Design of a Planar UWB Antenna with New Band Enhancement Technique

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Abstract **─** A planar antenna and a technique for enhancing its bandwidth for UWB applications have been proposed in this paper. The proposed antenna which has a compact structure and the total size of 30 × 22 mm^2 consists of a square patch and a partial ground plane. Numerical study shows that the bandwidth of the proposed antenna can be controlled mainly by the patch size and width of the feeding line. The cutting triangular shape slots on the top edge of the ground plane help to increase the bandwidth by 43.6% (3.89 GHz). The measured -10 dB return loss bandwidth of the proposed antenna ranges from 2.95 GHz to 15.45 GHz which covers the entire UWB band. The nearly stable radiation pattern with a maximum gain of 5.9 dBi makes the proposed antenna suitable for being used in UWB communication.

Index Terms **─** Microstrip feed-line, partial ground plane, planar antenna, ultra-wideband.

I. INTRODUCTION

Ultra-wideband (UWB) technology has been regarded as one of the most prolific wireless technologies having the capability of revolutionizing a high data rate transmission. A number of new techniques to support high data rate in wireless communication for the next generation technologies have been rapidly increasing after the release of 3.1–10.6 GHz unlicensed band for UWB communication by the Federal Communication Commissions (FCC). UWB also have wide applications in short range and high speed wireless communication, such as ground penetrating radars, microwave imaging system, wireless local area networks (WLAN), communication systems for military, and short pulse radars for automotive even or robotics and in all these applications antenna with wideband plays a vital role. As a key component of UWB systems, the antennas with wide bandwidth have been investigated by both academia and industry.

The design of a compact, lightweight antenna for wideband applications is still a major challenge. Many coplanar waveguide-fed and microstrip line- fed antennas have been proposed for UWB applications. Several bandwidth enhancement techniques-have also been considered, such as associating several radiating elements to form an array antenna[1], using log periodic arrays in which the different elements are deduced from a homothetic ratio in order to reach the desired bandwidth [2], introduction of a capacitive coupling between the radiating element and the ground plane [3], addition of slots on the side of the radiating element [4-5], using a tapered feed line [6], notching the ground plane and/or the patch [7-8], modifying the shape of the radiating element and adding a shorting pin [9]. However the antennas mentioned above are not planar structured as they were set above a big ground plane which resulted in increased antenna size and cannot be easily embedded into wireless devices or cannot be integrated with other RF circuits.

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Recently other techniques have also been examined to enhance the antenna bandwidth, including the insertion of a modified trapezoid-shaped slot in the patch [10], the use of trident-shaped feeding strip and a tapered impedance transformer [11] and embedding a pair of notches in the two lower corners of the patch and the notch structure in the upper edge of the ground plane [12]. The use of two bevel slots on the upper edge and two semicircle slots on the bottom edge of the ground plane [13], insertion of a rectangular slot on the top side of the ground plane[14] and a half-bowtie radiating patch with staircase shape [15] have also been reported for the bandwidth enhancement. Techniques such as adding steps to the lower edge of the patch [16], inclusion of circular ring-shaped patch [17], the insertion of additional stub to the one side of circular patch [18], and addition of the slit on one side of the radiating element [19] have also been reported for bandwidth enhancement in planar monopole antennas. Recently, it was demonstrated in [20] that by etching two rectangular slots in the ground plane, the total bandwidth of the monopole antenna can be significantly increased up to the surface current distribution to ameliorate the antenna's impedance bandwidth.

Many of the above mentioned printed UWB antennas consisting of a planar radiator and system ground plane is essentially an unbalanced design, where the electric currents are distributed on both the radiator and the ground plane so that the radiation from the ground plane is inevitable. Therefore, the performance of the printed UWB antenna is significantly affected by the shape and size of the ground plane in terms of the operating frequency, impedance bandwidth, and radiation patterns [21- 23].

In this paper, a technique to enhance the bandwidth of a microstrip-fed planar monopole antenna has been proposed. The monopole antenna fed by a 50Ω microstrip feed line is fabricated on the FR4 substrate. To improve the bandwidth, the top side of the partial ground plane has been modified to form a sawtooth-shape and by this modification it is found that, the bandwidth is enhanced by 43.6% compared the initial design. The proposed antenna is easy to be integrated with microwave circuitry for a low manufacturing cost.

II. ANTENNA DESIGN

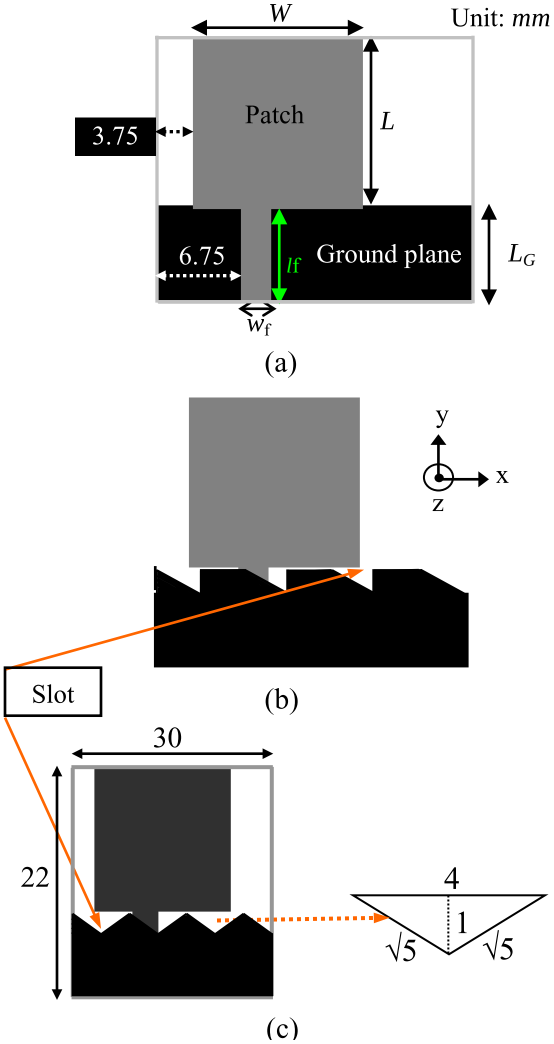
The geometries of square patch planar monopole antennas that are considered in this paper are shown in Fig. 1. The planar monopole antennas are chosen in this paper due to their remarkably compact size, low spectral power density, simplicity, stable radiation characteristics, and easy to fabricate and very easy to be integrated with microwave circuitry for low manufacturing cost. A shortcoming of this structure is limited bandwidth. The objectives of this paper are to modify the structure of the ground plane and incorporate the techniques to increase the bandwidth.

The configuration in Fig. 1 (a) is the first antenna used for a parametric study. The almost square patch with dimension $W \times L$ is printed on a 30×22 mm^2 low cost FR4 PCB substrate of thickness 1.6 *mm*, with relative permittivity 4.6 and loss tangent 0.02. The radiating patch is 6.75 *mm* away from the left edge of the substrate. A microstrip feed line of width w_f which is 3.75 *mm* away from the left edge of the substrate is also printed in the same side of the patch as a radiator. The partial ground plane having side length L_G is printed on the other side of the substrate. The length of the microstrip feed line is fixed at 7.25 *mm* to achieve a 50Ω characteristic impedance.

The patch size of the proposed antenna is the first parameter to optimize for widest bandwidth while the other parameters are kept constant. The results in Fig. 2 show that, the increase of patch size is resulting in a reduction of the bandwidth. It is also seen that that decrease in patch size from a certain value gives a better return loss value at the cost of bandwidth reduction. A patch size of 14.5×14.75 mm^2 is taken as the optimized value.

The width of microstrip feed line is the most sensitive parameter which influences the bandwidth most. It can be seen from the Fig. 3 that, when the feeding width increases the bandwidth decreases dramatically giving two distinct frequency bands with lower return loss values. The bandwidth also decreases when the feeding width is decreased from a certain value. A feeding width of 3 *mm* is the best fitting to give the widest impedance bandwidth.

To compact the antenna it is desirable that the ground plane must have the minimum size. The dimensions of the partial ground plane are the next parameters to be optimized which influence the return loss as well as the bandwidth. A change in the ground plane size offers a simple way to improve the antenna performance, but at the cost of increasing the antenna volume. From Fig. 4, it is observed that, when the ground plane dimensions increases the bandwidth decreases. Again, the bandwidth is decreases with the decrement of ground plane dimension from a certain value though it provides the lowest return loss values. The ground plane dimension of 30 × 7.5 mm^2 is taken as the optimized value to give the widest bandwidth. From the optimization of these parameters it is seen from the Fig. 5 that, the antenna without any slot in the ground plane is capable tuning from 3.04 GHz to 11.94 GHz providing an impedance bandwidth of 8.89 GHz.



(a)

(b)

(c)

Fig. 1. Geometries of the proposed planar antenna (a) initial design, (b) with straight slots, and (c) final design with sawtooth shape slots in ground plane.

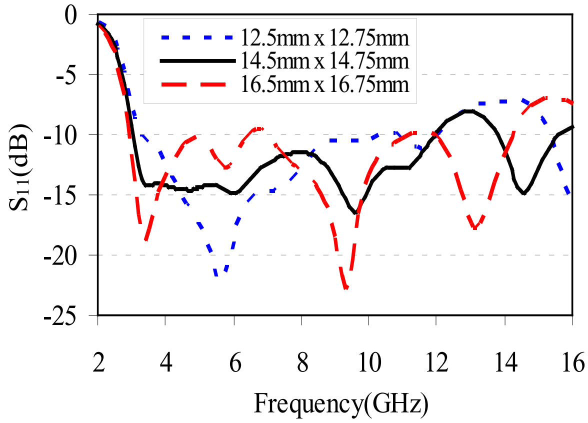


Fig. 2. Simulated *S* parameters for different patch sizes (*W*×*L*).

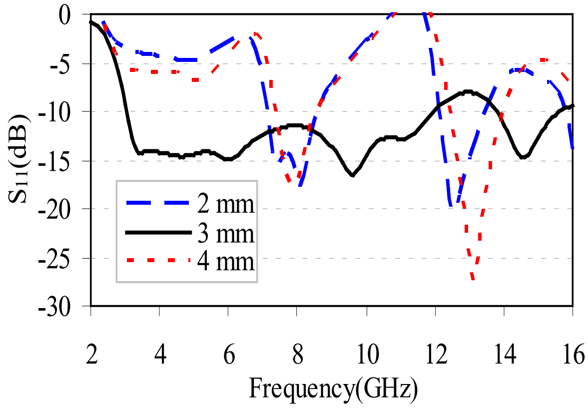


Fig. 3. Simulated *S* parameters for different feeding width, W_f.

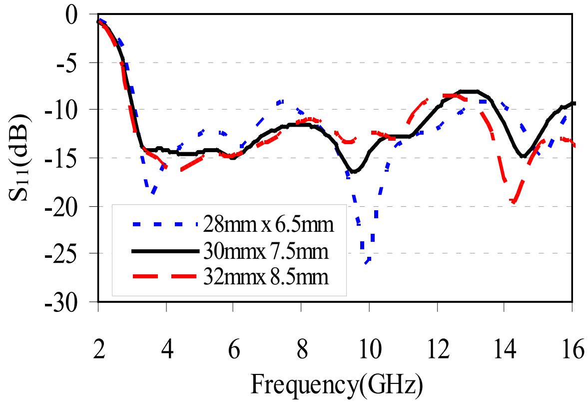


Fig. 4. Simulated *S* parameters for different ground plane size (W×L_G).

To improve the bandwidth of the antenna, triangular shape slots are introduced at the top side of the ground plane. The resultant antenna is shown in Fig. 1(b). The return losses in Fig. 5 shows that the triangular slots of dimension $2 \times 1 \times \sqrt{5}\ mm^3$ has small effect on the lower edge frequency while it increase the upper edge frequency of the operating band and the antenna can provide an impedance bandwidth of 9.48 GHz operating from 2.96 to 12.44 GHz. Compared to the initial design without slot in the ground plane, the antenna with triangular slots on the top edge of the ground plane can enhance the bandwidth by 0.59 GHz.

To enhance the bandwidth further, the top edge of the partial ground plane is reshaped to form a sawtooth shape top edge, as shown in Fig. 1(c). The optimized dimension of the triangular shape slot is $4 \times \sqrt{5} \times \sqrt{5}\ mm^3$. From the return loss curve shown in Fig. 5, it is seen that the modified ground plane with sawtooth shape top edge has little effect on lower edge frequency while it significantly influences the upper edge frequency of the operating band. It is also seen from Fig. 5 that the antenna with modified ground plane can be operated from 2.92 GHz to 15.70 GHz providing an impedance bandwidth of 12.78 GHz. It is also observed that, introduction of triangular shaped slots not only widens the bandwidth but also reduces the return loss. The insertion of slots in the top edge of the ground plane increases the gap between the radiating patch and the ground plane and as a result the impedance bandwidth increases further due to extra electromagnetic coupling in between the radiating element and the ground plane. Compared to the result associated with the initial design, the antenna with a modified sawtooth shape ground plane can increase the bandwidth by 43.6% (3.89 GHz) as shown in Fig. 5. From Figs. 2-5, the effect of a triangular shape slots on the top edge of the partial ground plane can be thoroughly comprehended. From Fig. 2, it can be seen that the first two resonant frequencies are tunable by the patch size and square patch capable of supporting multiple resonant modes. Second, it is also clear from the Figs. that the third resonance is determined by slots on the ground plane and the slots almost have no effect on the first two resonant frequencies. As the size of the slots increases, the return loss value at third resonant frequency also increases.

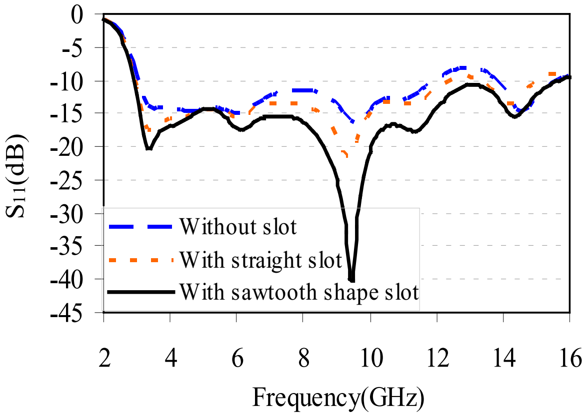
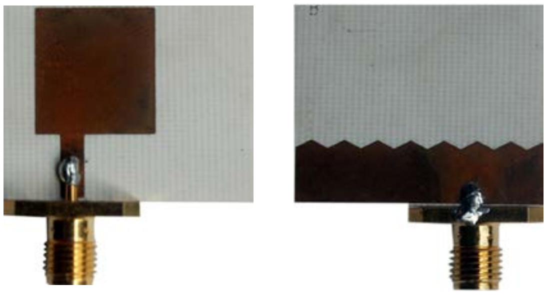


Fig. 5. *S* parameters without, with straight and with sawtooth shape slot in the ground plane.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The performance of the proposed antenna has been analyzed and optimized by commercially available method of moments based full-wave electromagnetic simulator IE3D ver. 12.3 from Zeland. The antenna was subsequently prototyped for experimental verification as shown in Fig. 6. The antenna has been measured in an anechoic chamber using Satimo hybrid StarLab 16 near field antenna measurement system and Agilent E8362C PNA series vector network analyzer [24]. To achieve untruncated extent near field sampling using a probe array, the spherical scanning system was utilized for this near-field antenna measurement system and is shown in Fig. 7.



Top view Bottom view

Fig. 6. Photograph of the realized antenna.

Fig. 7. Antenna measurement setup in StarLab.

Using standard spherical wave expansion techniques, the antenna radiation can be fully defined by a set of modal coefficients. These modal coefficients are fed to software employing a ray propagation technique. Probe array technologies are now accepted as an efficient and accurate tool for antenna measurements.

Figure 8 shows the measured and simulated return losses. The simulated -10 dB return loss bandwidth ranges from 2.92 GHz to 15.70 GHz (137.3%). This wideband characteristic of the printed compact planar monopole antenna is confirmed in measurement, with only a small shift of the lower and upper edge frequency to 2.95 GHz and 15.45 GHz, respectively.

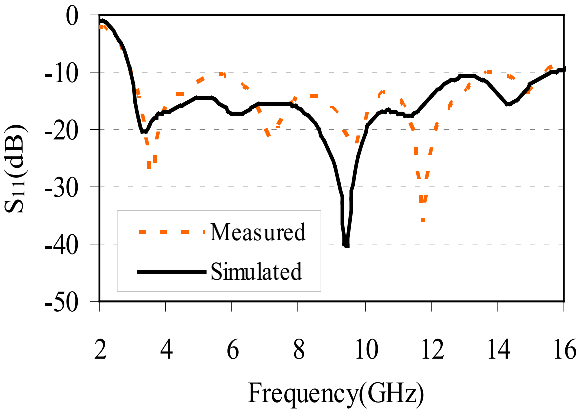


Fig. 8. Measured and simulated *S* parameters.

The disparity between the measured and simulated results is possibly attributed due to manufacturing tolerance and imperfect soldering effect of the SMA connector. It also may be due to the effect of the feeding cable, which is used in the measurements but not considered in simulation. The measured peak gain of the proposed realized antenna at boresight (+z direction) in the frequency range of 3 to 11 GHz is shown in Fig. 9. It is observed that the antenna has a good gain with a maximum value of 5.9 dBi at 9.4 GHz. The average gain is 3.92 dBi and the measured gain variations are less than ± 2 dBi. The measured radiation efficiency of the proposed antenna at boresight ($\theta=0^0$, $\varphi=0^0$) is shown in Fig. 10. The antenna has a maximum of 90.2% radiation efficiency. The gain and radiation efficiency of the proposed antenna are affected by the size of the partial ground plane.

Figure 11 shows the measured radiation patterns of the proposed antenna in two principal planes-namely, *xz*- and *yz*- planes for three resonant frequencies of 3.3, 6.2, and 9.4 GHz. It is observed that the radiation patterns of the proposed antenna present approximately omnidirectional and stable radiation characteristics in *xz*-plane over the operating band. Although some harmonic is introduced at higher frequencies, in *yz*-plane radiation patterns are about the same as that of a monopole antenna. The dips that observed mainly in E_φ both in *xz*- and *yz*-plane could be due to the fact that the microstrip feed line is directly printed below the slotted partial ground plane (along *y*-axis).

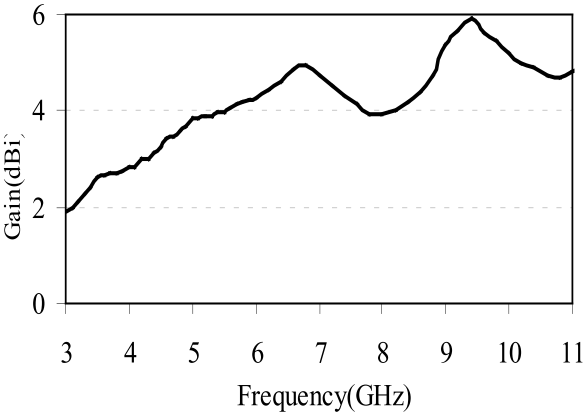


Fig. 9. Measured peak antenna gain.

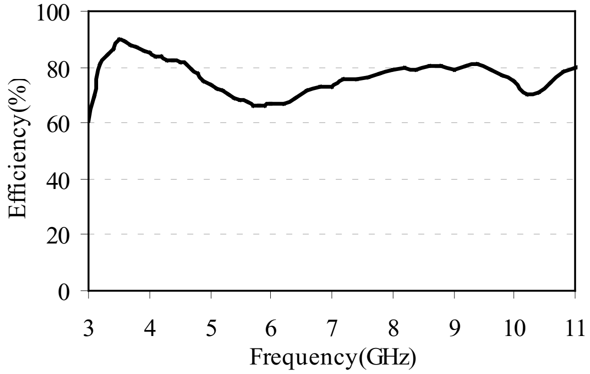


Fig. 10. Measured radiation efficiency.

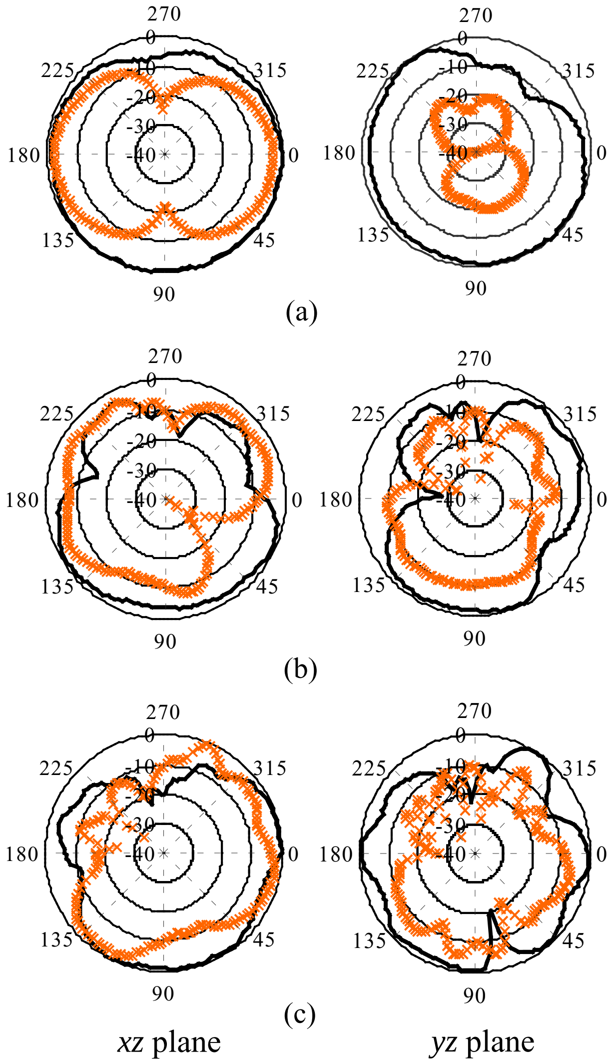


Fig. 11. Measured radiation patterns at (a) 3.3, (b) 6.2, and (c) 9.4 GHz [▬ E_θ, ···××× E_φ].

IV. CONCLUSION

A compact planar antenna and a technique to enhance the impedance bandwidth have been proposed and implemented. The proposed planar antenna having a total size of 30 × 22 mm^2 is printed on an inexpensive FR4 substrate. The technique, cutting triangular shape slots on the top edge of the ground plane helps to increase the bandwidth by 43.6 %(3.89 GHz). Measurement shows that, the proposed antenna with the modified sawtooth shaped ground plane has the -10 dB return loss bandwidth ranges from 2.95 GHz to 15.45 GHz (12.5 GHz) which covers the entire UWB band. The stable radiation patterns with a maximum gain of 5.9 dBi makes the proposed antenna suitable for being used in UWB communication.

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