance bandwidth and axial ratio bandwidth (ARBW) are becoming important factors in the design of CP antennas. Very often, CP antennas are designed using slot antennas or patch antennas. However, slot antennas and patch antennas theoretically have the disadvantages of larger sizes and less bandwidths compared with those of monopole antennas which therefore have a great potential to be used for the design of CP antennas.

In this paper, a CP antenna employing of two monopole elements as radiators is proposed. The feed network to the monopole elements is composed of a Wilkinson power divider and a phase shifter. In [10], it was shown that a phase shifter designed using CRLH TL unit cells could achieve a wider operating bandwidth [10], thus the phase shifter used in our proposed CP monopole antenna is designed and implemented using a composite right/left-handed transmission line (CRLH TL) unit cell. The objective of the studies is to demonstrate that a wider ARBW can be achieved if the phase shifter of the CP antenna is designed using a CRLH TL unit cell. The study of the proposed CP antenna is carried out using the EM simulation tool CST. Simulation results show that the proposed CP antenna has a wider ARBW than those CP antennas studied in [1-9]. The simulated results on the reflection coefficient, AR, radiation pattern, and realized boresight gains are presented in this paper.

II. ANTENNA DESIGN

The layout of the proposed CP monopole antenna is shown in Fig. 1, which consists of two simple monopole elements with microstrip-lines fed. The monopole elements have a length of $\lambda_g/4$, where $\lambda_g$ is the guide wavelength at the operating frequency of about 2.3 GHz. The feed network is composed of a Wilkinson power divider which divides the input signal into two signals with equal power and same phase. The two arms of the Wilkinson power divider are $Z_0/4$ transformers, having a characteristic impedance of 1.414$\times Z_0$. At the outputs of the Wilkinson power divider, a chip resistor with a value of 100 $\Omega$ is used to connect the terminals together [11]. One of the signals from the power divider is directly fed to the monopole element on the left of the CP antenna via the 90°-phase shifter, as shown in Fig. 1(a), while the other signal is fed to the other monopole element on the right via a feed line. The microstrip-feed lines have a characteristic impedance of 50 $\Omega$. The 90°-phase shifter is implemented using a CRLH TL unit cell which has a series of inter-digital fingers to realize the series capacitance and two centrosymmetrical vias shunted to ground on the other side of the substrate to realize the shunt
inductance in the equivalent circuit given in [10]. By adjusting
the length of the inter-digital fingers and the distance between
the fingers, the unit cell can be designed to produce the
required phase shift of about 90° [10]. The feed line on the
right of the antenna, due to the propagation delay, will also
introduce some phase shift to the signal, so the feed network as
a whole is designed in such a way that the signals arriving at
the corresponding monopole elements will be in quadrature
phase, with the signal to the monopole element on the left
leading the phase by 90°. As the two monopole-antenna
elements are placed in perpendicular to each other, the CP
antenna will generate a left-handed (LH) CP signal. The CP
antenna is designed on a substrate with an area of 80×56 mm²,
a relative permittivity of 3.66 and a loss tangent of 0.04 using
the EM simulation software tool CST. The dimensions of the
final design are listed in Table I.

Table I. Optimized Dimensions of Proposed Antenna (mm)

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<tr>
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<tbody>
<tr>
<td>L1</td>
<td>11.5</td>
<td>L6</td>
<td>3.0</td>
<td>L11</td>
<td>3.2</td>
<td>Lg</td>
<td>55.0</td>
</tr>
<tr>
<td>L2</td>
<td>2.8</td>
<td>L7</td>
<td>11.9</td>
<td>L12</td>
<td>31.9</td>
<td>g1</td>
<td>1.0</td>
</tr>
<tr>
<td>L3</td>
<td>6.0</td>
<td>L8</td>
<td>2.0</td>
<td>L13</td>
<td>5.5</td>
<td>g2</td>
<td>0.3</td>
</tr>
<tr>
<td>L4</td>
<td>3.0</td>
<td>L9</td>
<td>6.9</td>
<td>L14</td>
<td>36.0</td>
<td>W1</td>
<td>1.8</td>
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<tr>
<td>L5</td>
<td>4.5</td>
<td>L10</td>
<td>0.8</td>
<td>Ls</td>
<td>80.0</td>
<td>W2</td>
<td>0.9</td>
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<tr>
<td>L6</td>
<td>0.8</td>
<td>Ws</td>
<td>56.0</td>
<td></td>
<td></td>
<td>hs</td>
<td>0.8</td>
</tr>
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III. Simulation Results and Discussions

The simulated S11 and axial ratio (AR) of the proposed
monopole CP antenna are shown in Fig. 2. It can be seen that
the antenna has several resonances at the frequencies of about
2.0, 2.63 and 3.04 GHz, which lead to a wide impedance
bandwidth (for S11<−6 dB) from 1.89 to 3.2 GHz (1.31 GHz,
51.4%). It is shown later that, with the value of S11<−6 dB, the
radiation efficiency is above 70%. The simulated ARBW is
from 2.08 to 2.36 GHz (0.28 GHz, 12.6%) which is narrower
than the impedance bandwidth from 1.89 to 3.2 GHz, so the
ARBW determines the operation bandwidth of the CP antenna.
Within the ARBW, the simulated S11 is between −8 to −9 dB.

The simulated radiation patterns in co-polarization (which is RHC)
and cross-polarization (which is LHCP) at 2.2 GHz
(the center frequency of the ARBW) are shown in Fig. 3. Note
that as the antenna is designed to be in LHCP, for an observer
in the direction of propagation, co-polarization is clockwise
circular and cross-polarization is anti-clockwise. The clockwise
circular looking into the antenna from the +x direction is co-
polarization, but looking into the antenna from the −x direction
becomes cross-polarization. Fig. 3 shows that the radiation
pattern in co-polarization is directional pointing at the +x direction,
but there is no null at the −x direction. The radiation
pattern in cross-polarization has a null at the +x direction,
and points at the −x direction. These results indicate that the peak
gain of the radiation pattern is not pointing at the boresight
direction. Thus more studies have been carried out on the 3D
radiation patterns and results are shown in Fig. 4. It can be seen
that the radiation pattern has a peak gain at θ= 120° and φ=15°
in LHCP.

The simulated realized boresight gains in co-polarization
and cross-polarization are shown in Fig. 5. It can be seen that,
within the frequency band for AR < 3 dB, the boresight gain in
coopolarization is from -1.3 to -2.5 dBi across the ARBW,
while the gain in cross-polarization is lower than -16 dBi. The
radiation efficiency is above 70% in the ARBW.

Finally, the ARBW of the proposed CP antenna is
compared with some of the other antennas in [1-9] in Table 1.
It can be seen that the proposed antenna has a much larger
ARBW.

Fig. 1. Geometries of proposed antenna: (a) top view (b) side view (c)
bottom view (metal on top layer, metal on bottom layer)
Fig. 2. Simulated S11 and AR

Fig. 3. Simulated radiation patterns at 2.2 GHz (co-polarization – , and cross-polarization – )

Fig. 4. 3D radiation pattern in LHCP

Fig. 5. Simulated efficiencies and gains of co-polarization and cross-polarization

TABLE II. COMPARISON WITH OTHER ANTENNAS IN [1-9]

<table>
<thead>
<tr>
<th>Ref</th>
<th>Center Frequency (GHz)</th>
<th>ARBW (%)</th>
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<tbody>
<tr>
<td>[1]</td>
<td>2.26</td>
<td>0.84</td>
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<tr>
<td>[2]</td>
<td>2.19</td>
<td>2.1</td>
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<tr>
<td>[3]</td>
<td>2.41</td>
<td>0.5</td>
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<td>[4]</td>
<td>1.53</td>
<td>0.75</td>
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<td>[5]</td>
<td>2.45</td>
<td>3.3</td>
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<tr>
<td>[6]</td>
<td>10.1</td>
<td>0.8</td>
</tr>
<tr>
<td>[7]</td>
<td>2.47</td>
<td>2.0</td>
</tr>
<tr>
<td>[8]</td>
<td>2.44</td>
<td>0.82</td>
</tr>
<tr>
<td>[9]</td>
<td>1.59</td>
<td>6.3</td>
</tr>
<tr>
<td>Proposed antenna</td>
<td>2.22</td>
<td>12.6</td>
</tr>
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IV. CONCLUSIONS

A CP monopole antenna with the feed-network based on using CRLH TL has been presented. The antenna consists of two monopole elements as radiators, a feeding network using the Wilkinson power divider, and a 90°-phase shifter implemented using CRLH TL unit cell. Simulated results have showed that the proposed antenna has an ARBW from 2.08 to 2.36 GHz, radiation efficiency of above 70%.

REFERENCES


