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A Compact Wideband Circularly Polarized Monopole Antenna for Bluetooth/ WLAN and WiMAX Applications

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Abstract

In this paper, a compact wideband circularly polarized (CP) printed monopole antenna is designed and demonstrated. The proposed antenna geometry comprises a monopole having two orthogonal stubs and a defected ground plane. Upon optimization of both the stubs present in top plane and the slot present in the ground plane, a wideband right-hand circularly polarized (RHCP) radiation is achieved. The geometry exhibits a 10-dB impedance bandwidth of 3.17 GHz (2.08 – 5.25 GHz) and an axial ratio bandwidth (ARBW) of 2.0 GHz (2.2 – 4.2 GHz). Additionally, the antenna features a low profile, compact size, and broadside radiation with adequate gain. The geometry has been fabricated and reasonable agreement is observed between the simulated and measured responses.

1. Introduction

The use of circularly polarized (CP) antennas in communication systems give several advantages as compared to its linearly polarized counterpart such as, opposing multipath interferences, minimizing the Faraday rotation effect, and negating the requirement of a similar orientation between the transmitting and receiving antennas [1]-[5]. Thereafter antenna engineers are focusing their research to design broadband circularly polarized (CP) antennas that can cover the bands corresponding to various applications like Bluetooth/ WLAN, WiMAX, RFID, radar, etc. [6]-[7]. The CP radiation can be achieved by exciting two orthogonal E-field components having a unity amplitude ratio and 90° phase difference between them. Over recent years, several techniques have been used to design CP antennas namely slot antenna [8], dielectric resonators [9], metamaterial-based structures [10], SIW based antenna [11], printed monopoles [12]-[13], etc. Among these designs, printed monopole antennas are the most preferred choice due to various advantages, such as thin profile, low cost, simple geometry, excellent radiation efficiency, and wide impedance bandwidth.

Therefore, several wideband printed monopole antennas capable of generating CP radiation have been proposed over the years. With time, the focus has been given in reducing the antenna footprints. A broadband CP slot-based monopole antenna has been presented in Ref. [14], where the geometry exhibits a 3-dB axial ratio bandwidth (ARBW) of 30%. However, the antenna size is large, consuming an overall dimension of $0.80\lambda \times 1.45\lambda$, λ being the free space wavelength at center frequency. In Ref. [15], a printed monopole antenna utilizing Vivaldi structure as the design concept is presented. It produces a 3-dB ARBW of 41.4% with overall antenna dimensions of $0.97\lambda \times 0.97\lambda$. A leaky-wave wideband CP antenna using exponentially tapered slots is designed in Ref. [16]. Although this antenna yields a large value of 3-dB ARBW (around 53%), the overall size of the structure is significantly large ($1.49\lambda \times 1.49\lambda$). In Ref. [17], a printed monopole with two parasitic patches and a grounded stub is designed. The geometry offers an ARBW of 27.45% at the expense of a large size ($0.65\lambda \times 0.65\lambda$). In Ref. [18], a wide slot antenna with a rectangular bracket-shape strip type feeding technique in a coplanar waveguide (CPW) is demonstrated. This antenna produces an ARBW of 49% and has an overall antenna size of $0.42\lambda \times 0.46\lambda$. Thus, CP antennas with simultaneously wide ARBW and miniaturized size are still in great demand amongst the antenna designers.

In this work, a compact wideband CP monopole antenna is designed and developed for Bluetooth/ WLAN (2.4-2.484 GHz) and WiMAX (2.5 - 2.69 GHz, 3.2 - 3.8 GHz) applications. The antenna geometry contains two orthogonal printed monopole stubs and one rectangular slot in the defected ground plane. A combination of stubs and the slot gives two adjacent CP resonances, which get coupled with each other to result in a broadband CP resonance. The geometry exhibits a wide ARBW of nearly 62.5% with comparatively reduced dimensions of $0.5\lambda \times 0.5\lambda$. Surface current distributions and parametric analysis explaining the CP operation mechanism have been explained in subsequent sections. The structures have also been fabricated and the responses are compared with optimized simulated response.

2. ANTENNA DESIGN AND ANALYSIS

The optimized geometry of the printed monopole antenna is displayed in Figure 1. A FR4 substrate having thickness 1.6 mm, a permittivity value 4.4 and a loss tangent value of 0.02 has been used to print the monopole antenna. The overall dimensions of the antenna are 50×50 mm^2. The structure comprises two orthogonal monopole stubs and a defected ground plane which is fed by a 50 Ω transmission line of length and width l_f and w_f, respectively. Other geometric dimensions are enlisted in Figure 1.

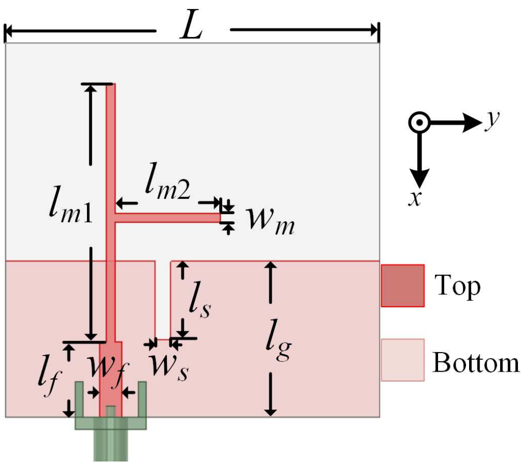

Figure 1. Optimized geometry of the antenna element. (L = 50, l_f = 10.0, w_f = 3.0, w_t = 2.3, l_{m1} = 34.5, l_{m2} = 14.0, w_m = 1.2, l_s = 9.5, w_s = 2.0, l_g = 20.8; units: mm).

Various evolution stages of the antenna structure explaining the CP mechanism and their associated responses are shown in Figure 2. Ant. 1 (reference antenna) contains a vertical monopole only with a partial ground plane. The design radiates a linearly polarized electromagnetic (EM) wave with an impedance bandwidth of 1.7 GHz (1.9 – 3.6 GHz). In Ant. 2, a vertical rectangular slot is created in the ground plane. This slot disturbs the horizontal current in the ground plane and produces two orthogonal E–field components, thereby achieving a narrow-band CP resonance. The CP behavior is observed at around 2.3 GHz along with S_{11} bandwidth of 2.05 GHz (1.75 – 3.8 GHz). In the final stage (Ant. 3), an optimized length of horizontal stub is added. As a result, one more CP resonance is occurred at 3.7 GHz while the first CP resonance is shifted to 2.5 GHz. Thus the geometry produces a wide ARBW of 62.5% (2.2 – 4.2 GHz) with an impedance bandwidth of 86.5% (2.08 – 5.25 GHz). Ansys HFSS 2020 has been used to design various antenna stages.

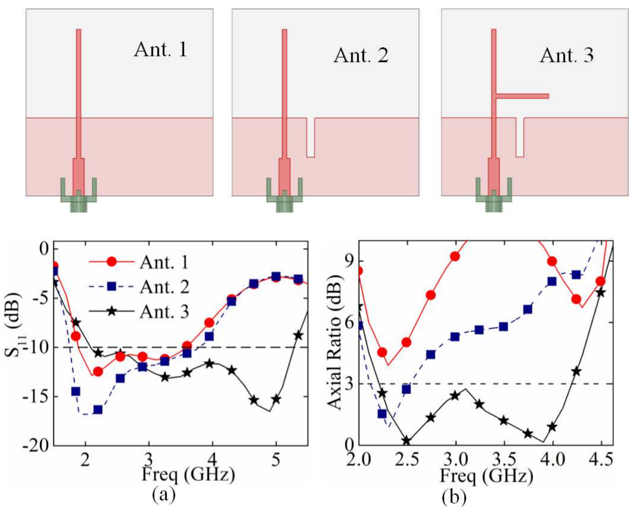

Figure 2. Evolution stages of the antenna along with (a) reflection coefficient (S_{11}), and (b) axial ratio results.

The pictorial representation of surface current of the proposed design at the center frequency (3 GHz) of the ARBW is shown in Figure 3. It is witnessed that at time phase ωt = 0, the monopole is radiating in –x direction, while at ωt = T/4 time phase, the horizontal stub is radiating along +y direction. Surface currents correspond to other two instant i.e. ωt = T/2 and 3T/4 are just opposite to that of ωt = 0 and T/4, correspondingly. Therefore, a space orthogonal phase response with 90° time phase has been achieved by the antenna to produce the CP behavior. It is also evident from the figure that the sense of rotation is clockwise way, and indicates the right-hand circularly polarized (RHCP) behavior. Furthermore, the antenna attains a good radiation efficiency of more than 90% and a decent maximum gain of 2.16 dBic within the operating band, as shown in Figure 4. The 2-D radiation patterns at 3 GHz in xz and yz planes are also depicted in Figure 5, which further confirms that the geometry is radiating RHCP wave in the broadside direction.

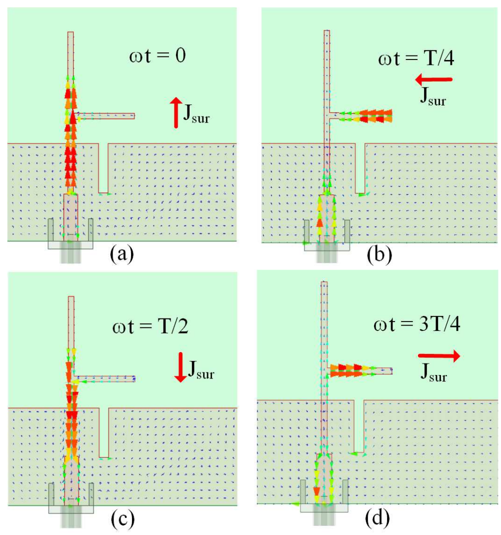

Figure 3. Surface current distribution of the design at 3.0 GHz.

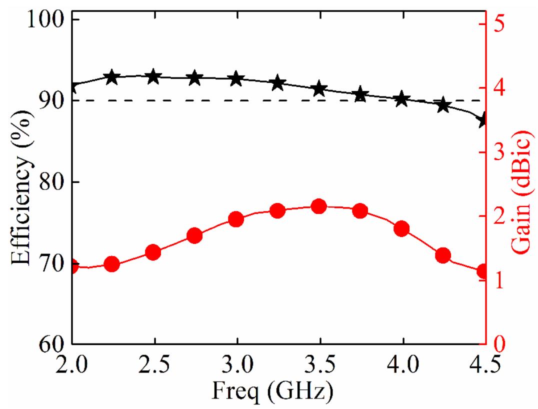

Figure 4. Simulated gain and efficiency of the antenna.

For an in-depth analysis of the CP response, a few parametric variations concerning the horizontal stub length (l_{m2}) and vertical slot length (l_s) are shown in Figures 6 and

7, respectively. The S_{11} and axial ratio responses for the horizontal stub length (l_{m2}) are shown in Figures 6(a) and 6(b). With the increase in the length, the higher resonance is shifting toward the lower side. Further, the polarization purity is adversely affected at 3 GHz. Upon

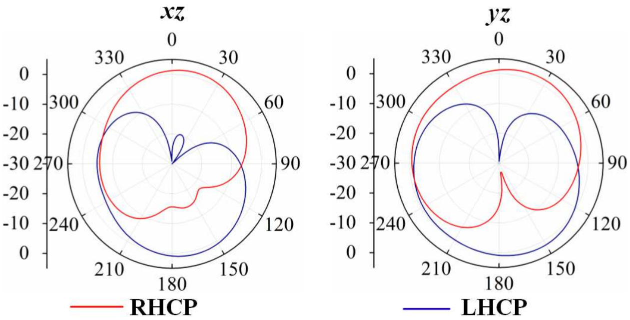

Figure 5. 2-D radiation pattern of the optimized design at 3 GHz.

optimization of the length, a wideband CP is obtained. On the contrary, the variation in the vertical slot length (l_s) mainly affects the ARBW. As the length of the slot is increased from 9.5 to 11.5 mm, both the CP resonances are shifting toward each other, causing a decrease in the overall ARBW, as illustrated in Figure 7 (b).

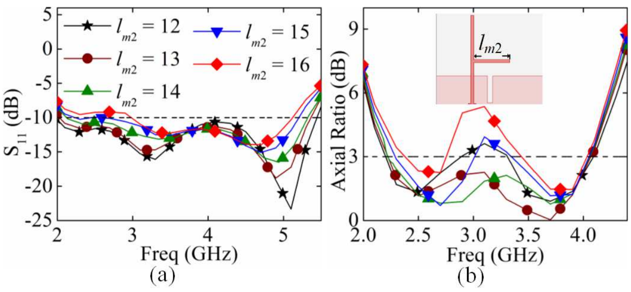

Figure 6. Simulated parametric variation of (a) S_{11}, and (b) axial ratio response for certain horizontal stub lengths (l_{m2}).

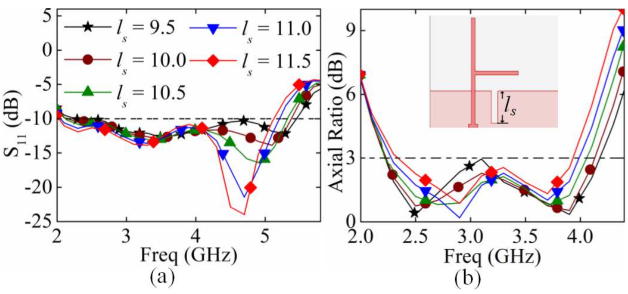

Figure 7. Simulated parametric variation of (a) S_{11}, and (b) axial ratio response for certain vertical slot lengths (l_s).

3. FABRICATION AND MEASUREMENT

The optimized antenna has been fabricated using LPKF protomat S-104 PCB prototyping machine and the associated S-parameter responses have been measured in a vector network analyzer Anritsu S820E. Figure 8 depicts the photograph of the fabricated antenna prototype. A comparison between the measured S_{11} response and the simulated results in Figure 9 and the concept is validated by observing the resemblance between the plots.

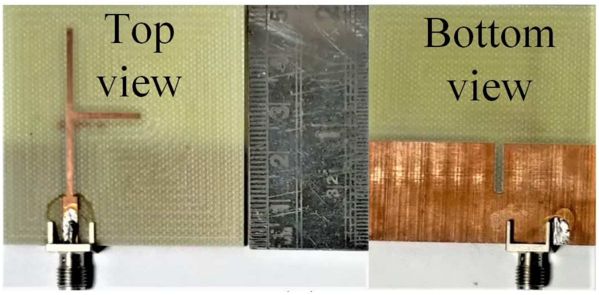

Figure 8. Photograph of the fabricated antenna prototype.

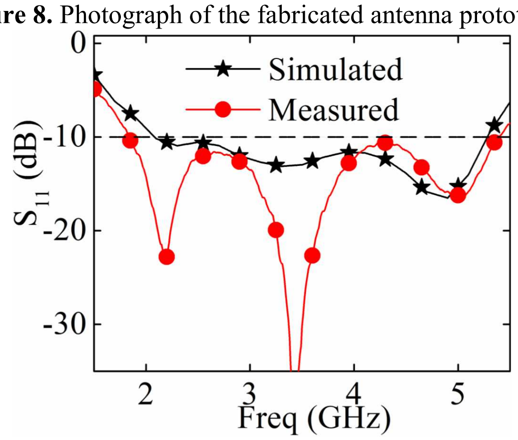

Figure 9. Comparison between simulated and measured S_{11} of the proposed Antenna.

Table 1: Comparison with other wideband CP antennas.

Reference	Imp. BW (%)	AR BW (%)	Antenna size
Ref. [17]	71.63	27.45	0.65λ × 0.65λ
Ref. [18]	55.50	42.00	0.39λ × 0.39λ
Ref. [19]	62.00	49.00	0.46λ × 0.42λ
Proposed structure	**86.50**	**62.50**	**0.50λ × 0.50λ**

4. CONCLUSION

In this work, a compact wideband CP printed monopole antenna is demonstrated. By exploiting the dimensions of the orthogonal stubs present in the top pattern and the rectangular slot present in the bottom layer, a wideband impedance bandwidth of 86.50% and ARBW of 62.50% are attained while retaining the compactness of the geometry. A comparison has been made between the proposed antenna and some previously reported designs featuring the similar microwave frequency range is displayed in Table I. An improved performance in terms of impedance bandwidth as well as ARBW are observed at the expense of using a similar (or even smaller) antenna size. The geometry has also been fabricated and its results are in congruence with the simulated ones. The designed antenna has numerous applications in wireless communication, with the aim to be used in Bluetooth/ WLAN (2.4-2.484 GHz) and WiMAX (2.5- 2.69, 3.2- 3.8 GHz) applications.

6. Acknowledgements

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