Design of Circular Polarized Antenna by Using Inverted Suspended Circular Patch Design for WLAN Application at 2.4 GHz

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Abstract. In this paper, an inverted suspended circular patch antenna with circular polarization is proposed for wireless local area network (WLAN) operating at 2.4 GHz frequency. The antenna was designed based on inverted suspended circular patch with an air gap between substrate and ground plane layer at distance of 10 mm. L-probe technique is used in this antenna design in order to feed the signal from SMA probe to the feedline of the circular patch structure. The design and simulation process are done by using Computer Simulation Technology (CST) software. Antenna performances in term of return loss, resonant frequency, bandwidth, gain, directivity, axial ratio, total efficiency and radiation pattern at 2.4 GHz frequency are discussed. The comparison result of simulation and measurement show that the proposed circular polarized antenna obtained bandwidth more than 100 MHz with gain and return loss achieved more than 5 dB and -13 dB at 2.4 GHz.

1. Introduction

Microstrip patch antennas are popular structures in modern wireless communication system as they are compact in nature. However, in their basic form (rectangular, circular or triangular) it normally provides linear polarization, but by certain modification to the basic antenna geometry or feed it can provide circular polarization (CP). These modifications comprise modifying of the basic patch with one or more feeds, feeding the patch from its corner along the diagonal, feeding the patch at adjacent sides, trimming the corners of a square patch [1,2] and cutting a slot inside the patch [2,3].

Circular polarization is regarded as the well-known polarization schemes applied in current wireless communication system for example satellite, radar and navigation system, mainly because it can offer better mobility and weather penetration than linear polarization [4,5]. However, microstrip patch antenna is constrained with narrow bandwidth and low gain. In order to overcome this problem, a few modifications need to be done are included adding slot [6-8], fed by L-strip [9-11] and others. In this paper, L-probe technique was used for the antenna design where the antenna having a circular polarization axial ratio and high gain at 2.4 GHz frequency which is for WLAN application.
2. Antenna Design

In this paper, the antenna was designed by using FR4 substrate with thickness, \( h = 1.6 \) mm, dielectric constant \( \varepsilon_r = 4.4 \) and tangent loss, \( \tan \delta = 0.019 \). The thickness of copper, \( t = 0.035 \) mm. L-probe technique is used in this antenna design and the 50 ohm probe feed SMA type was used to feed the signal from feedline to the circular patch structure. The width (\( W_f \)) and length (\( L_f \)) of feedline is 3.1 and 12 mm respectively. The width and length of substrate and copper plate layer is similar which is 80 x 80 mm. The substrate and copper plate layer is separated by an air gap with 10 mm distance. The circular patch radius is initially calculated based on equation (1) and equation (2) but later been choose as 29 mm after optimization for the best result of parametric study. Effective radius of circle patch antenna can be calculated by using equation (3).

The actual radius of the circular patch can be obtained by

\[
R = \frac{F}{\sqrt{\left[1 + \frac{2h}{\pi \varepsilon_r} \right] \ln \left( \frac{2F}{\pi \varepsilon_r} + 1.7726 \right)}}
\]  
\( (1) \)

Where,

\[
F = \frac{8.791 \times 10^9}{f_c \sqrt{\varepsilon_r}}
\]  
\( (2) \)

The effective radius of the antenna is given by

\[
R_e = R \sqrt{1 + \frac{2h}{\pi R} \left[ \ln \left( \frac{R}{2h} \right) + 1.7726 \right]}
\]  
\( (3) \)

Where,

- \( R \) = radius of circle patch
- \( R_e \) = effective radius of circle patch
- \( f_c \) = operating frequency (GHz)
- \( h \) = thickness of substrate (mm)
- \( \varepsilon_r \) = dielectric permittivity of substrate

Figure 1 demonstrated the overall configuration and also the fabricated prototype for the antenna design. The front view of the inverted suspended antenna design is just an empty substrate as shown in Figure 1 (a), while at the back view having the circular patch with the feedline as shown in Figure 1 (b). Dimension of the inverted circular patch antenna is tabulated as in Table 1.

![Diagram of antenna design](image.png)
Figure 1. Fabricated structure of inverted suspended circular patch (a) front view (b) back view (c) vertical configuration view (d) prototype top view (e) prototype side view.

Table 1. Dimension of circular polarized inverted suspended circular patch antenna design.

| Design Parameter | Dimension (mm) | Description                        |
|------------------|----------------|------------------------------------|
| Air gap          | 10             | Air gap                            |
| h                | 1.6            | Thickness of FR4 substrate         |
| t                | 0.035          | Thickness of copper                |
| L_s              | 80             | Length of substrate & copper plate |
| L_f              | 12             | Length of feedline                 |
| W_s              | 80             | Width of substrate & copper plate  |
| W_f              | 3.1            | Width of feedline                  |
| R                | 29             | Radius of circular patch           |

3. Result and discussion
In this section, the antenna parameter which comprised of resonant frequency (f_r), return loss (RL), bandwidth (BW), gain, directivity, axial ratio and radiation pattern are analysed and discussed at 2.4 GHz frequency. Other than that, simulation and measurement result of return loss, gain and radiation pattern for the proposed antenna design at 2.4 GHz also been compared and discussed.

3.1. Return loss (RL), resonant frequency (f_r) and bandwidth (BW)
Figure 2 illustrates the simulated and measured return loss performance for the antenna design which is -15.54 dB at resonant frequency 2.404 GHz and -17.80 dB at resonant frequency 2.36 GHz. While at 2.4 GHz frequency, the return loss for simulated and measured is -15.48 dB and -13.60 dB respectively. The simulated and measured bandwidth is 146 MHz from frequency range 2.33–2.48 GHz and 138 MHz which is from 2.29–2.43 GHz. From the comparison of bandwidth result, measurement frequency range is slightly shifted to a lower frequency where the bandwidth also decreases around 8 MHz compared to the simulated bandwidth.
Figure 2. Comparison result of simulation and measurement return loss (S11) for inverted suspended circular patch antenna design.

3.2. Axial ratio
Figure 3 demonstrates the simulation result for axial ratio which is used to determine antenna polarization. Axial ratio for linear polarized is above 3 dB while for circular polarized it must be less than 3 dB. Based on the simulation result, the axial ratio for the antenna design at 2.4 GHz is less than 3 dB which is 0.42 dB with 1030 MHz axial ratio bandwidth (ARBW) starting from 2.15-3.18 GHz.

Figure 3. Simulation result of axial ratio versus frequency.

3.3. Directivity and total efficiency
Figure 4 (a) and (b) shows the simulation result of directivity and total efficiency versus frequency from frequency range of 1-5 GHz. As demonstrated in Figure 4 (a) the directivity of the antenna is more than 8 dBi starting from 1.92-2.61 GHz frequency range where the highest directivity is at 2.2 GHz with 8.54 dBi. At 2.4 GHz, the directivity of the antenna is slightly decreases to 8.46 dBi. As shown in Figure 4 (b), the highest total efficiency of the antenna is at 2.4 GHz with -0.56 dB where the efficiency is close to 0 dB. Total efficiency must be more than -3 dB to get more than 50% antenna efficiency.
3.4. Radiation pattern
The radiation pattern of antenna is measured in far field region. Figure 5 demonstrate the comparison of simulated and measured radiation pattern of the antenna at 2.4 GHz when phi = 0°, phi = 90° and theta = 90°. The radiation pattern obtained from measurement result is more or less similar with the simulation result.

**Figure 4.** Simulation result of (a) directivity (b) total efficiency versus frequency.

**Figure 5.** Comparison of simulation and measurement radiation pattern at 2.4 GHz (a) phi = 0° (b) phi = 90° and (c) theta = 90°.
Table 2 shows the result of axial ratio bandwidth (ARBW), axial ratio (AR), directivity and total efficiency at 2.4 GHz. While, Table 3 shows the result of return loss bandwidth (RLBW), resonant frequency (fr), return loss and realized gain at 2.4 GHz. Based on Table 3, the simulation result of gain is 7.90 dB and calculation gain for the measurement result is 5.19 dB respectively.

### Table 2. Performance result of simulation axial ratio, directivity, total efficiency and axial ratio bandwidth at 2.4 GHz

| Antenna Design (simulation result) | Axial Ratio (dB) | Directivity (dBi) | Total Efficiency (dB) | Axial Ratio Bandwidth (below 3dB) |
|-----------------------------------|------------------|-------------------|-----------------------|----------------------------------|
| Sim.                              | 0.42             | 8.46              | -0.56                 | 2.15-3.18 1.03                   |

### Table 3. Comparison result of simulation and measurement for return loss, realized gain, return loss bandwidth and resonant frequency at 2.4 GHz

| Antenna Design (Sim. Vs. Meas.) | Return Loss (dB) | Realized Gain (dB) | Return Loss Bandwidth  |
|---------------------------------|------------------|-------------------|------------------------|
| Sim.                            | -15.48           | 7.90              | 2.33-2.48 146          |
| Meas.                           | -13.60           | 5.19              | 2.29-2.43 138          |

### 4. Conclusion

In this paper, an inverted suspended circular patch antenna operating at frequency of 2.4 GHz for WLAN application is design based on inverted circular patch with L-probe technique of SMA connector to feed the antenna from ground to the feedline and air gap separation of 10 mm between patch and ground plane. Parameter of return loss, resonant frequency, ARBW, RLBW, realized gain, total efficiency, directivity and radiation pattern is monitor in order to analyse the performance result of the antenna. From observation on the simulation result at 2.4 GHz, axial ratio for the antenna is below 3 dB which is 0.42 dB with return loss -15.48 dB. The total efficiency is above -3dB which is -0.56 dB with directivity 8.46 dBi. The bandwidths for this antenna for simulation and measurement are more than 100 MHz which is 146 MHz and 138 MHz. Result of gain for measurement is 5.19 dB, slightly reduces compare to the simulation result which is 7.90 dB. Measurement result for resonant frequency is shifted a little bit to a lower frequency which is 2.36 GHz with -17.80 dB return loss. Overall, the simulation and measurement result for the antenna design meet a good agreement for the requirement of circular polarized antenna that can operating at 2.4 GHz for WLAN application.

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