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A Circularly Polarized Planar Monopole Antenna with Wide AR Bandwidth Using a Novel Radiator/Ground Structure

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Abstract- A wideband circularly polarized (CP) printed monopole antenna is proposed. The 3-dB axial ratio (AR) is realized by protruding a horizontal stub from a vertical monopole and creating a slot on the ground plane beneath the protruded stub. The monopole and slot resemble rotated T-shape structures when viewed from the top. The proposed antenna has a size of 25 × 25 mm2. Numerical results show that the antenna can realize an S11≤ -10 dB impedance bandwidth of 85.6 % from 4 -10 GHz, and a broadband 3-dB AR bandwidth of 73.9 %, from 4.54 – 9.8 GHz. The proposed antenna is simple to design, compact and suitable for circular polarization applications in C band.

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ACIRCULARLYPOLARIZEDPLANARMONOPOLEANTENNAWITHWIDEARBANDWIDTHUSINGANOVELRADIATORGROUNDSTRUCTURE

Strictly as per the compliance and regulations of:

A Circularly Polarized Planar Monopole Antenna with Wide AR Bandwidth Using a Novel Radiator/Ground Structure

Mubarak Sani Ellis [α], Abdul-Rahman Ahmed [σ] & Jerry John Kponyo [ρ]

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I. Introduction

With the rapid development of wireless communications systems, antennas with different polarizations have become very important. Circular polarization (CP) has become very useful in many communication systems due to its resilience to polarization mismatch which is otherwise a problem in linearly polarized (LP) antennas. A lot of research has focused on implementing CP in slot antennas due to their relatively wide impedance bandwidths [1] – [7]. In [1] – [3], L shaped ground strips were embedded inside a square slot to achieve and improve the AR bandwidth. In [4] – [6], perturbations in the form of feed lines were introduced in the slot antenna to realize CP characteristics.

Another uncommon technique is introducing sequential array configuration [7], [8] aside using slot antennas. This method can realize wideband AR but the design is complicated due to the array design and the use of a power divider and a large circuit board. Recently, research has gone into using planar monopole antennas to realize broadband CP [9] – [12] but some of these designs have wide AR bandwidths and/or suffer from design and fabrication complexities. There is a scarcity of techniques to achieve CP with planar monopole antennas compared to slot antennas.

In this work, a new and structurally simple planar monopole broadband CP antenna is proposed. The presented antenna consists of a microstrip-fed vertical radiator and a rectangular ground plane structure. To realize broadband CP, a horizontal stub is protruded from the vertical radiator above the ground plane, and an identical slot structure is created on the ground plane just beneath the radiator. In this design, the 3-dB AR bandwidth reaches as large as 5.26 GHz which is about 73.9 % which covers the WLAN (5.2 GHz, 5.8 GHz), WiMAX (5.5 GHz) and other wireless systems in C band.

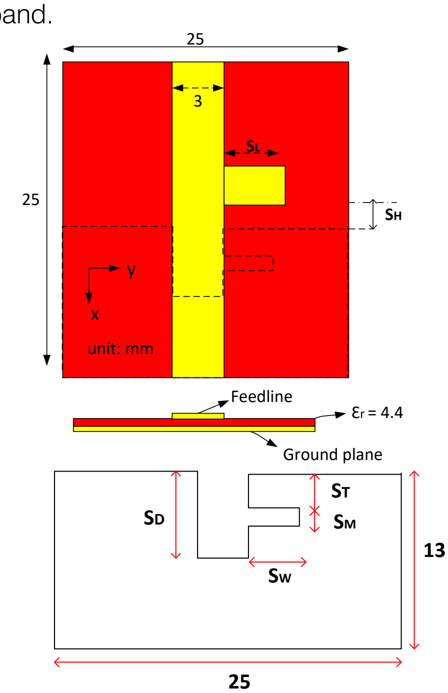

Fig. 1: Geometry of the proposed antenna (S_D = 4, S_L = 4, S_W = 4, S_M = 0.5, S_T = 2, S_H = 1.5)

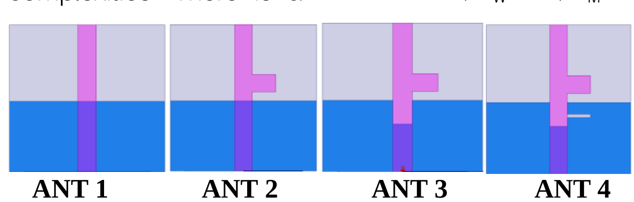

Fig. 2: Evolution of the proposed antenna

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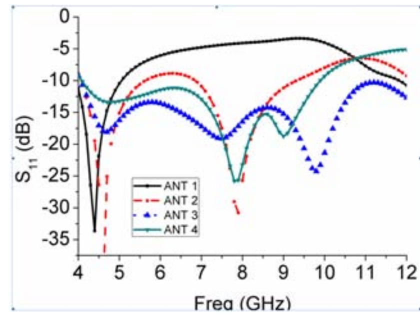
II. Antenna Design

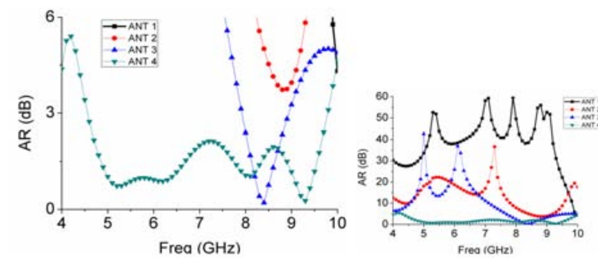
1. The geometry of proposed antennas is shown in Fig. 1. The proposed antenna is fed by a 50-Ω microstrip feedline printed on the top of an FR4 substrate of thickness 1.6 mm and dielectric constant of 4.4. The ground plane is printed on the bottom of the substrate. A horizontal stub is protruded from the monopole towards the +y axis, just above the ground plane. A gap is created in the middle-top of the ground plane towards the +x axis. Another slot is created from the first slot and moved towards the +y axis. The overall area of the proposed antenna is 25 × 25 mm^2. The antenna is printed on the *xoy* axis as shown in Fig.1.
2. The evolution of the proposed antenna is shown in Fig. 2. in order to explain how the CP performance is introduced into the antenna. Four separate antennas will be discussed. These are: antenna 1 (Ant 1), antenna 2 (Ant 2), antenna 3 (Ant 3), and antenna 4 (Ant 4). Ant 1 is a fundamental monopole antenna which has been widely used [13] while Ant 4 is the proposed antenna. At the first stage, Ant 1, which is simply a micro strip antenna which consists of a vertical monopole and a ground plane, is designed. In Ant 2, a horizontal stub is protruded from the radiating monopole (towards the +y axis) at a short distance above the ground plane. The radiator, here, resembles a rotated uneven T-shaped monopole. In Ant 3, a slot is created on the ground plane just beneath the radiating monopole, along the +x axis. Lastly, in Ant 4, a horizontal slot is created on the ground plane along the initial slot and towards the +y axis to resemble a rotated T-shaped slot. The effect of each antenna will be discussed in Section III.

III. Results and Discussion

The antennas were simulated with Ansoft commercial high frequency structure simulator (HFSS) software. To demonstrate the performance of the proposed antenna from stages 1 to 4, the S_{11} bandwidth and AR performances have been compared in Fig. 3. It can be noticed in Fig. 3(a) that Ant 1 resonates around 4.5 GHz which corresponds to a quarter of the guided wavelength for the monopole's length above the ground plane. The bandwidth is however very small and the impedance matching becomes poor after 5 GHz. It is also linearly polarized with an AR value around 50 dB as seen in Fig. 3(b). To enhance the S_{11} bandwidth significantly, a horizontal stub is protruded from the monopole, like in Ant 2. From Fig. 3, the S_{11} bandwidth is greatly enhanced due to another resonance at 8 GHz. The AR is also improved from 50 dB to about an average of 20 dB average across band, except at 9 GHz.



(a)



(b)

Fig. 3: Simulated (a) S_{11} and (b) AR results for antennas 1 – 4

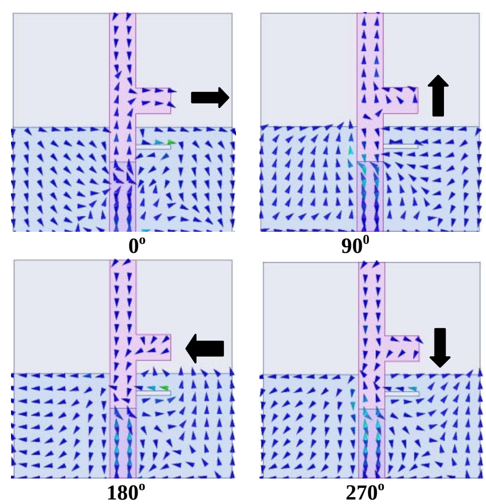


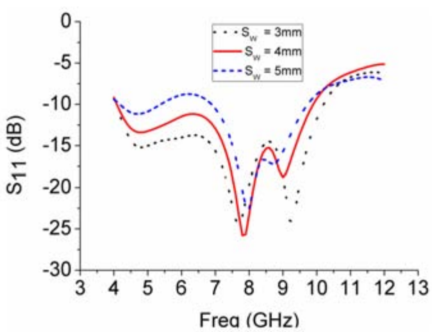
Fig.4: Distribution of surface current at 7 GHz at 0°, 90°, 180°, and 270°

where the AR improves to 4 dB. Overall, Ant 2 is still linearly polarized with enhanced S_{11}.

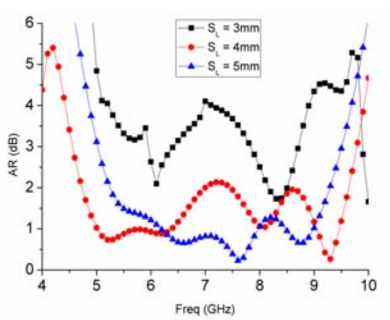
CP is generated by two orthogonal electric vectors with equal amplitude and 90 degrees phase difference, where the complex E-vectors are the vertical E-field, E_{VER}, and the horizontal E-field, E_{HOR}. When the slot is created on the ground plane in Ant 3, the S_{11} plot shows an improved overall S_{11} performance thereby increasing the bandwidth. This is because the slot reduces the coupling between the ground plane and feed line, which in return reduces the reflection coefficient at those frequencies. Fig. 3(b) shows that Ant 3 realizes CP performance between 8 and 9 GHz which is an improvement of Ant 2. To significantly enhance the bandwidth of Ant 3, a slot is created from the initial slot in Ant 3 and extended towards the +y axis to complete the slot structure on the ground plane. Here, the overall slot resembles an uneven rotated T-shape, like the monopole structure. This is illustrated in the proposed design (Ant 4). Fig. 3(a) shows that Ant 4 has better S_{11} performance than Ant 1 and Ant 2, but not Ant 3. Ant 3 has an S_{11} bandwidth from 4 GHz - over 12 GHz, while Ant 4 has an S11 bandwidth from 4 GHz - 10 GHz.

However, the AR performance shows a significantly improved performance in Ant 4: from 4.6 GHz to 9.8 GHz. Here, a phase difference of 90^0 is achieved over a wide bandwidth between E_{VER} and E_{HOR}.

The time-varying surface current distribution of the proposed antenna (Ant 4) is shown in Fig. 4. It can be seen that the surface current distribution at 0^0 and 90^0 are equal in magnitude and opposite in phase to 180^0 and 270^0. This shows right-hand circular polarization (RHCP) in the +z direction, but left-hand circular polarization (LHCP) in the -z direction.

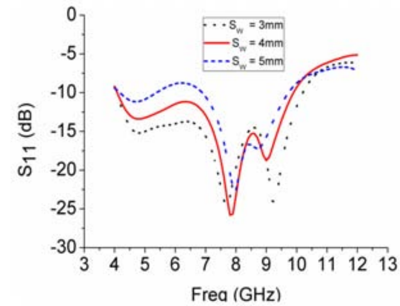


(a)

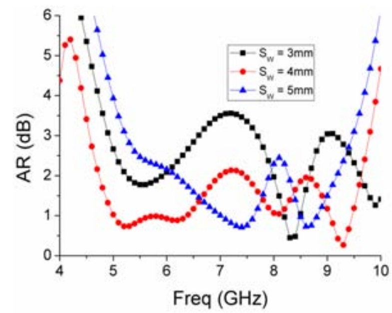


(b)

Fig. 5: Effect of stub length S_L on S_{11} and AR

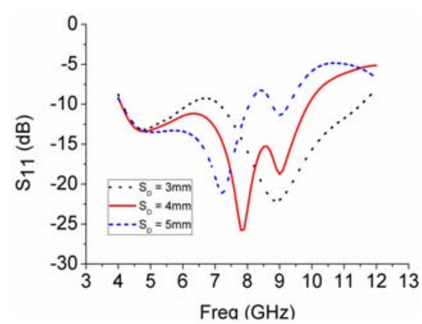


(a)

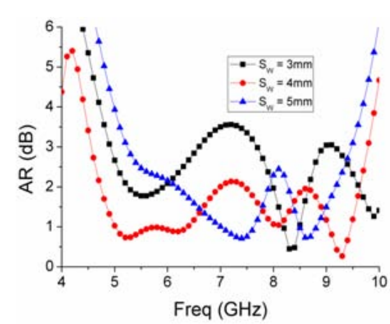


(b)

Fig. 6: Effect of stub length S_w on S_{11} and AR

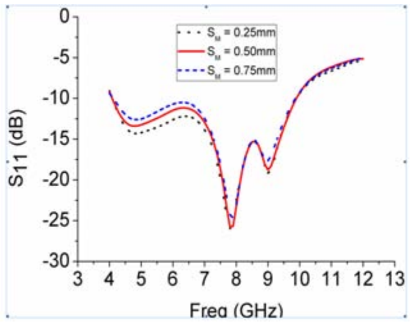


(a)

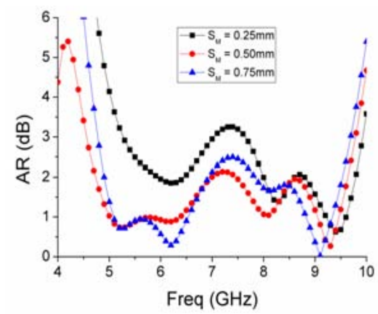


(b)

Fig. 7: Effect of slot length S_D on S_{11} and AR

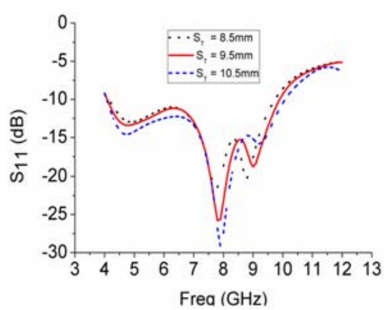


(a)

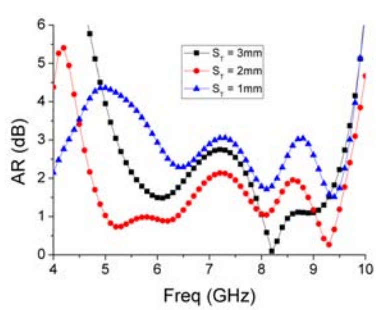


(b)

Fig. 8: Effect of slot length S_M on S_{11} and AR

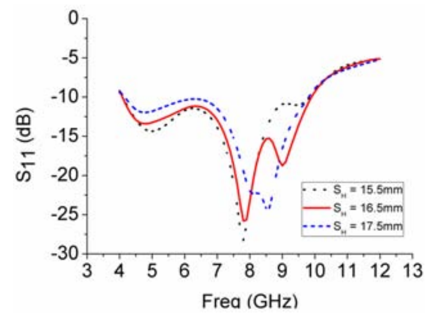


(a)



(b)

Fig. 9: Effect of slot length S_T on S_{11} and AR



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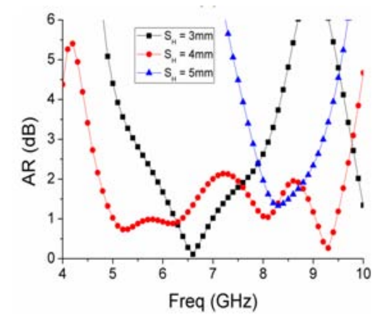

(b)

Fig. 10: Effect of slot length S_H on S_{11} and AR

IV. Parametric Analysis

The results of parametric studies on the proposed antenna are presented in this section. The parameters discussed here are the stub length (S_L), slot length (S_D), slot length (S_W), slot width (S_M), slot position (S_T), and stub position (S_H). For each varying parameter, the other dimensions remain fixed as the values indicated in the caption of Fig. 1. The results will be discussed to provide knowledge on how the antenna's S_{11} and AR performances are affected by each parameter.

A. Effect of S_L

The results of different S_L values on AR and S_{11} are shown in Figs. 5(a) and (b). It can be realized that the S_{11} does not significantly change when S_L is varied except at low frequency, between 4 GHz – 7 GHz, where the S_{11} worsens as S_L increases. In the AR plot in Fig. 5(b), the AR value decreases (improved CP) as S_L increases from 3mm to 5mm, especially between 6 – 8 GHz. For an AR $\leq$ 3 dB threshold, the bandwidth however is largest when S_L = 3mm.

B. Effect of S_W

The effect of S_W values on AR and S_{11} bandwidths is demonstrated in Fig. 6(a) and (b). The S_{11} is affected at the low frequency points when S_W increases. The AR value decreases as S_W increases, especially around 7 GHz. The largest bandwidth is however achieved when S_W = 4.

C. Effect of S_D

Figures 7(a) and (b) show the effect of L_W on AR and S_{11}. Above 5 GHz, the S_{11} is greatly affected by S_D. When S_D is small, there is considerable coupling between the ground and monopole which is reduced when a gap of adequate length is created. When the gap is relatively big however, (e.g. S_D = 5mm), the worst S_{11} is achieved since the ground plane's effective area is reduced. In the AR plot, a small gap produced a poor AR at lower frequencies below 6.5 GHz, which improved when the S_D increased. After 6.5 GHz, an insignificant change is noticed with changes in S_D.

D. Effect of S_M

The effect of S_W on AR and S_{11} bandwidths is demonstrated in Figs. 8(a) and (b). S_M does not affect the S_{11} and AR significantly. The S_{11} plot remains unchanged except at low frequency where an increase in S_M worsens the S_{11} slightly. The AR plot is also significantly affected only at lower frequency when S_M = 0.25mm. At S_M = 0.5mm and 0.75mm, the AR remains unchanged except with S_M = 0.5mm realizing a slightly larger bandwidth than S_M = 0.75mm.

E. Effect of S_T

The effect of S_W on AR and S_{11} bandwidths is shown in Figs. 9(a) and (b). The S_{11} plot shows no significant change except very slightly at lower frequency. In the AR plot however, significant changes are noticed, i.e., when the gap between the horizontal slot and top edge of the ground is close, the AR is worsened but improves when the gap is increased. The largest bandwidth for AR≤ 3 dB is achieved when the gap, S_T, is 2mm.

F. Effect of S_H

The effect of S_H on AR and S_{11} bandwidths is shown in Figs. 10(a) and (b). A significant change is noticed in the AR plot while a slight change is noticed in the S_{11} plot when S_H changes. From Fig. 10 (b), it shows that the AR bandwidth is dependent on S_H. When S_H is 3mm, a wideband AR is achieved from 5.5 – 8 GHz. When S_H increases to 5mm, the AR shifts to about 7.8 – 9.2 GHz. The largest bandwidth is realized when S_H = 4mm.

V. Conclusions

A novel, low profile, broadband CP monopole antenna is introduced in this work. The results show that the antenna can achieve a broadband AR bandwidth from 4.54 – 9.8 GHz (73.9 % fractional bandwidth) and an impedance bandwidth from 4 – 10 GHz (85.7 % fractional bandwidth). To achieve CP performance, a rotated T-shaped monopole and a rotated T-shaped slot are employed. In addition to the simple structure, the proposed antenna provides a novel design in enhancing AR bandwidth and CP operation. The proposed antenna is useful for wireless communications in C-band, including WLAN (5.2, 5.8 GHz) and WiMAX (5.5 GHz).

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