A Broadband Dual Circularly Polarized Compact Printed Monopole Antenna

Rohit Kumar Saini

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Abstract

A novel broadband microstrip line feed dual circular polarized, two port printed monopole antenna is presented. The proposed antenna comprises of a partial ground plane with arrow shaped stub at the corner which is capable to generate wide axial ratio bandwidth and a pair of inverted L-shaped feed lines for radiating left hand circular polarized wave when the port 1 is excited and right hand circularly polarized wave when the signal is applied at port 2 with in the same axial ratio bandwidth. The 3 dB axial ratio bandwidth of the antenna is about 58% (1.7 GHz–3.1 GHz) in which the return loss and isolation are better than 10 dB and 12 dB respectively. A parametric study of proposed antenna’s parameters is given for understanding of the antenna performance. The gain, $S_{11}$ and $S_{21}$ are higher than 1, 10 and 12 dB respectively within the axial ratio and impedance band.

Keywords Dual circular polarization · Two port antenna · Polarization diversity · Printed monopole antenna

1 Introduction

With the fast development of the industry of wireless communication, circularly polarized printed antennas have been widely used in various modern wireless communication systems such as satellite communication, WLAN, WiMAX, Cellular Networks, Indoor base station, GPS and RFID readers due to flexible orientation of the transmitter ($T_X$) and receiver ($R_X$) antennas [1–5]. For wireless communication with high data wide bandwidth planar antennas are useful. The microstrip line feed becomes more attractive because of various advantages such as easy integration and fabrication. System employing circular polarized antennas at both the transmitter ($T_X$) and receiver ($R_X$) ends have high cross polarization discrimination.

For frequency reuse and polarization diversity a dual circular polarized antenna is very useful [6–17]. PIN diodes and biasing arrangement are used for polarization diversity application [18, 19]. Two port or dual circular polarized planar antenna was realized in [22] and [23].
However, their structures are complex and have limited axial ratio bandwidth. Two port or dual circular polarized planar antenna are designed in [20–26].

Based on the aforementioned literature we proposed a novel design of microstrip line fed two port, wideband circularly polarized printed monopole antenna for WiMAX, WLAN and ISM Band. A very less attempts have been made to design two port wideband circularly polarized monopole antenna. The HFSS 14 was used to design, simulation and optimization of the proposed planar antenna structure. The proposed planar antenna suitable for application of polarization diversity.

2 Antenna Configuration

The schematic diagram of the proposed monopole antenna and photograph of fabricated antenna is illustrated in Fig. 1. Its optimized dimensions are summarized in Table 1. An FR4 substrate ( thickness = 0.8 mm, $\varepsilon_r = 4.41$ and loss tangent = 0.02) is used for fabrication. The overall actual volume of the antenna is 50 mm $\times$ 50 mm $\times$ 0.8 mm.

The approximate value for the length of monopole feed line is given by

$$L(L_{21} + L_{22}) \approx \frac{\lambda_g}{2} = \frac{\lambda_r}{2\sqrt{\varepsilon_{eff}}} = \frac{c}{2\sqrt{\varepsilon_{eff}f_r}}$$  \hspace{1cm} (1)
where \( c \) is the speed of light, \( \lambda_r \) is the free-space wavelength of the monopole lower cut-off resonant frequency \( f_r \), and \( \varepsilon_{\text{eff}} \) is the approximated effective dielectric constant.

The basic antenna consists of a pair of inverted L-shaped monopole and partial ground plane with arrow shaped stub attached at the corner of ground plane as shown in Fig. 1. The antenna is fed by a 50 \( \Omega \) microstrip line, having the signal line of width 1.6 mm. The vertical branch of port 1 has identical width 3.2 mm as that of the horizontal branch of port 2. The asymmetric signal line is a basic monopole antenna for linear polarization. An arrow shaped stub is attached to the one of the corners of square ground plane between the feedlines at an angle of 45° to generate closely spaced multiple two orthogonal modes with a 90° phase difference as shown in Fig. 1. The arrow-shaped stub with partial square ground plane excite the feed line and strongly influence the closely spaced multiple two orthogonal modes with a 90° phase difference. Thus, the antenna is able to generate the wideband CP radiation by optimizing the gap between the arrow-shaped arms and the vertical arm of feed line. The gap between the arrow stub and feed line also play a vital role for impedance matching.

The feedline is act like a monopole antenna with linear polarization. However, after inserting an arrow-shaped grounded stub at the corner of ground plane, the magnetic current distribution is altered and moves in clockwise or anticlockwise direction as shown in

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2}
\]

(2)

### 3 Antenna Design and Analysis

Antenna evolution steps are explained by three prototypes in Fig. 2 to justify the development process. Antenna 1 has a pair of monopole feed line and a square ground plane on the bottom side; Antenna 2 includes a pair of monopole feed line and a stub connected to the ground plane; and Antenna 3 has a pair of monopole feed line and an arrow shaped stub connected to the ground plane. Their simulated results are shown in Fig. 3. The antenna is connected to a 50 \( \Omega \) SMA (Sub Miniature version A) connector for signal practical measurement. An arrow shaped stub is connected to the square ground plane to generate closely spaced multiple two orthogonal modes with a 90° phase difference due to capacitive loading. Thus, it is possible to increase the axial ratio bandwidth by optimizing the gap between the arrow-shaped grounded stub and the horizontal/vertical arm of feedline 2/1. This gap plays a vital role for impedance matching. It also improves the isolation and axial ratio bandwidth.

The feedline is act like a monopole antenna with linear polarization. However, after inserting an arrow-shaped grounded stub at the corner of ground plane, the magnetic current distribution is altered and moves in clockwise or anticlockwise direction as shown in
Fig. 4. This improves axial ratio bandwidth significantly because they create closely spaced multiresonant orthogonal modes by providing multiresonant paths. A comparison among between Antenna 1, Antenna 2 and Antenna 3 has been shown in Fig. 3a, b and c where

Fig. 3 Simulated a $|S_{11}|$, b $|S_{21}|$ and c axial ratio of Ant 1–3
the arrow-shaped grounded stub not only enhance the 10-dB impedance bandwidth up to 58% (Antenna 3) at a centre frequency of 2.4 GHz but also generate closely spaced multiple orthogonal modes with a 90° phase difference, which helps to achieve less than a 3 dB axial ratio bandwidth up to 58% (Antenna 3) with respect to the centre frequency of 2.4 GHz.

Figure 4a shows the surface current distribution at the central frequency of axial ratio bandwidth when the port 1 is excited. The circular polarized wave is generated by the surface current of the antenna. The 0° phase shows that the current is in +y directed with φ is 135°. For 90° phase, the current is in +x directed with φ is 45° and for 180° phase, current is in opposite direction to the current at 0° phase. The current direction of 270° phase is opposite to the current at 90° phase.

The surface current rotate clockwise, and result in left hand circularly polarized (LHCP) radiation toward the +Z direction when the signal is applied to port 1. The surface current rotates anticlockwise, and result in the right hand circularly polarized (RHCP) radiation toward the +Z direction when the signal is applied to port 2.

By using parametric variation of different parameters of proposed antenna, as depicted in Figs. 5 and 6 this concept was investigated.

4 Parametric Analysis

To evaluate the influence of the various main antenna geometric parameters on the S_{11}, S_{22} and AR bandwidth, a parametric observation is presented. Figures 5 and 6 shows the simulated S_{11}, S_{21} and AR with different optimized values of L_g2, L_{11} and L_{22}. All the other parameters remain same at their optimized values. Figure 5a, b and c show the simulated S_{11}, S_{21} and axial ratio as functions for different lengths of arrow shaped grounded stub L_g2. From the figures, it can be clear that this variable mainly affects the AR in the operating band. This can be expected that the gap significantly affects the energy coupling between the ground planes and inverted L-shaped strip. With regard to AR, the AR bandwidth slightly shifts to higher frequency as gap decreases, because of a greater capacitor.
Fig. 5 Effect of $L_{g2}$ on antenna characteristics (axial ratio in $+Z$ direction)
obtained. Wide axial ratio with wide reflection coefficient bandwidth has been achieved by using the optimized dimension $L_{g2} = 18$ mm.

Next, the effect of the length of the feed lines is investigated as shown in Fig. 6. The impedance bandwidth increases when the lengths of feedlines ($L_{11}$ and $L_{21}$) become.
higher. This parameter mainly affects the $S_{11}$ bandwidth of the proposed antenna, where the upper cut-off frequency slightly changes and lower cut-off frequency changes significantly. From Fig. 6a, c, it can be seen that the length of the feed lines has significant influence on reflection coefficient and slightly effects on AR. When the feed lines length is fixed at $L_{11}$ and $L_{21} = 38.2$ mm, the widest bandwidth of the proposed antenna can be achieved.

5 Results and Discussions

The final prototype of the proposed antenna is fabricated and measured. Simulated results are verified with the help of network analyzer. From comparison between simulated and measured results, depicted in Fig. 7, the measured impedance bandwidth of $S_{11}$ at below $-10$ dB is about 1.4 GHz (1.7–3.1 GHz) which is about 58% with respect to the centre frequency at 2.4 GHz.

And the isolation is more than 12 dB in the impedance bandwidth. Measured 3 dB AR bandwidth is around 1.4 GHz (1.7–3.1 GHz) which is about 58% at central frequency 2.4 GHz as shown in Fig. 8.
There is a difference between the simulated and measured results. The reasons may be due to the rough welded joint of the SMA (Sub Miniature version A) connector of the antenna and measurement error in anechoic chamber caused by the environment. The measured and simulated gains of the antenna are depicted in Fig. 9. The average measured gain varies from 1 to 1.24 dB in operating band of axial ratio.

The measured radiation pattern at 2.4 GHz are plotted in Fig. 10. The antenna has bidirectional radiation pattern with opposite sense circular polarization. The polarization of the antenna is LHCP for Z > 0 while RHCP for Z < 0 when the signal is applied to port 1. The antenna has opposite sense of polarization when the signal is applied to port 2.

For comparison of the performance of the proposed antenna, the axial ratio bandwidth, (Δf/f₀) of axial ratio and antenna size of the reported antennas in the literature review summarized in Table 2. It can be observed from the table that the proposed antenna has small area and large value of (Δf/f₀) of axial ratio bandwidth.
6 Conclusion

This paper describes a novel shaped monopole antenna with wideband CP radiation pattern. The impedance and axial ratio bandwidth are easily enhanced by optimizing the length and width of the ground plane and the gap between the arrow-shaped grounded stub and the horizontal/vertical arm of feedline 2/1. The proposed two port monopole antenna has a good symmetry opposite sense bi-directional radiation with LHCP in the +Z direction and RHCP in the −Z direction with an average peak gain of 1.07 dB when the signal is applied to port 1 and port 2 respectively. Due to the advantages of structural simplicity, compact size and bidirectional broadband circular polarization property, this antenna can have practical applications for various wireless communication like Bluetooth/WLAN (2400–2484 MHz) and Wi-MAX (2500–2690 MHz).
### Table 2 3-db AR bandwidth, volume, type, $f_0$ and $(\Delta f/f_0)$ of some existing dual CP antennas

| References | [20] | [21] | [22] | [23] | [24] | [25] | [26] | Proposed |
|------------|------|------|------|------|------|------|------|----------|
| AR BW (%)  | 59.65| 80.7 | 4.7  | 12.85| 7.25 | 20.8 | 16   | 58       |
| Volume (mm$^3$) | 60×60×1.6 | 32×32×1 | –    | 60×60 | 252×252×1.6 | 83×83×1 | 76×76×0.726 | 50×50×0.8 |
| Type       | CPW Slot antenna | Monopole Antenna | Annular Slot Antenna | CPW Slot antenna | Dual Substrate | Microstrip Slot antenna | Dual Substrate with back Cavity | Monopole Antenna |
| $f_0$(GHz) | 2.85 | 6.27 | 2.46 | 2.45 | 0.9  | 2.6  | 3.7  | 2.4      |
| $(\Delta f/f_0)$ | 20.93 | 12.87 | 1.911 | 5.25 | 8.06 | 8    | 4.324 | 24.17    |
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Declarations

Conflict of Interest We have no conflicts of interest.

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**Rohit Kumar Saini** received his B. Tech. degree in Electronics and Communication Engineering from Sir Chhotu Ram Institute of Engineering and Technology, Meerut, India in the year of 2006 and Master of Technology degree in Microwave Electronics from Delhi University South Campus, Delhi, India, in year 2012. Ph.D. degree in RF and Microwave Engineering from the Department of Electronics Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, India, in, 2018. Currently he is working as pdf with IPR Gandhinagar taking leave without pay from Faculty of Engineering, Teerthkantor Mahaveer University, Moradabad, Uttar Pradesh, India. His recent research interest activities have focused on the Antennas, RF planar circuits and Computational Electromagnetic