Improved bandwidth and F/B ratio of a CPW-fed planar monopole antenna

M.S. Ellis*, A.-R. Ahmed, J.J. Kponyo, K.O. Gyasi, K.S.O. Kwakye, S. Ameyaw

Department of Telecommunication Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ARTICLE INFO

Keywords:
Planar antennas
Reflector
FR4
Unidirectional
Monopole
Efficiency
Gain

ABSTRACT

A directional planar monopole antenna is described. The antenna comprises of a circular monopole, coplanar waveguide (CPW) feed line and a ground plane. To achieve unidirectional radiation, a stub is also attached to on the ground plane to increase the lower end impedance bandwidth and also increase the Front-to-Back ratio (F/B). The proposed antenna is etched on a 50 × 50 mm² FR4 substrate. Simulated and experimental results reveal that the proposed antenna can achieve an impedance bandwidth from 2.3 – 10.5 GHz for S₁₁ < −10 dB, and unidirectional radiation patterns with high gain and high efficiency.

1. Introduction

Rapid development of wireless communication systems has created avenues for increased demand for unidirectional antennas with wide operating bandwidth [1]. The planar monopole unidirectional antenna has gained a lot of recognition due to its small size, flat structure, and its ease of integration with other microwave circuit components. In recent years, several antennas have been published to meet these properties. A quasi-Yagi antenna has been proposed to meet these demands [2, 3, 4, 5, 6]. Here a large ground plane is required to act as a reflector which makes the antenna size large. The loop-dipole antenna has also been reported to realize unidirectional radiation and wide bandwidth [7]. Several variations of the loop antenna including the addition of parasitic strips [8, 9, 10], metamaterials [11, 12] have been presented as well. However, the above designs suffer from large sizes [7], narrow bandwidth [8, 9], complicated designs [11]. Other techniques include using split ring resonators as monopoles for bandwidth enhancement [13] and circular ring monopoles with circular parasitic elements for bandwidth enhancement [14]. Generally, planar monopoles exhibit omni-directional radiation in their H-planes and quasi omni-directional radiation in their E-planes. This feature is attractive in communication systems. However, in other systems like radar, positioning, and other point-to-point application systems, this feature is not attractive. Unidirectional radiation patterns are rather preferred. This is due to the fact that when omnidirectional/quasi-directional antennas are attached to objects like walls or metallic objects or even the human body, the radiation on the opposite side of that object will cause degradation in antenna performance.

A few efforts have being made to make the planar monopole antenna directive as it is preferred than the quasi-Yagi and loop dipoles antennas. In [15, 16, 17], a metallic sheet is placed at some distance behind the antenna to serve as a reflector. However this makes to antenna very bulky, impractical and impossible to integrate in any MMIC.

Recently, a new type of unidirectional planar monopole antennas was published [18]. This method uses via to connect the ground plane of the antenna to the monopole of the antenna on either side. By doing so, the antenna radiates in one direction only. Even though this technique works well, the bandwidth was quite small.

In this work, a circular radiator fed by a CPW is employed. A metallic strip is attached to the ground plane on the right of the waveguide to the top of the substrate. By doing so, the impedance bandwidth of the antenna is greatly improved and the F/B is improved as well. Compared to the aforementioned antennas, the bandwidth is greatly improved, no additional reflectors are required making the proposed antenna more compact. A table of comparison has been shown in Table 1 to compare the proposed antenna to the referenced antennas.

2. Antenna design and implementation

The proposed antenna is shown in Figure 1. It is printed on an FR4 substrate of thickness 1.6 mm and relative permittivity of 4.4. The width of the feed line is 3 mm. A CPW feed line is employed. This means the monopole and ground plane are all etched on one side of the substrate.
with nothing on the reverse side. The radiator consists of a circular radiating patch. A vertically attached metallic strip is extended on the right end of the ground plane, making the overall ground plane look like a laterally inverted L shape. This is responsible for the improved impedance matching and bandwidth of the proposed antenna, as well as the increased F/B. The proposed antenna is fed by a 50-Ω SMA connector. The optimized geometry of the proposed antenna is shown in Figure 1 above. The antenna is printed on the xoy axis.

Theoretically, a circular disk monopole of radius, \( r \), can be equated to a cylinder with height, \( l \), and radius \( a \). Therefore, its first resonance frequency can be calculated by equating the area of the circular monopole to that of a cylindrical monopole. Also, the diameter of the disk \( 2r \) can be equated to the height of the cylindrical monopole \( l \), as shown [19]:

\[
2\pi al = \pi r^2, \quad 2r = l.
\]

The length of the monopole for a real input impedance is given by:

\[
l = 0.244F, \quad \text{where} \quad F = \left(\frac{l}{a}\right) + \left(1 + \frac{l}{a}\right).
\]

From the above equations, the first resonant frequency of a disc monopole can be calculated as:

| Ref. | BW (%) | Area          | Min. F/B ratio (dB) | Peak Gain (dBi) |
|------|--------|---------------|---------------------|-----------------|
| [8]  | 40.7   | 0.382 × 0.458 | 10                  | 4.8             |
| [9]  | 56.6   | >0.436 × 0.265| 10                  | 4.9             |
| [10] | 67     | 0.275 × 0.283 | 10                  | 5.4             |
| [11] | 52     | 0.256 × 0.256 | 9                   | 3.2             |
| [12] | 34     | 0.253 × 0.296 | –8                  | 4.5             |
| [13] | 66     | 40 × 44       | –                   | 5               |
| [14] | 50.19  | 40 × 30       | –                   | 6.12            |
| This work | 128 | 0.384 × 0.384 | 10                  | 6.5             |

**Table 1.** Comparison between proposed antenna and reference antennas.

Figure 1. Geometry of proposed antenna with coordinate system (radius = 7 mm, length of extension = 29 mm).

Figure 2. Simulated transient current distribution at 2.8 GHz at 0°, 50°, 100°, 150° phases.
\[ f = \frac{3 \pi}{2r}, \text{ } r \text{ is in centimeters.} \]

It is should be noted that the above experimentation is true when the ground plane is a conventional rectangular ground plane. In the proposed antenna, the ground plane extension effectively acts as a radiator as on its own as illustrated by the current distribution plot in Figure 2. There the effective radius \( r \) will be greater than 7 mm as used in Figure 1. The effective \( r \) will be almost 2 \( r \). Hence, for the proposed antenna, the first resonant point will be around:

\[ f = \frac{3.2}{2r} = \frac{3.2}{2(0.7)} = 2.3 \text{ GHz} \]

Figure 2 shows the current distribution at different phases (or times) of the antenna. It can be noticed that in the beginning, the predominant current is dominated around the feedline and at the top edge of the
The design evolution of the antenna is shown in Figure 3. Ant 1 is a plane and extension play a role as role. The monopole is not the only contributor to radiation but the ground and the top part of the extension show dominant current. This shows that circular monopole. As time traverses, the right edge of the ground plane measured and simulated peak gain and efficiency of the proposed antenna. Figure 7 shows the fabricated and measured as shown in the next chapter.

3. Experimental results and discussion

The proposed antenna is fabricated and measured by using an Agilent E8363B performance network analyzer (PNA) and far field measurements were done with a Pyramidal Anechoic chamber (500 MHz–40 GHz) with Emerson and Cuming absorber. Figure 7 shows the fabricated antenna. Figure 8 shows the plot of the combined measured and simulated reflection coefficient. It can be noticed that the antenna works for S11 ≤ 10 between 2.3 – 10.5 GHz. Good agreement is observed between simulated and measured results. It should be noted that numerical simulations have been performed using the commercial package HFSS to achieve the optimized design of the antenna. The measured gain and efficiency plots are shown in Figure 9. It can be noticed that the measured gain ranges from 3 dBi to 6.5 dBi across the operating band. The measured efficiency ranging from 75 – 80 % is realized as well.

Simulated and measured E-plane (xoy, θ = –90) and H-plane (yoz, φ = 90) radiation patterns at 2.4, 4.8, 7 and 9 GHz are shown in Figure 10. Unidirectional radiation with F/B > 10 dB is achieved in both planes at all frequencies. The direction of radiation will mostly directed in the areas marked yellow in Figure 7. This is because the ground extension acts as a reflector in that direction.

4. Conclusion

A directional planar monopole UWB antenna has been described in this paper. By modifying the ground plane to act as a corner reflector, unidirectional radiation over an UWB frequency is achieved with improved impedance matching and bandwidth. The antenna achieves a 129.1 % fractional bandwidth from 2.3 – 10.5 GHz (VSWR <2) which is a 47.1 % increase in the original antenna. The antenna is printed on a low cost FR4 substrate, and it doesn’t employ external reflectors to achieve unidirectional radiation. The proposed antenna has a high and stable gain, and high efficiency. The proposed antenna is suitable for unidirectional UWB applications.
Figure 10. Simulated and measured $E$-plane (left) and $H$-plane (right) radiation pattern of the proposed antenna at (a) 2.4 GHz (b) 4.8 GHz (c) 7 GHz (d) 9 GHz.
Declarations

Author contribution statement

M. S. Ellis: Conceived and designed the experiments; Performed the experiments; Wrote the paper.
A.-R. Ahmed & J. J. Kponyo: Contributed reagents, materials, analysis tools or data.
K. O. Gyasi & K. S. O. Kwakye: Analyzed and interpreted the data.
S. Ameyaw: Performed the experiments.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

No data was used for the research described in the article.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] P.F. Hu, Y.M. Pan, S. Zheng, B.J. Hu, The design of miniaturized planar endfire antenna with enhanced front-to-back ratio, IEEE Trans. Antenn. Propag. 68 (10) (Oct. 2020) 7190–7195.
[2] N. Kaneda, W.R. Deal, Y. Qian, R. Waterhouse, T. Itoh, A broadband planar quasi-Yagi antenna, IEEE Trans. Antenn. Propag. 50 (8) (Aug. 2002) 1158–1160.
[3] Q. Chu, X. Li, M. Ye, High-gain printed log-periodic dipole array antenna with parasitic cell for 5G communication, IEEE Trans. Antenn. Propag. 65 (12) (2017) 6338–6344, Dec.
[4] J.G. Estrada, C.I. Pérez, A. Fajardo, A new broadband quasi Yagi-Uda antenna with an EBG-truncated ground plane, IEEE Antenn. Wireless Propag. Lett. 12 (2013) 1392–1395.
[5] P. Chi, Y. Chou, Planar quasi-Yagi antenna for future 5G and “WiGig” applications, in: Proc. IEEE Int. Symp. Antennas Propag. USNC/URSI Nat. Radio Sci. Meeting, 2018, pp. 1213–1214.
[6] H. Wang, K.E. Kedzie, J. Park, A high-gain and wideband seriesfed angled printed dipole antenna array, IEEE Trans. Antenn. Propag. 68 (7) (Jul. 2020) 5708–5713.
[7] W.-J. Lu, W.-H. Zhang, K.F. Tong, H.-B. Zhu, Planar wideband loop-dipole composite antenna, IEEE Trans. Antenn. Propag. 62 (4) (Apr. 2014) 2275–2279.
[8] J. Wu, Z. Zhao, Z. Nie, and Q.H. Liu, A broadband unidirectional antenna based on closely spaced loading method, IEEE Trans. Antenn. Propag. 61 (1) (Jan. 2013) 109–116.
[9] J. Wu, Z. Zhao, Z. Nie, Q. Liu, A printed unidirectional antenna with improved upper band-edge selectivity using a parasitic loop, IEEE Trans. Antenn. Propag. 63 (4) (Apr. 2015) 1832–1837.
[10] K. Ding, C. Gao, B. Zhang, Y. Wu, D. Qu, A compact printed unidirectional broadband antenna with parasitic patch, IEEE Antenn. Wireless Propag. Lett. 16 (2017) 2341–2344.
[11] S. Ahdi Rezaieh, M.A. Antoniades, A.M. Abbosh, Compact wideband loop antenna partially loaded with mu-negative metamaterial unit cells for directivity enhancement, IEEE Antenn. Wireless Propag. Lett. 15 (2016) 1893–1896.
[12] S. Ahdi Rezaieh, M.A. Antoniades, A.M. Abbosh, Gain enhancement of wideband metamaterial-loaded loop antenna with tightly coupled arc-shaped directors, IEEE Trans. Antenn. Propag. 65 (4) (Apr. 2017) 2090–2095.
[13] M. Boddapati, P. Kishore, Bandwidth enhancement of CPW-fed elliptical curved antenna with square SRR, Proc. Int. Journat of Intelligent Eng. And Systems 12 (11) (2018) 68–75.
[14] T. Anilkumar, B.T.P. Madhav, M.V. Rao, B.P. Nadh, Bandwidth reconfigurable antenna on a liquid crystal polymer substrate for automotive communications applications, AEU Int. J. Electr. Commun. 117 (153096) (2020) 1–13.
[15] X. Qing, Z.N. Cheng, A miniaturized directional UWB antenna, Proc. IEEE Int. Symp. Antennas Propag Soc. (2011) 1470–1473.
[16] S. Xiang, Y. Wu, M. Zhu, Design of wide band high gain unidirectional antenna with low profile, in: Proc. IEEE Int. Symp. Antennas Propag. Soc. USNC/URSI Nat. Radio Science Meeting, 2017, pp. 583–584.
[17] L. Ge, K.M. Luk, Band-reconfigurable unidirectional antenna: a simple efficient magneto-electric antenna for cognitive radio applications, IEEE Trans. Antennas Propag. Mag. 58 (2) (Apr. 2016) 18–27.
[18] M.S. Ellis, A. Ahmed, J.J. Kponyo, J. Nourinia, C. Gholami, B. Mohammadi, Unidirectional planar monopole antenna using a quasi-radiator, IEEE Antenn. Wireless Propag. Lett. 18 (1) (Jan. 2019) 157–161.
[19] G. Kumar, R.P. Ray, Broadband Microstrip Antennas, Artech House, Boston, M. A, 2003.