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A Planar Monopole UWB Antenna with Improved Lower End Bandwidth Using an L-shaped Stub Extended on the Ground Plane

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Abstract—In this work, a planar monopole ultra-wideband (UWB) antenna with an L-shaped stub on the ground plane is proposed. The novel extended L-stub in conjunction with the UWB radiator achieves an ultra wideband impedance matching with a compact size. The proposed antenna is fabricated and measured showing an ultra wide operating frequency range from 2.3 to over 14 GHz (VSWR < 2) with a unidirectional gain from 3–6.5 dBi and efficiency from 70–85% within the UWB band from 3.1–10.6 GHz. The proposed antenna provides a new way to improve ultra wideband impedance matching other than the frequently used tapered microstrip feed line. It also provides a way to improve the lower frequency bandwidth of the antenna without increasing the antenna's physical size, which is the most common method to use.

1. INTRODUCTION

With the rapid development in wireless communications, UWB systems have gained popularity because of its wide operating bandwidth. Planar UWB antennas [1–3] have gained tremendous interests due to their compact size, low cost, ease of fabrication and low power spectral density. Several UWB monopole configurations have been proposed, such as circular, square, elliptical, pentagonal, hexagonal and circular, among which the square monopole and circular monopole are most popular.

The circular monopole was investigated in [4]. It consists of a circular radiator connected to a 50-Ω microstrip line printed on the top of a substrate, and a ground plane printed at the back of the substrate. In [5], it was reported that the microstrip feed line had significant effects on the performance of the circular monopole UWB antenna. Three different microstrip feed structures were demonstrated, i.e., the uniform feed, the one point touch type and the tapered microstrip line [5]. The tapered microstrip line was recorded to achieve the best impedance matching. Since then, most of the reported circular monopole UWB antennas have utilized the tapered microstrip feed line technique to improve their impedance matching.

In planar monopole antennas, the lowest frequency is determined by the longest electrical length of the surface current. In this vein, many different antennas [6–8] have been studied to improve the lower frequency by using monopole shapes capable of extending the electrical length of the currents.

In this paper, an L-shaped stub is extended on the ground plane to improve the impedance matching and extend the low frequency bandwidth of a circular planar monopole UWB antenna without increasing the antenna's physical size. Here, the proposed L-shaped stub is investigated for two antennas; (1) a reference antenna [9], which is a planar monopole antenna with a corner reflector to introduce unidirectionality in radiation, and (2) a similar antenna like in (1) but without the corner reflector for omnidirectional radiation. In both cases, the L-shaped stub works the same and increases the lower end bandwidth to achieve a UWB bandwidth without increasing the antennas' physical sizes.

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To validate our design, simulations are done on both antennas (1) and (2); however, measurements are done only on the reference antenna; (1), for simplicity.

2. ANTENNA DESIGN AND ANALYSIS

The proposed antenna structure is shown in Figure 1. It is printed on an FR4 substrate with a thickness of 1.6 mm and a relative permittivity of 4.4. The width of the feed line is 3 mm. The antenna consists of a circular radiating patch and a microstrip feed line with a taper printed on the top layer of the substrate, while the ground plane with a corner reflector and the L-stub are printed on the bottom. The proposed antenna is fed by a 50-Ω SMA connector. The optimized geometry is shown in Figure 1(a). The proposed antenna occupies an area of $50 \times 50\,\mathrm{mm}^2$. This is the same size as is used in [9], which only achieved a starting frequency of 5.5 GHz. By using the extended L-stub proposed in this paper, we can improve the lower end impedance bandwidth to cover the entire UWB band without increasing antenna size. The antenna used in [9] is used as a reference antenna to validate the proposed technique.

In principle, the L-stub provides an extra current path to help improve the low frequency bandwidth. This is illustrated in Figure 2. It shows three snapshots of the transient current distribution in one cycle at 2.5 GHz. It can be noticed from the figure that, in the beginning, the maximum transient currents flow along the microstrip line. After 67 ps, the maximum transient currents flow along the edges of

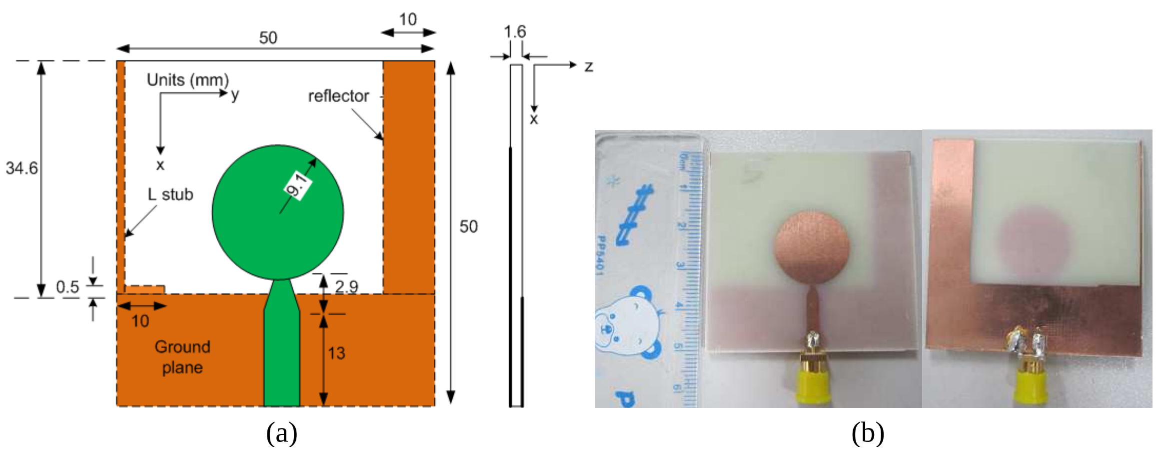

Figure 1. Proposed antenna configuration. (a) Geometry of the proposed antenna. (b) Photograph of the fabricated prototypes of the antenna.

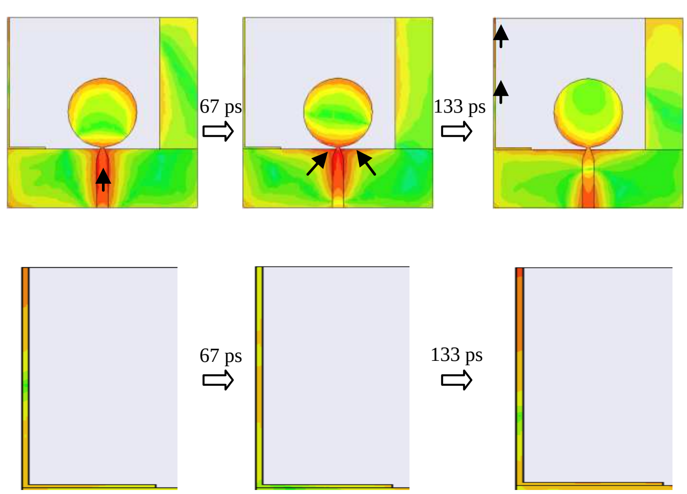

Figure 2. Transient current distribution at 2.5 GHz.

the ground plane beneath the radiator and along the bottom half of the radiator. After 133 ps, the maximum transient currents flow along the L-stub thereby increasing the electrical currents path. At this point, the L-stub acts like an independent monopole radiator and it introduces a resonant point at that frequency leading to an increase in bandwidth.

Figures 3(a)–(c) show the different geometries of the circular planar monopole antenna. (a) Shows the reference antenna. (b) Shows the reference antenna with tapered feed. (c) Shows the reference antenna with the proposed L-stub extending from the ground plane. Figure 3(d) shows the simulated S_{11} for all the three geometries. It can be noticed that, the reference antenna is poorly matched with the lower frequency starting at 5.5 GHz. However, the impedance matching is slightly improved by using the tapered feed line. When the L-stub is introduced, the impedance matching in the low frequency band is greatly improved, and the antenna satisfies the UWB frequency band.

With the knowledge of how the L-stub works, different stub lengths are investigated to see how they affect the antenna. It can be noticed in Figure 4 that, as the length of the L-stub reduces, the impedance matching gets worse at low frequency. This is because the antenna ceases to resonate at the design frequency and the impedance matching worsens. This is further explained in Section 3.

To demonstrate that the effect of the L-stub is not affected by the corner reflector of the reference antenna in [9], the L-stub is also demonstrated on the same antenna without the corner reflector. It can be noticed in Figure 5(d) that, the antenna with the L-stub in Figure 5(c), still achieves the best impedance matching and bandwidth, the tapered feed line in 5(b) is next and the uniform feedline

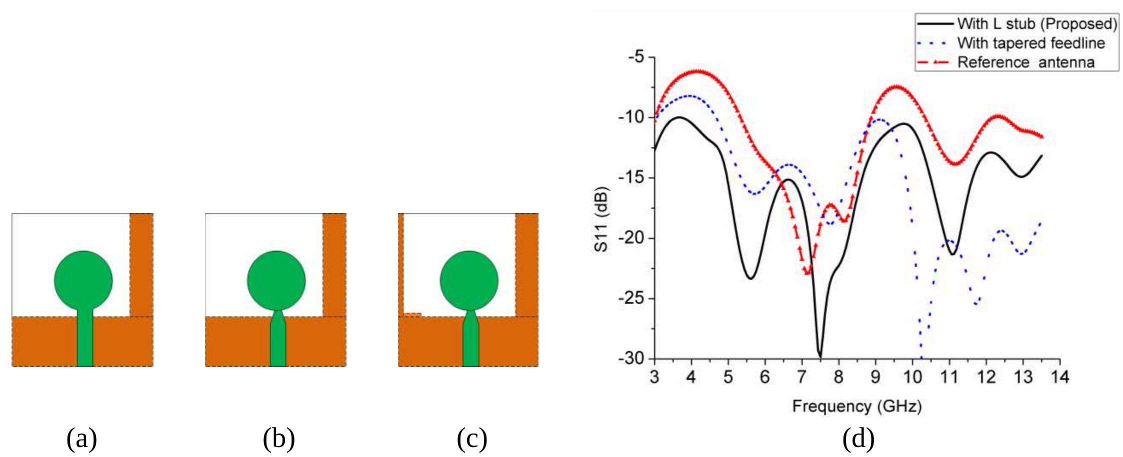

Figure 3. (a) reference antenna. (b) Reference antenna with tapered feed. (c) Reference antenna with proposed L-stub. (d) Return loss for the antennas a, b, and c.

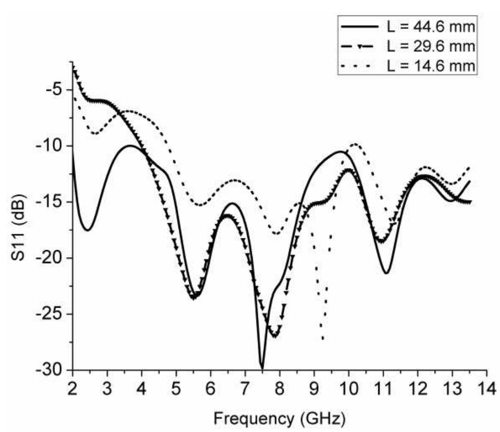

Figure 4. Effect of different L-stub lengths on impedance matching and bandwidth.

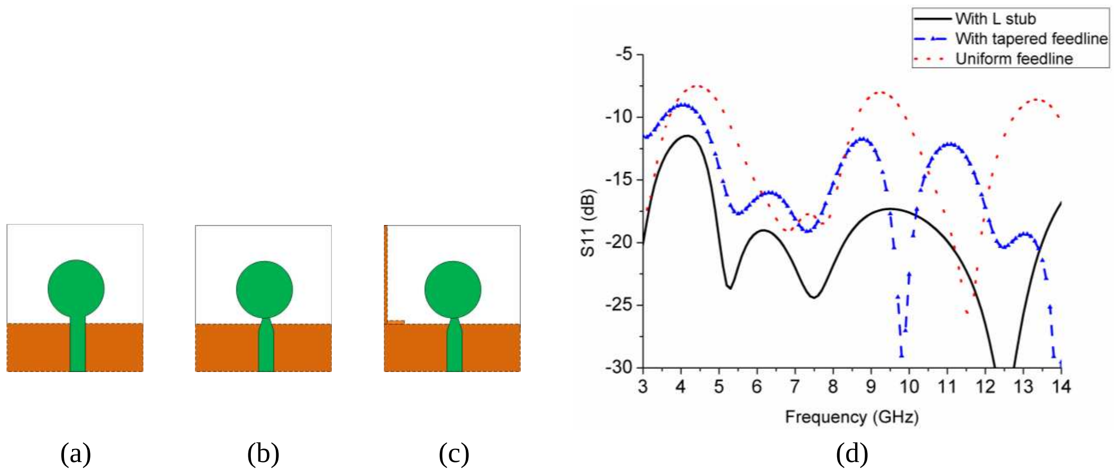

Figure 5. (a) Uniform feed. (b) Tapered feed. (c) Proposed L-stub. (d) Return loss for the antennas a, b, and c (reference antenna **WITHOUT** the corner reflector).

in 5(a) has the worst impedance matching. This result is in agreement with the reference antenna designs in Figure 3(d). Therefore it is safe to say that the L-stub works the same for both antennas; with and without the corner reflector.

3. EXPERIMENTAL RESULTS

The theory behind the L-stub is that at microwave frequencies it acts as an independent radiating monopole. Hence it resonates at its design frequency and increases the bandwidth of the antenna. Since the stub acts as a monopole, the initial value of the length can be given as, $L = \lambda_e/2$, $\lambda_e = \lambda_o/\sqrt{\varepsilon_e}$, $\varepsilon_e \approx (\varepsilon_r + 1)/2$. In our design, the resonant frequency is chosen at 2.5 GHz. The initial (calculated) value obtained by using the equation is approximately 36.5 mm. The length is then optimized to achieve a final value. It should be noted that the vertical part of the L-stub is mostly responsible for improving the impedance matching, and the horizontal part acts somewhat as a feed to the vertical part and also helps increases the intensity of the resonant points. Therefore the calculated value for L, shown in the equation corresponds to the vertical part of the extended stub. In our design, the final (optimized) value to achieve a resonance at 2.5 GHz was 34.6 mm which is close to the initial (calculated) value of 36.5 mm.

The optimized antenna was simulated with HFSS and measured with an E8363 performance

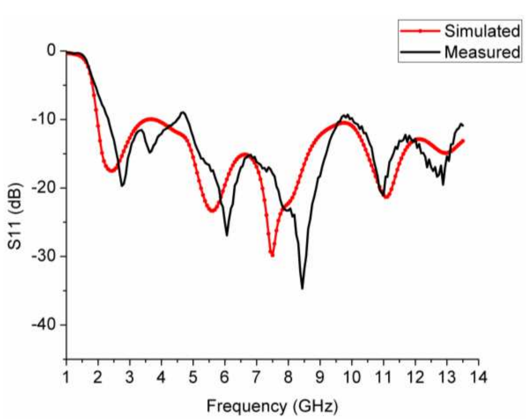

Figure 6. Simulated and measured return loss of the proposed antenna.

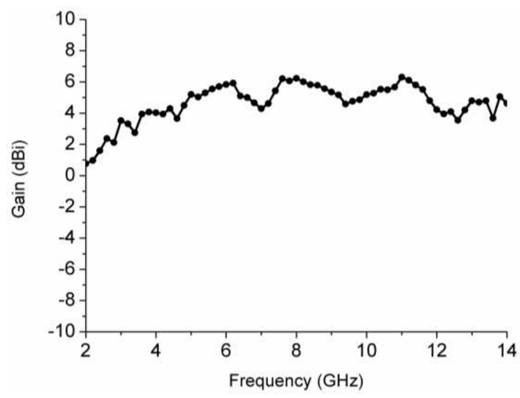

Figure 7. Measured gain of the proposed antenna.

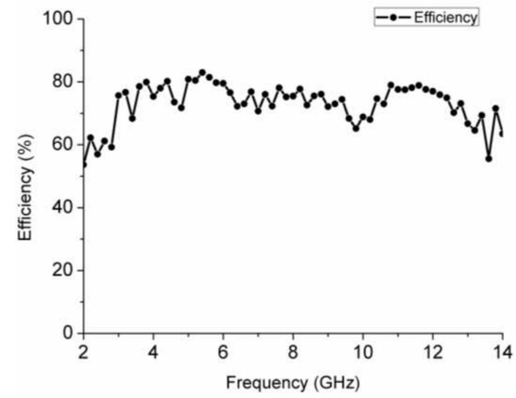

Figure 8. Measured efficiency of the proposed antenna.

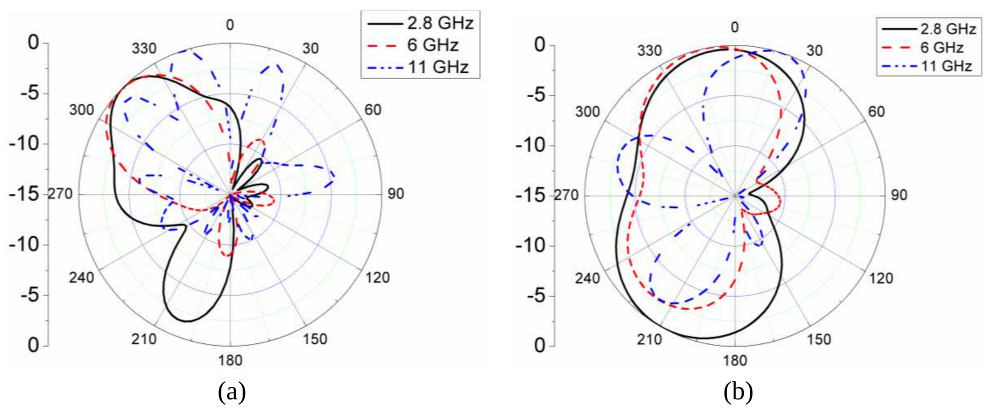

Figure 9. Measured radiation patterns of proposed antenna. (a) E-plane. (b) H-plane.

network analyzer (PNA) and a SATIMO measurement system. The simulated and measured S_{11} are plotted in Figure 6. It can be noticed from the measurements that the antenna resonates close to 2.5 GHz as predicted from calculation. The discrepancy between the simulated and measured results is due to the numerical errors in simulation and the attached SMA connector. The bandwidth from 2.3 to over 14 GHz (VSWR < 2) is achieved, compared to the reference antennas lower frequency of 5.5 GHz in [9]. The simulation and measurement agree well. The measured gain and efficiency are shown in Figures 7 and 8, respectively. Peak gain between 3–6.5 dBi and efficiency between 75–80% are achieved across the entire UWB bandwidth.

The measured radiation patterns are given in Figure 9. The antenna is printed on the xy plane. The E-plane (xy, $\theta = -90°$) and H-plane (yz, $\phi = 90°$) are shown in Figures 9(a) and 9(b) respectively. The E- and H-planes depict a unidirectional radiation pattern with F/B ratio $\geq$ 10 dB at all three frequencies. It should be noted that, even though the L-stub is in the end-fire direction, it doesn't attenuate the radiation towards it and it solely works to improve to the impedance matching and lower end bandwidth of the antenna.

4. CONCLUSION

A planar circular monopole UWB antenna with a novel L-shaped stub extending from the ground plane is proposed and investigated. It was shown by both simulations and experiments that the proposed UWB antenna achieves a bandwidth form 2.3 to over 14 GHz, with an average gain of 4.75 dBi and an average efficiency of 77.5%. With the help of the L-stub, the impedance matching and lower frequency bandwidth of the antenna are improved to realize a UWB band. Results also show that the performance of the L-stub is unaffected by the ground plane modifications (reflector). This technique is proven to improve lower frequency impedance bandwidth without modifications in monopole, ground plane and without changing the antenna's physical size. The proposed antenna will be suitable for UWB radar applications and other UWB point-to-point applications.

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