# Design of a Compact Planar Antenna for Ultra-wideband Operation

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***Abstract*** ─ In this paper, a new compact planar antenna is proposed for UWB (Ultra-wideband) operations. The proposed antenna has a low profile structure, consisting of a radiating patch, notched ground plane, and a novel arc-shaped strip connected between the microstrip feed line and the radiating patch. By using the proposed structure, broadband antenna with good impedance matching is obtained. Measured results show that the antenna can achieve a bandwidth of 96.22%. The proposed antenna is optimized in order to satisfy the required band with a good radiation pattern. The fabricated antenna has a compact size of $16 \times 20 \times 1.6$ mm$^3$. These features demonstrate that the proposed antenna is a suitable candidate for UWB applications, due to its simple configuration, compactness, and low fabrication costs.

***Index Terms*** ─ Broadband antenna, planar antenna, ultra-wideband antenna.

## I. INTRODUCTION

Ultra-wideband system has been widely used for the last few years due to its amazing frequency spectrum in wireless communication. According to the Federal Communications Commission (FCC), UWB system is defined as any radio system operating in the band of 3.1-10.6 GHz, has a 10 dB bandwidth larger than 25% percent of the center frequency and a maximum equivalent isotropic radiated power spectral density of -41.3 dBm/MHz [1-3]. In applications such as wireless personal area networks, low data rate communication and low power consumption with location and tracking, UWB technology became a favorable candidate in wireless system [4-7]. It is a known fact that UWB antenna is one of the promising key parts in a UWB system [8]. Also, any antenna implemented in a UWB system plays a more unique role than it does in conventional narrowband systems. However, antenna design for UWB applications faces many challenges.

Planar antennas present appealing physical features, such as low profile, small in size, conformability, easy to integrate with other devices and low cost. Owing to these attractive characteristics, planar antennas have gained the attention for use in UWB operations, especially in the Body Area Network (BAN) for medical applications [9-13]. However, the size optimization in the UWB frequency band remains a challenge for antenna designers.

Various structures have been studied to achieve ultra-wideband antennas [14-16] in practical applications, such as the waveguide horn [17], log periodic [18], planar inverted cone [19], and biconical [20]. A new bi-arm rolled monopole antenna with small characteristics for UWB has been investigated in [21]. In [22], planar ultra-wideband (UWB) dipoles used by elliptical elements are introduced. Again, small sized UWB antennas printed with quasi transmission lines and band dispensation are presented in [23-25]. However, these designs require large grounding area or a large radiator. In addition, antennas with circular, square, elliptical, pentagonal shapes are

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proposed in [26-29] for UWB applications. However, the ground planes of these structures are perpendicular to the radiator, which leads difficulty to use for integration with PCB technology.

Recently, a double sided microstrip antenna using modified ground plane is investigated [30-32]. In [31], the antenna comprises of a rectangular patch with an inverted L-shaped slits, cut out in the ground to control the antenna's resonant frequency and bandwidth. Although these antennas can cover the UWB band, it cost more with a larger antenna size. In this paper, a new compact planar antenna with arc-shaped strip, connected to microstirp feed line and radiating patch is introduced for UWB applications. The proposed antenna is smaller and more compact compared to the designs reported in [30-32].

## II. ANTENNA DESIGN

Figure 1 shows the layout of the proposed planar antenna. The antenna is fed by a microstrip line and printed on an FR4 substrate with a thickness of 1.6 mm and a permittivity of 4.4. The width of the microstrip feed line is fixed at 2.8 mm. The proposed antenna consists of a notched radiating patch, feed line, a ground plane, and a new arc-shaped strip. The patch is connected to the feed line with a width and length of $W_x$ and $L_x$, respectively. In this design, a new arc-shaped strip, connected from the microstrip feed line to the radiating patch is proposed. This extended arc-shaped protruded strip acts as an impedance matching element to control the impedance bandwidth of the proposed antenna by creating additional surfaces of current paths in the antenna. Therefore, the excited current shifts its upper resonances, so much so that a wider impedance bandwidth can be produced, especially at upper band. Further more, the ground plane comprises of a rectangular slit that is almost centered under the feed-line, which creates an extra resonance, leading to the improvement in the bandwidth. The introduction of a notch on the left corner of the radiating patch reduces the size of patch and helps to acquire better matching at lower frequency band. There is a gap that is equal to *s* between the radiating element at the top layer and the ground plane at the bottom layer. Parametric analysis concerning the choice of the optimum value of *s* indicated that it should not be larger than the thickness of the substrate *h*, in order to get the wider operation bandwidth. The photograph of the antenna is shown in Fig. 2, which has a surface area of $20 \times 16$ mm$^2$. The proposed antenna is significantly smaller by 51.5%, 87.2%, and 46.7% compared to the recently designed antennas reported in [30], [31] and [32], respectively. A 50 Ω SMA connector is connected to the end of the feeding strip and grounded to the edge of the ground plane. The proposed antenna is analyzed by the electromagnetic simulator HFSS, based on finite element method. The optimized values of the proposed antenna design parameters are as follows: $L$=20 mm, $W$=16 mm, $L_x$=8 mm, $W_x$=11 mm, $L_{x1}$=6 mm, $L_g$=8 mm, $W_f$=2.8 mm, $W_s$=3.7 mm, $L_s$=4 mm, $s$=0.3 mm, $L_{arc}$=2.7 mm, $h$=1.6 mm, $L_{x2}$=2 mm, and $W_{x1}$=0.5 mm.

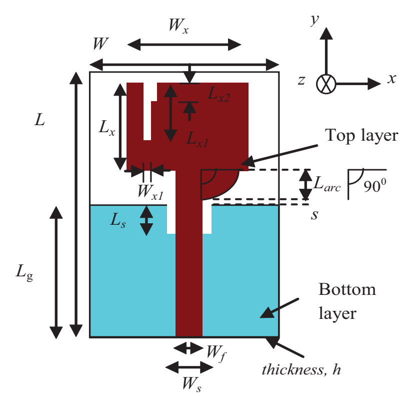
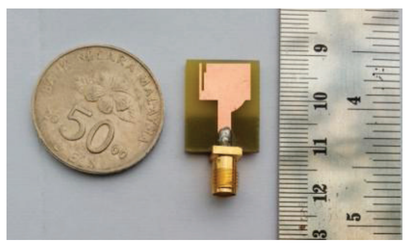
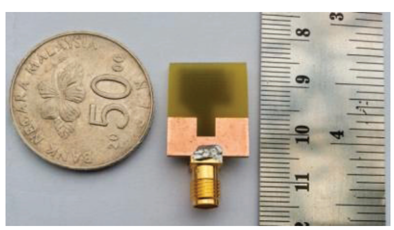



Fig. 1. Geometry of the proposed antenna.



(a)



(b)

Fig. 2. Photo of the proposed antenna: (a) top layer, and (b) bottom layer.

## III. RESULTS AND DISCUSSIONS

The microstrip antenna has been constructed and optimized to exhibit the effect of the bandwidth enhancement technique. Figure 3 shows the simulated reflection coefficient of the optimized proposed antenna and proposed antenna without an arc-strip, notched in radiator and ground plane slit.

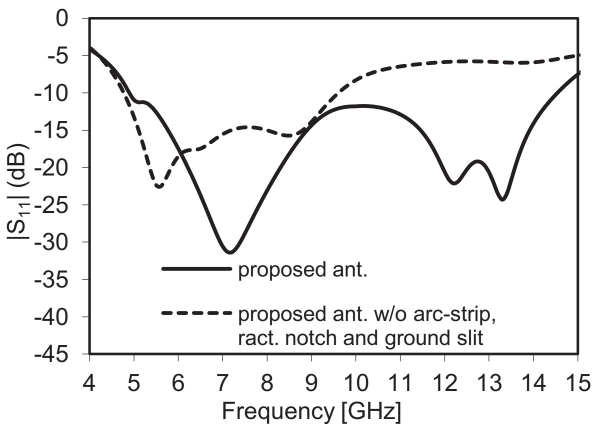



Fig. 3. Simulated reflection coefficient: (a) proposed antenna, and (b) proposed antenna without arc strip and ground slit.

As shown in the figure, firstly, the proposed antenna was configured with a compact microstrip fed rectangular patch, with a partial ground plane on the bottom layer to provide the fundamental and next higher resonances at 5.6 GHz and 8.6 GHz, respectively. Then, a newly proposed arc-shape strip is integrated with the design that produces higher current flow at higher frequencies. This results in the fundamental frequency shifting to 7.2 GHz, and next higher resonant frequency shifts to 9.7 GHz, resulting in a wider frequency band from 4.8 to 11.7 GHz. This technique implies that the arc-strip plays an important role in the broadband characteristics and in determining the sensitivity of impedance matching. A small rectangular slit of 4 mm by 3 mm is inserted into the ground plane as reported in [7], to obtain better matching on the frequency band. The integration of this technique causes the upper resonance of the designed antenna to shift from 9.7 GHz to 12.1 GHz, and a new resonance is introduced at 13.1 GHz, leading to the achievement of higher frequency band to up to 14.5 .GHz.

Figure 4 shows the simulated and measured VSWR of the proposed antenna. The proposed antenna is measured with a Rohde & Schwarz ZVA24 vector network analyzer. The simulated bandwidth covers from 4.8 GHz to 14.5 GHz, while the measured bandwidth covers from 4.8 GHz to 13.7 GHz. The discrepancies between the simulated and measured results may be attributed to the connector, which is not taken into account in the simulation. Figure 5 shows the current distribution at 6 GHz and 9 GHz. At 6 GHz, it can be observed that most of the electric currents are distributed on the bottom edge of the feeding strip, the junction of the rectangular radiator, and the left side of the notched ground plane. Again, at 9 GHz, the majority of the electric current is concentrated around the arc-shaped strip and the bottom edge of the radiator. This suggests that the arc-shaped strip has a significant effect on the antenna performance at higher operating frequencies.

To measure and identify $S_{21}$ and group delay values, a distance of 50 cm between the two equal (Tx/Rx) antennas was chosen. Figure 6 shows the measured values of $S_{21}$ in the face-to-face scenarios. Figure 7 indicates group delay on the antennas. The measured group delay is almost flat, at about 2ns, while the variation is about 0.48ns. This small variation in group delay signifies a good linear transmission function characteristics of the proposed antenna for UWB applications. Figure 8 shows the variation of the simulated and measured peak gain of the antenna. It is observed that the proposed antenna has a gain above 2.56 dBi in the entire operating band.

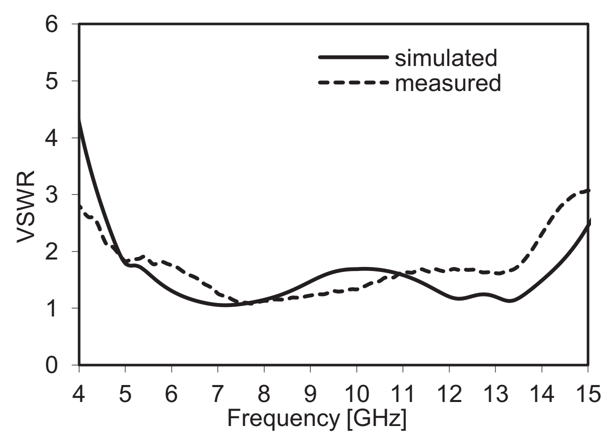



Fig. 4. Simulated and measured VSWR of proposed antenna.

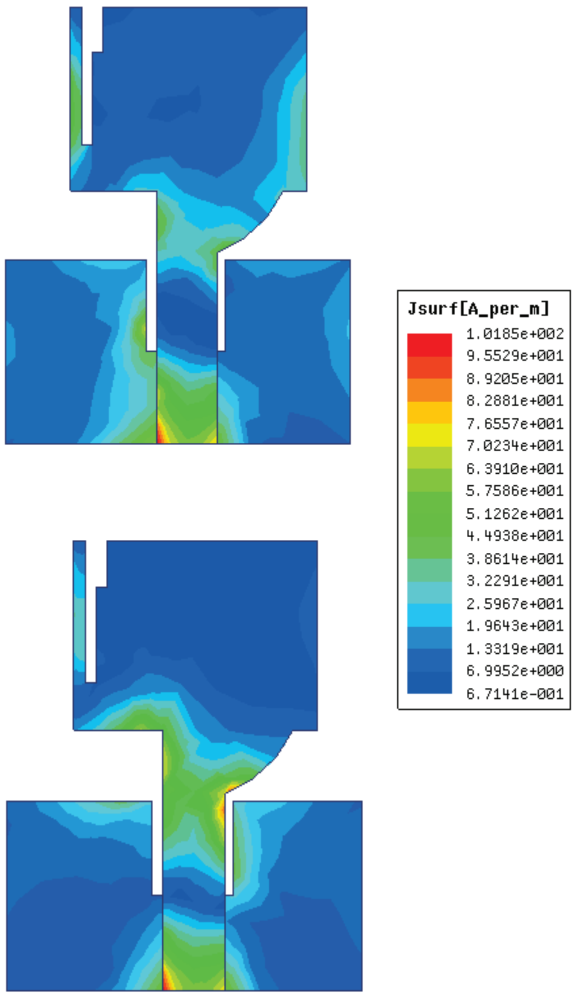



Fig. 5. Current distribution of the proposed antenna at: (a) 6 GHz, and (b) 9 GHz.

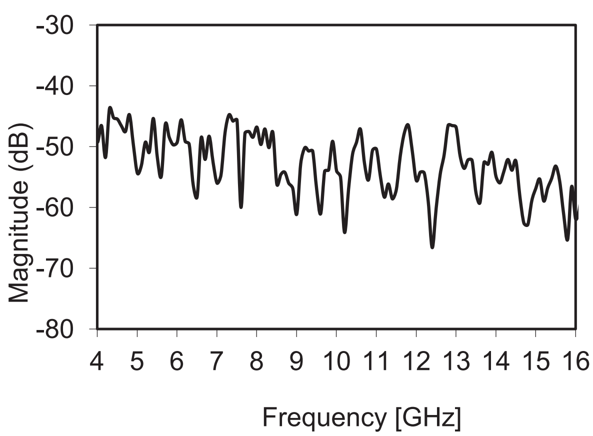



Fig. 6. Measured $S_{21}$ (magnitude) of the proposed antenna.

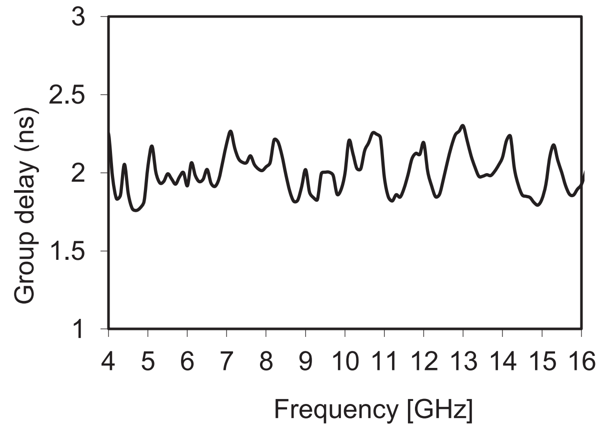



Fig. 7. Measured group delay of the proposed antenna.

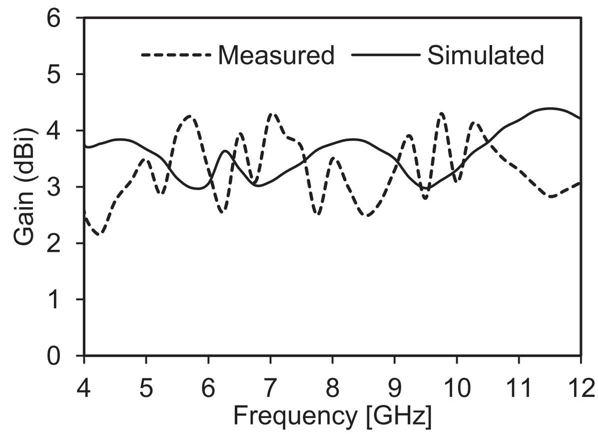



Fig. 8. Simulated and measured gain of the proposed antenna.

Figure 9 illustrates the simulated and measured radiation patterns, including the co-polarization and cross-polarization in the E-plane (*xz*-plane) and H-plane (*yz*-plane) at 6 GHz. It can be seen that the radiation patterns in *xz*- and *yz*-plane are quasi omni-directional at 6 GHz.

A parameter study has been performed to observe the effect on the antenna performances on the impedance matching, due to changes in the $s$ parameter. As shown in Fig. 10, increasing or decreasing the $s$ parameter experiences better matching at the lower frequency band, but at the expense of reducing the upper edge frequency, resulting in a reduction in the bandwidth. Hence, $s$=0.3 mm was chosen as the control model. In Fig. 11, with decreasing $L_{arc}$, a mismatch on the antenna leads to small bandwidth drop on the upper frequency. With increasing $L_{arc}$, the lower and upper resonances shift upward which causes band reduction on the antenna. Hence, $L_{arc}$=2.7 mm was chosen as control model.

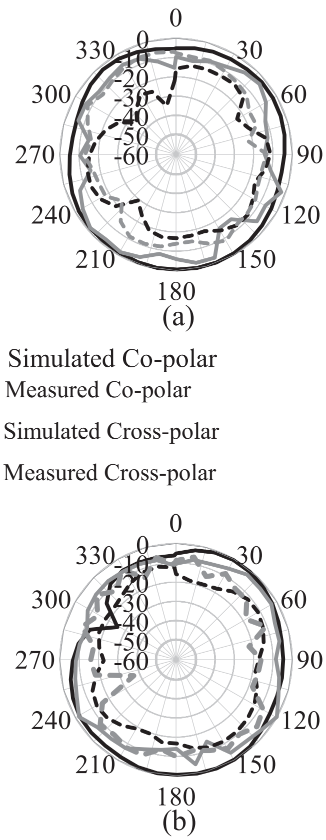



Fig. 9. Simulated and measured radiation pattern of the antenna at 6 GHz: (a) *xz*-plane, and (b) *yz*-plane.

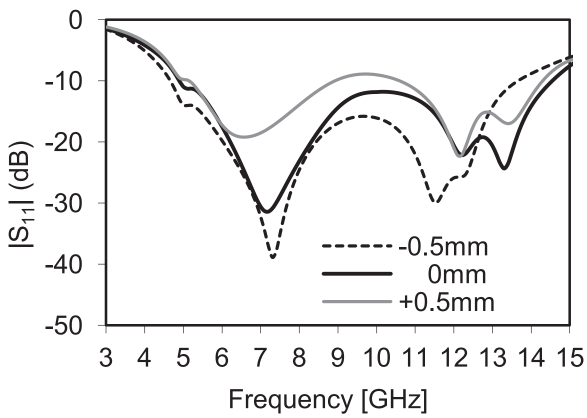



Fig. 10. Effects on reflection coefficient with changing *s* parameter.

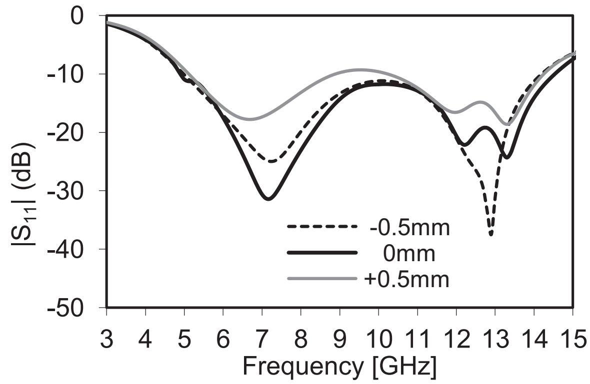



Fig. 11. Effects on reflection coefficient with changing $L_{arc}$ parameter.

In Fig. 12, with increasing or decreasing $L_s$, a mismatch is occurred on the entire band, leads to a bandwidth reduction on the antenna. At Fig. 13, with decreasing $L_g$, a mismatch is occurred in the frequency. But, the operating bandwidth remains the same. With increasing $L_g$, the resonances shift upwards, causing bandwidth fall on the antenna. Hence, $L_g$=8 mm was chosen as control model.

In Fig. 14, with increasing $W_s$, the lower frequency shifts upward, leads to a bandwidth drop on the antenna. With decreasing $W_s$, a mismatch occurs in the frequency, but the operating band remains the same. Hence, $W_s$=3.7 mm was chosen as control model. In Fig. 15, with changing $L$, the designed structure performs good matching on the antenna. In Fig. 16, with increasing $W$, a good matching is observed. But, with decreasing $W$, the upper resonant shifts upward, causing a bandwidth drop on the upper frequency. Hence, $W$=16 mm was chosen as control model.

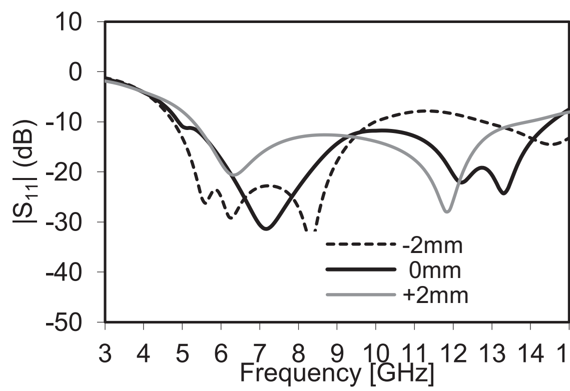



Fig. 12. Effects on reflection coefficient with changing $L_s$ parameter.

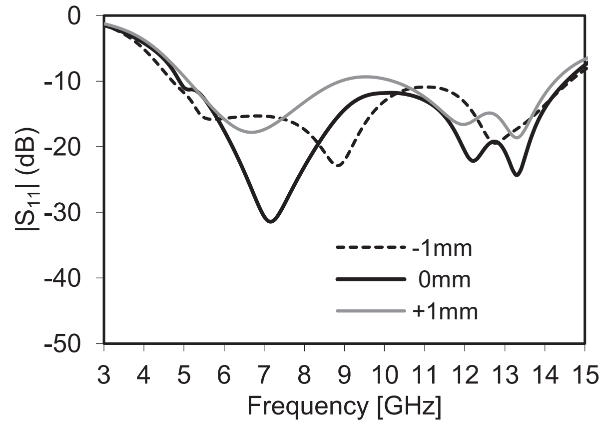



Fig. 13. Effects on reflection coefficient with changing $L_g$ parameter.

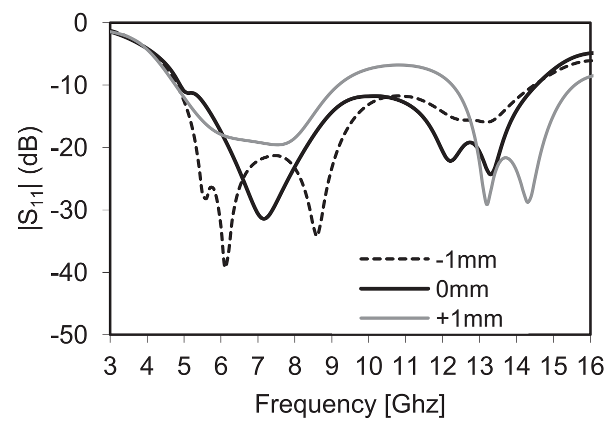



Fig. 14. Effects on reflection coefficient with changing $W_s$ parameter.

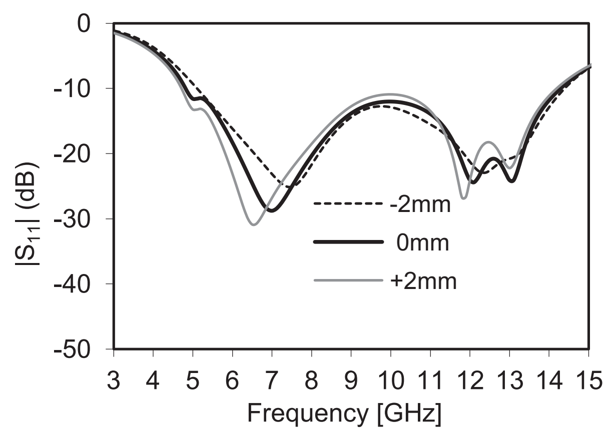



Fig. 15. Effects on reflection coefficient with changing $L$ parameter.

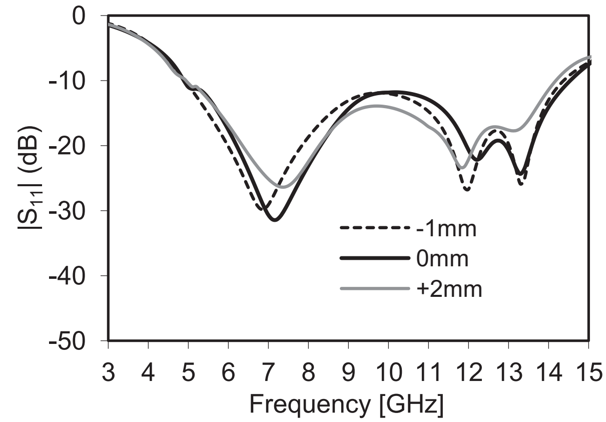



Fig. 16. Effects on reflection coefficient with changing $W$ parameter.

## IV. CONCLUSION

In this paper, a new compact planar UWB antenna has been presented and analyzed in detail. By successfully utilizing the arc-shaped strip structure, radiating plate, notched ground plane and adjusting the parameters, the antenna has obtained a wide bandwidth with quasi omni-directional radiation pattern. Despite exhibiting wide impedance bandwidth, the antenna has achieved compact and low profile characteristics. The prototype has been fabricated and measured. The results have shown a good agreement between simulations and measurements. Therefore, these characteristics have made the proposed antenna a suitable candidate for UWB applications.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