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Unidirectional Planar Monopole Antenna Using a Quasi-radiator

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***Abstract*—A compact wideband planar monopole antenna with unidirectional radiation properties is proposed in this paper. The measured results demonstrate that the antenna has an S_{11} < -10 dB bandwidth ranging from 2.3 – 6 GHz with an end-fire radiation pattern with front-to-back ratio (F/B) > 10 dB across the operating frequency range. The antenna is very simple; comprising of a slotted-stepped radiating patch attached to the ground plane through a shorting side-stub. The antenna has: a small size of 20 × 20 mm^2, good F/B, and does not require cavity-backed structures and ground plane extensions, making it attractive for compact wireless devices. The antenna also possesses stable main lobe directions.**

***Index Terms*— compact, reflector, wideband, unidirectional.**

I. Introduction

MORDEN wireless communication systems require antennas with compact sizes and good impedance matching over a large bandwidth. In certain applications like indoor wireless communications, unidirectional radiation characteristics are particularly required since it may be desirable to propagate the antenna's energy in a particular direction to avoid wastage, prevent interference, and for security reasons. Monopole antennas, owing to their simpler structure, ease of fabrication, light weight and low cost, would be advantageous for unidirectional radiation purposes. However, they have bi-directional radiation patterns.

Research on introducing unidirectional radiation patterns on conventional wire monopole antennas has been introduced in recent years [1]-[3]. In [1], a monopole that is vertically placed over a ground plane is made to radiate unidirectionally. This was achieved by loading an electrically dense material on one side of the monopole, thereby making the monopole radiate strongly in the one direction, and weakly in the direction of the dense material. In [2], an L-shaped monopole that is erected over a large ground plane is designed to realize circularly polarized unidirectional radiation. In [3], a vertical monopole antenna, erected over a large ground plane, is made to radiate unidirectionally by using the theory of soft and hard surfaces [4]. The aforementioned antennas [1]-[3] are non-planar monopole antennas.

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Research has also gone into introducing unidirectional radiation unto the planar/printed type of monopole antennas due to their low profile and ease of integration into MMICs. In [5]-[8], planar monopole antennas with cavity-backed structures, acting as reflectors, were proposed to achieve unidirectional radiation. However, the cavity-backed structures have to be placed at a distance greater than 0.1λ from the monopole. This technique achieves high F/B but makes the antennas large and impractical for portable systems. Some unidirectional planar monopole antennas have been introduced without cavity-backed structures [9]-[12]. Their unidirectional radiation is achieved by simply extending the ground plane to form an L-shaped structure, where the extended part serves as a reflector. Even though this method achieves unidirectional radiation to an extent, an F/B > 10 dB is difficult to realize and even when realized, doesn't cover the entire operating bandwidth. Additionally, the main lobe directions have various offsets at different frequencies which results in unstable radiation directions. There is a paucity of design techniques to achieve unidirectional radiation with planar monopole antennas. Recently, a new technique was introduced in [13] which employed a wrench-shaped feeding structure. This feed was used to introduce vertical currents and reduce horizontal currents on the antenna by studying the Theory of Characteristic Modes [14]. Even though this technique was novel compared to the reflector-techniques used in [5]-[12], it only realized unidirectional patterns at high frequencies: above 8 GHz.

This communication hereby aims at achieving three things. To: (1) introduce a new technique of realizing unidirectional radiation on planar omnidirectional monopole antennas, (2) attain F/B > 10 dB in the entire bandwidth and (3) produce a stable main lobe radiation direction at all frequencies. To achieve this, a simple, yet novel, and compact unidirectional wideband planar monopole antenna is presented. Unidirectional radiation is achieved by simply connecting the ground plane to the monopole using a shorting side-stub. By doing so, one edge of the radiator is shorted to the ground plane which results in non-radiation of the out-of-phase electric currents at that shorted end. Since only one side mainly radiates, the authors hereby term this as - a quasi-radiator. This configuration introduces unidirectional radiation with an F/B > 10 dB within the operating frequency of the antenna with stable main lobe directions across the entire bandwidth.

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II. Antenna Design and Evolution

The proposed antenna is shown in Fig. 1. It is fed by a 50Ω microstrip feedline printed on an FR4 substrate (thickness: 1.6 mm, relative permittivity: 4.4, loss tangent: 0.02). The evolution of the proposed antenna is shown in Fig. 2(a). Ant_1 has a basic monopole antenna structure: consisting of a radiator and a ground plane [15]. The evolution from Ant_1 to Ant_3 is explained as follows.

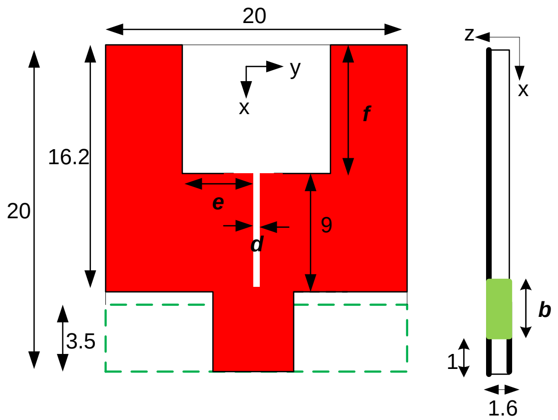


Fig. 1. Geometry of the proposed antenna with dimensions (b = 3mm, d = 0.8mm, e = 5.6mm, f = 7.2mm).

A. Formula for Resonant Frequency of Ant_1

The frequency corresponding to the lower resonance of a rectangular printed monopole can be approximately calculated by equating its area to that of an equivalent cylindrical monopole of same length L and equivalent radius R, as given below [16].

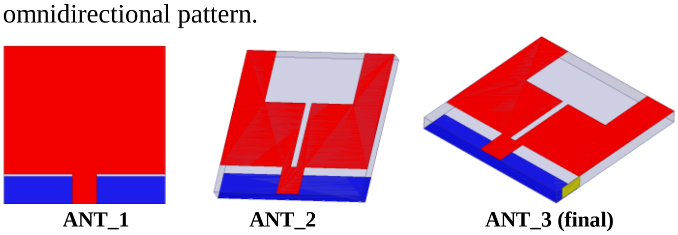
$$2\pi RL = LW \tag{1}$$

Where W is the width of the rectangular monopole.

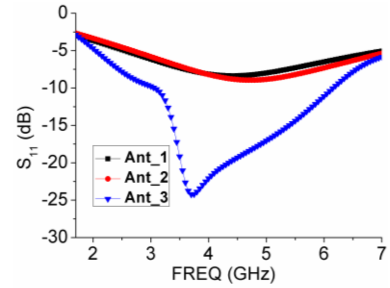
The lowest resonant frequency F_l (for $S_{11}\approx 10$dB) is given by:

$$f_l = 7.2 / (L + R + P)\ GHz \tag{2}$$

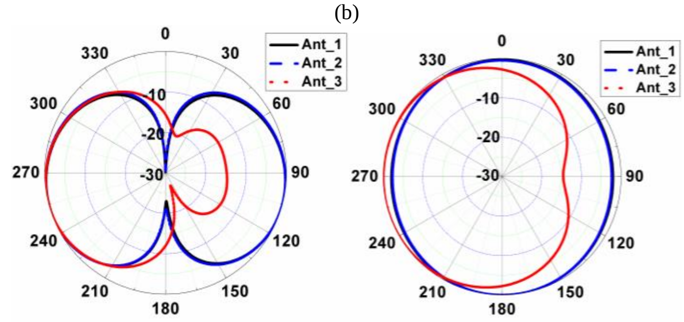
Where P is the probe length (gap between the ground plane and rectangular monopole). L, R, and P are in centimeters. Using equation (2) for chosen values of L=1.62cm, W=2cm, and P=0.03cm, a calculated f_l = 3.6 GHz is achieved. It can be verified in Fig. 2(b) that the S_{11} of Ant_1 (also Ant_2 and Ant_3) indeed starts to show signs of resonance around 4GHz. The impedance matching of Ant_1 is however poor due to the coupling between the ground plane's top edges and monopole's bottom edges due to their proximity. The impedance matching greatly improves when the gap is increased. This has not been shown for brevity. Figure 2(c) shows that Ant_1 has an omnidirectional pattern.



(a)



(b)

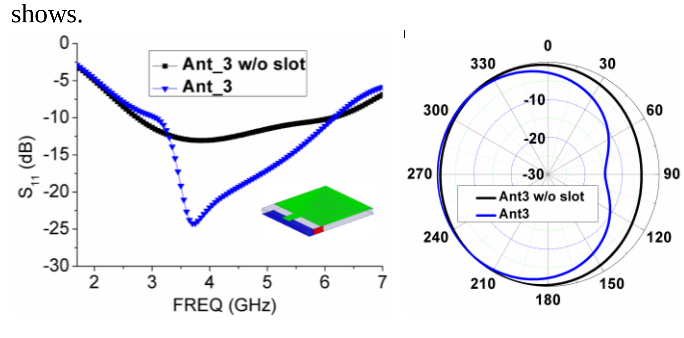


(c)

Fig. 2. Evolution of proposed antenna (a) design evolution (b) S_{11} evolution (c) evolution of simulated radiation pattern at 5 GHz in *xoy*- plane (left) and *yoz*-plane (right).

B. Importance of Fork-Shaped Slot in Ant_2

In Ant_2, a fork-like slot is introduced unto the radiator of Ant_1, with shape and dimensions (d, e, f) same as [11]. This slot separation helps to achieve better F/B and impedance matching when the side-stub (in Ant_3) is attached as shown in Fig. 3. It is noteworthy to mention that, introducing the fork-shaped slot alone into Ant_1 does not change the S_{11} and radiation pattern of Ant_1 as shown in Figs. 2(b) and 2(c). shows.



(a) (b)

Fig. 3. Combined simulated results of Ant_3 and Ant_3_without fork-slot: (a) S_{11}, (b) Radiation pattern at 5 GHz.

C. Introducing Shorting Side-stub in Ant_3

A side-stub is introduced next to connect the radiator and ground plane in Ant_3. The simulated S_{11} and radiation pattern are shown in Figs. 2(a) and 2(b) respectively. The results show that the impedance matching is greatly improved when the side-stub in introduced. Additionally, the antenna starts to exhibit unidirectional radiation pattern. The length of the side-stub and its effects when moved along the x-axis has no effect of the S_{11} and radiation patterns and has not been shown here for brevity. The position along y-axis, however, has been

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shown, in Fig. 4 below.

Effect of stub position: Figure 4 shows the effect on S_{11} and radiation patterns when the position of the stub is changed along *y*-axis. It shows that the best results are achieved when the side-stub is placed at the edge. When it moves 4mm in $-y$ direction, the S_{11} and F/B worsens but still maintains unidirectional radiation. When the stub moves 8mm in the $-y$ direction, the antenna loses its unidirectional properties and the S_{11} is very poor.

To make the proposed design method extendable to other frequencies, the following formulas have been proposed for our proposed antennas: $f\approx\lambda_0/10$, $l\approx f/5$, $w\approx\lambda_0/4$, $e\approx\lambda_0/13$, $d\approx e/5$, b≈$w/7$, $g_p\approx w/6$ (g_p = ground plane height), where λ_0 is the free space wavelength. To verify these empirical formulas, Ant_1, 2 and 3 were designed for f_l=2GHz and expected results, similar to Figs. 2, were realized. This has not been shown for brevity.

When the shorting side-stub is introduced, the currents are seen to be dominant towards the left monopole as shown in Fig. 5. From an electromagnetics perspective, this may be due to some image causing an array effect, or cancelling out the radiation towards the shorted end leading to unidirectional radiation. This can be confirmed from studying the vector surface currents in Fig. 6. When the side-stub is absent in Ant_2, symmetric current distribution is noticed on the left and right monopoles leading to in-phase current propagation. Now in Ant_3, the side stub causes the vector currents on the right monopole to be different from the left monopole. A reverse current distribution is noticed to appear on the right monopole which leads to phase cancellation of the currents at the shorted end. This phenomenon leads to the unidirectional radiation towards the -*y* direction.

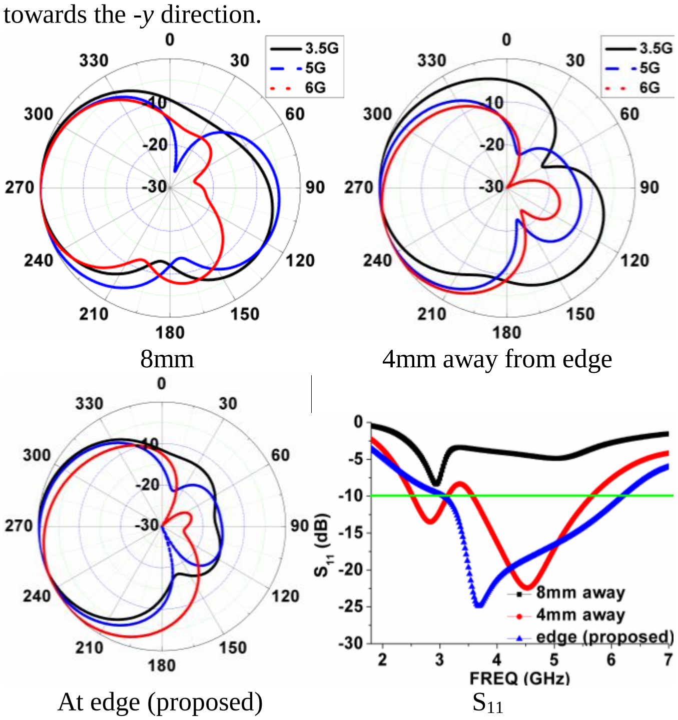

Fig. 4. Effect of stub position along *y*-axis on: S_{11} and radiation patterns at different frequencies

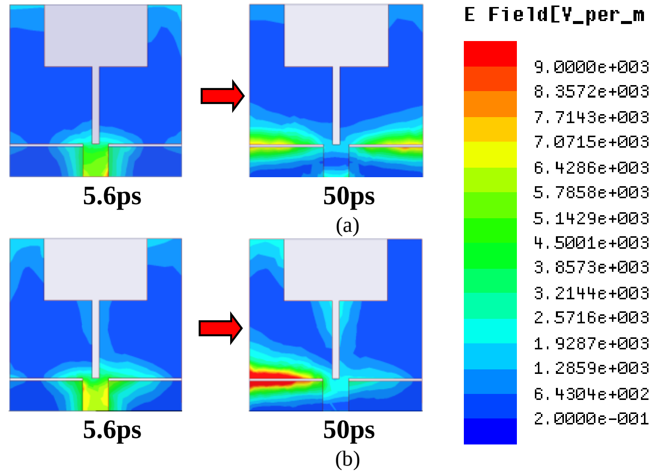

Fig. 5. Transient current distribution at 5 GHz for: (a) ANT_2 (without stub) (b) ANT_3 (with stub).

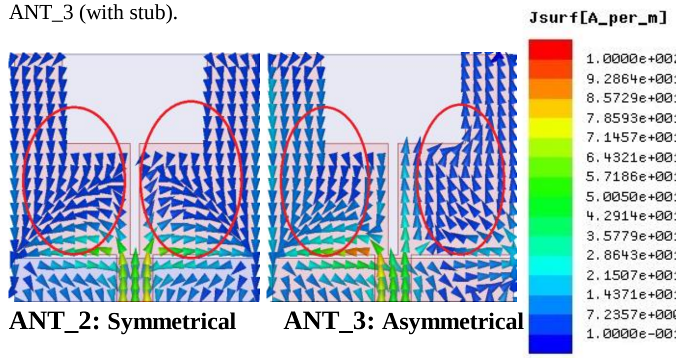

Fig. 6. Vector surface-current distribution of the antenna: with and without the shorting side-stub.

III. Experimental Results

The S_{11} of the proposed antenna was measured using a PNA E8363C Agilent Network Analyzer and the far-field measurements were done with a Pyramidal Anechoic chamber (500MHz-40 GHz) with Emerson and Cuming absorber. The fabricated prototype of the proposed antenna under test is shown in Fig. 7. The simulated and measured results are illustrated in Figs. 8 to 10. The measured S_{11} < -10 dB plot shows an impedance bandwidth from 2.3-6GHz, which is about the same as the simulated S_{11} with attached SMA. The simulated bandwidth is from 3-6GHz without SMA. As Fig. 8 shows, the discrepancy between the simulated and measured results is mainly due to the attached SMA connector. When the SMA is connected, it increases the electrical size of the ground plane, which improves the lower end frequency. Other minor discrepancies may be due to fabrication imperfections.

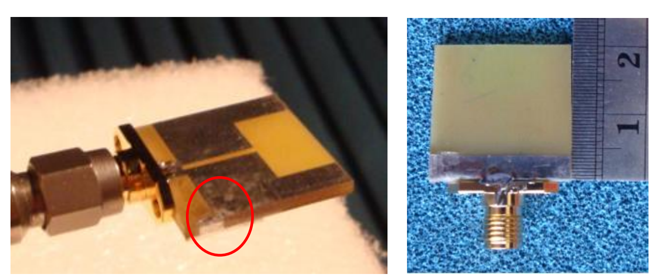

Fig. 7. Fabricated prototype showing a shorting side-stub and attached SMA.

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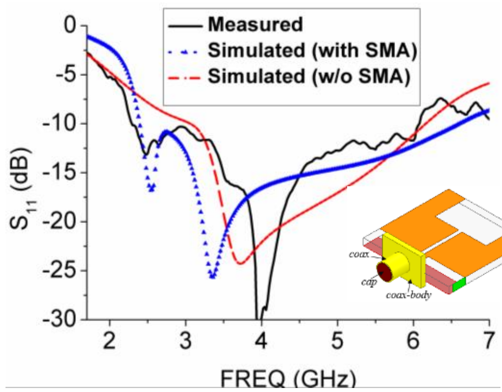
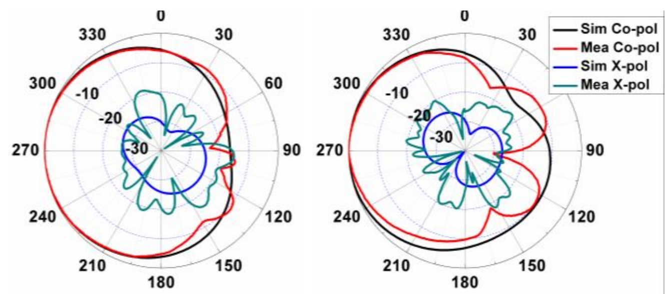
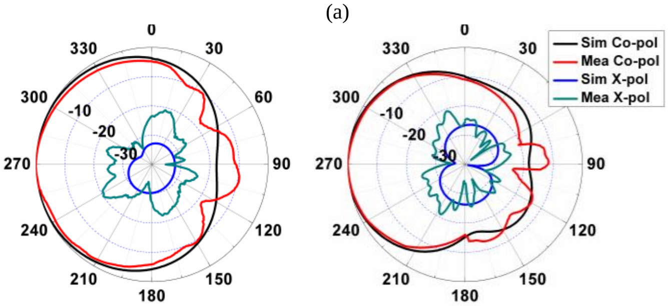


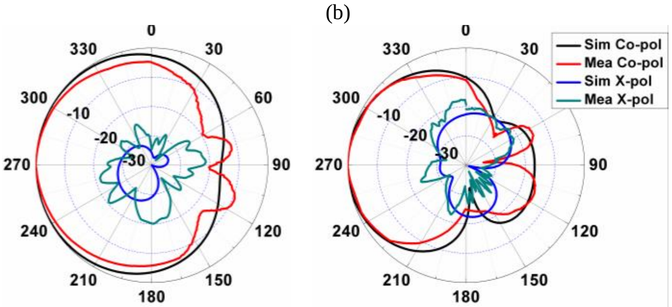
Fig. 8. Measured and simulated S_{11} of the proposed antenna.



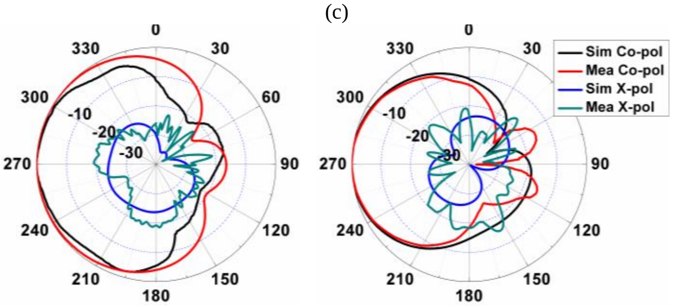
(a)



(b)



(c)



(d)

Fig. 9. Measured and simulated radiation pattern at *yoz (left)* and *xoy (right)* planes at: (a) 2.4 GHz (b) 3.5 GHz (c) 5 GHz (d) 6 GHz.

The simulated and measured radiation patterns are illustrated in Fig. 9. They show unidirectional radiation in both *E*- and *H*-planes. In both principal planes, the main lobe radiation directions are perfectly aligned in one direction (-90° or -*y*-direction) unlike [9]-[12], with F/B > 10 dB in both planes across all frequencies unlike [9]-[12]. The F/B is even better than 15 dB at some frequencies. The simulated and measured radiation patterns agree well. The simulated and measured peak gains are shown in Fig. 10. In the main lobe radiation direction, an average peak gain of about 2.25 dBi is realized within the operating bandwidth. Again, the discrepancy in results is due to the attached SMA connector. When the connector is included in simulation, the measured and simulated results are almost equal. Due to the similarity in shape between the proposed antenna and [11], Table I is shown below to compare them in terms of structure and electrical performance. It is worth noting that, even though achieving ultrawideband (UWB) was not the goal of this research, the proposed antenna can still realize UWB bandwidths [17]

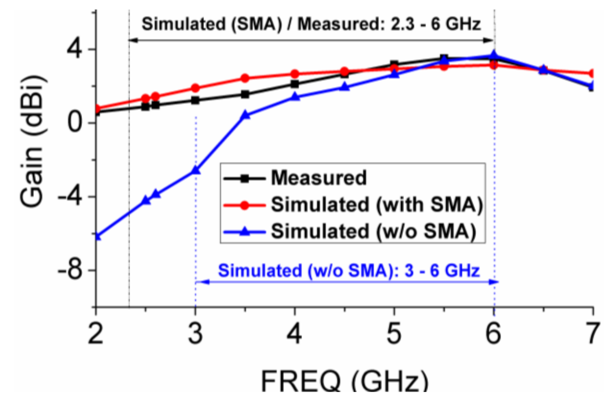


Fig. 10. Measured and simulated peak gain of the proposed antenna.

TABLE I
A COMPARISON OF PROPOSED ANTENNA WITH REF. [11]

Parameters	Proposed	Ref. [11]
Technique used	Quasi-radiator	Reflector
Structure	Microstrip	CPW
Size (mm^2)	20 × 20	20 × 20
S_{11} bandwidth (%)	89.2	38.3
F/B (dB)	>10 at all freqs	<10 at some freqs
Main lobe direction	No offsets	Various offsets

IV. CONCLUSIONS

A novel wideband unidirectional planar monopole antenna is presented in this communication. To achieve unidirectional radiation, a quasi-radiator is used. It has been demonstrated through simulation and measurement that this technique provides a novel way of converting a bidirectional/ quasi-omnidirectional planar monopole antenna to a unidirectional planar antenna, without cavity-backed reflectors or ground-plane extended reflectors.

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