A Compact Wide Slot Antenna for Ultra-Wideband Applications

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Abstract: The design and analysis of a compact and simple ultra-wide band (UWB) slot antenna, smaller in size than a rectangular patch, yet with better performance is presented in this paper. It has a triangular tuning stub that controls the coupling between a 50Ω microstrip transmission line and a large dome shaped slot. Results from simulation are compared with measurements from a prototype, fabricated on a $20 \times 24 \times 1.6mm^3$ FR4 substrate with relative dielectric constant of 4.3. The measured and simulated results have a good agreement in the frequency domain, time domain. In addition, the simulation results show that the antenna has very stable radiation characteristics along the operating band. These high performances enable the antenna to operate over the entire UWB frequency band with negligible amount of losses. The antenna can be used in portable UWB applications.
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1. INTRODUCTION

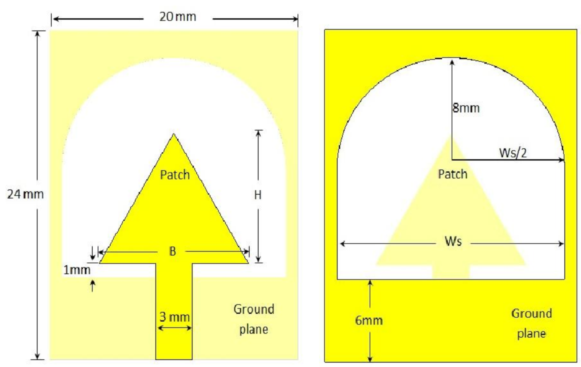
Ultra-wide band (UWB) slot antennas can be considered as a magnetic monopole antenna operating over a wide range of frequencies. Unlike the conventional UWB planar monopole antennas which have large electric near field, slot antennas tend to have a large magnetic near field, and, as a result, there is a reduction in the undesired electrical coupling with nearby components [1]. In addition to the ground plane and a feed line, the UWB slot antenna includes a large radiating slot and a tuning stub designed to enhance the coupling between the slot and the feed line [2]. UWB antennas have applications in the $3.1 - 10.6GHz$ frequency range as specified by the Federal Communication Commission (FCC).

Relatively large size high performance UWB slot antennas have been designed previously [3-5]. For size reduction, many mechanisms have been proposed. These mechanisms include, but are not limited to, the following: i) adding via holes to a relatively small slot antenna to cover the UWB frequencies [6], ii) modifying the slot and the tuning stub shapes to increase the coupling between the feed line and the slot over the UWB frequency range [7], and iii) adding many optimization parameters to achieve UWB ground plane-feed line coupling for the reduced size antenna [8]. UWB slot antennas have applications such as Global System for Mobile communications (GSM) [9] and on-body communications [10].

In this paper, we design and fabricate a highly compact UWB slot antenna with high antenna performance by merging the triangular stub [11] and a dome-shaped slot as proposed in [12]. The triangular tuning stub is fed by a 50Ω microstrip line. The dimensionsof the triangular stub are optimized to improve the antenna bandwidth, by reducing the return loss of the antenna at the middle frequencies and increasing the higher frequency edge of the return loss. On the other hand, the improvement of the lower edge of the return loss is accomplished by optimizing the slot width. The simulated and measured results show that the proposed antenna has a bandwidth covering the whole UWB frequency band, has very stable radiation characteristics along the operating bandwidth, and very desirable time domain characteristics. Analyses show that the antenna has more stable radiation characteristics and less time domain dispersion than that provided by the conventional rectangular slot antenna and even the aforementioned researches [3-12] in spite of its highly compact size. Following this brief introduction, the structure of the proposed antenna is presented in Section 2. The optimization of the antenna dimensions is studied intensively in Section 3, while Section 4 discusses the measured results of the prototype antenna. Finally, Section 5 summarizes the research findings.

2. Antenna Design

Figure 1 shows the front and the back views of the proposed slot UWB antenna. The antenna is built on an FR4 substrate with dielectric constant equal to 4.3 and loss tangent of 0.025 . The dimensions of the substrate are $20 \times 24 \times 1.6\, mm^3$, which also represents the dimensions of the overall antenna, thus usable in any UWB gadget. The proposed antenna consists of a triangular tuning stub attached to a $50\,\Omega$ microstrip feed line, ground plane located on one side of the substrate, and a dome shaped slot engraved on the ground plane. In fact, the triangular tuning stub has many advantages over the other stubs such as providing better coupling with the dome shaped slot and matching to $50\,\Omega$ line easily [11]. The dome shaped slot is simply a rectangle capped by a half ellipse. The dimensions of the triangular tuning stub (base B, and the height H) have been optimized to enhance the coupling between the feed line and the slot. The optimization process also includes the width of the dome shaped slot (Ws) to improve the lower frequency edge of the return loss of the antenna. The optimized values of these parameters are: $B = 12\, mm$, $H = 9.5\, mm$, $G = 1\, mm$, and $Ws = 18\, mm$. The following section discusses the effect of each of these parameters on the return loss of the proposed slot antenna.



(a) (b)

Figure 1. The geometry of the proposed UWB slot antenna (a) front view and (b) back view.

3. Parametric Study

Inorder to optimize the design for UWB applications, the effects of the dimensions of the triangular tuning stub, the gap between the stub and the ground plane, and the width of the dome shaped slot were investigated. In addition, the radiation characteristics of the proposed antenna after the optimization process were also looked into. The proposed design was analyzed through the CST Microwave Studio commercial simulation suite,prior to fabrication and testing.

A. Optimizing the Triangular Stub Dimensions

The dimensions of the triangular tuning stub can directly affect the coupling between the ground plane and the feed line over the operating frequencies. Figure 2 illustrates the effect of the triangular stub base (B) on the return loss of the proposed antenna. The optimal value of the stub base is found to be equal to $12\, mm$ since it supportsawider bandwidth as compared to other stub base values. Figure 3 shows the return loss of the slot antenna for different values of triangular stub height H. This parameter has also significant influence on the ground-feed line coupling along the operating frequencies, and the optimal value of triangular stub height that provides wider bandwidth is equal to $9.5\, mm$. It is clear that the dimensions of the triangular stub can modify the middle frequencies return loss and the higher frequency edge of the return loss. It has negligible effect on the lower frequency edge because the stub is used only for matching purposes and not for radiation. Consequently, its dimensions do not change the electrical size, which affects the lower edge of the return loss.

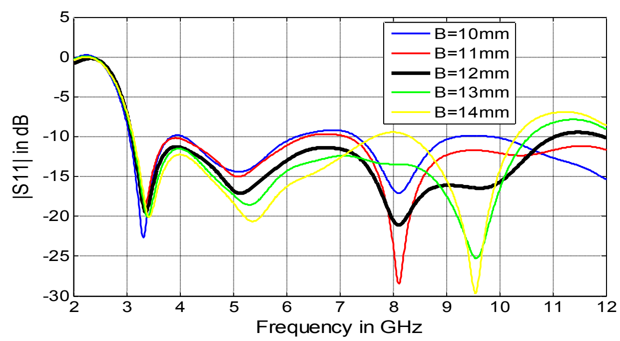


Figure 2. The return loss of the proposed UWB slot antenna at H=9.5mm, Ws=18mm, and different values of the triangular stub base (B).

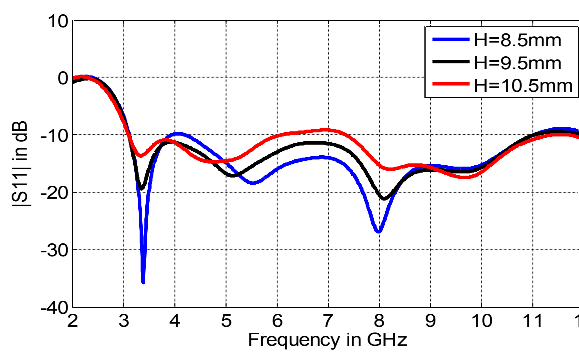


Figure 3. The return loss of the proposed UWB slot antenna at B=12mm, Ws=18mm, and different values of the triangular stub height (H).

B. Effect of the Slot Width

The width of the slot can control the lower frequency edge of the return loss. An increaseinthe slot width reduces the lower edge of the return loss significantly as the current path, in this case, is prolonged. In other words, increasing the slot width increases the electrical size of the antenna. Figure 4 shows the return loss of the antenna at different slot widths. From this figure, it can be seen that as the slot width gets larger the lower edge of the return loss gets smaller. The optimal value of the slot width is 18 mmsince it makes the lower frequency edge equal to 3.06 GHz, which is close to lower edge of UWB spectrum (3.1 GHz).

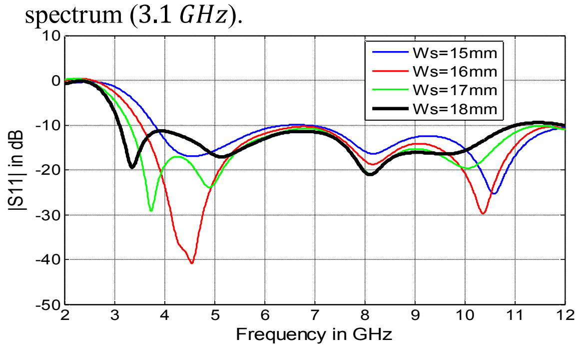


Figure 4. The return loss of the proposed UWB slot antenna at B=12mm, H=9.5mm, and different values of slot width (Ws).

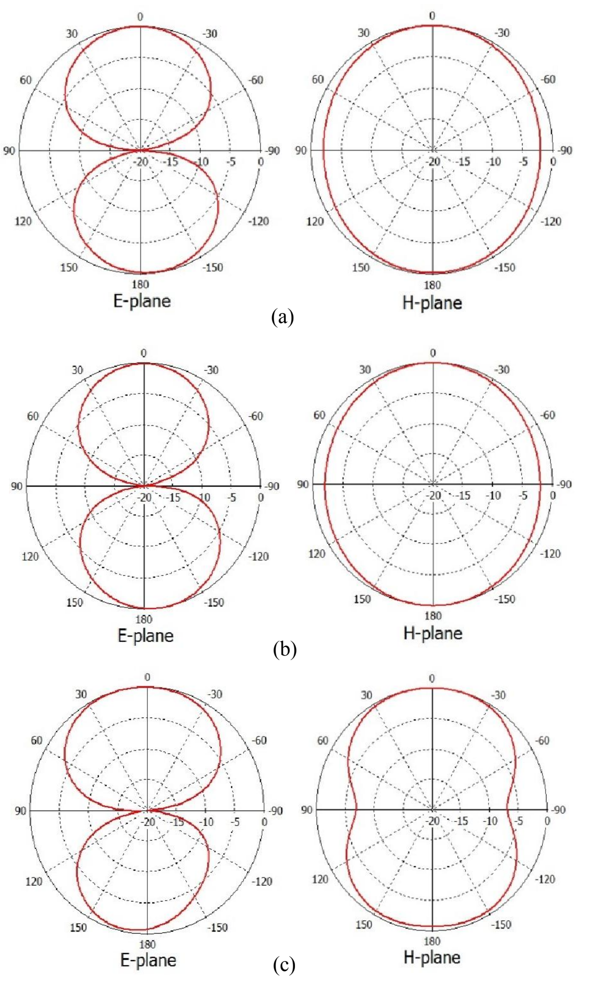


Figure 5.The power pattern of the proposed antenna at (a) 3.36GHz, (b) 5.15GHz, and (c) 8.1GHz.

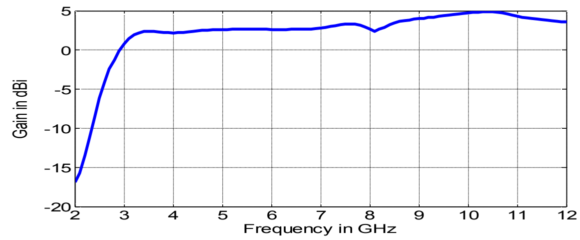


Figure 6. The gain of the proposed antenna as a function of

Following this optimization process, the return loss band width ($|S_{11}| \leq -10dB$) is equal to 7.94 GHz, which extends along the frequency range of $3.06 - 11$ GHz.

D. Radiation Pattern

The proposed antenna has three resonances overlapping with each other in such a way that they cover the entire UWB applications band. These resonances are centered at 3.36, 5.15, and 8.1GHz. The power patterns at these three frequencies in the E and H planes are illustrated in Figure 5. It is clear that the power patterns of the three frequencies are approximately similar, and this is an important property for the proposed antenna. The H-plane power patterns tend to be omnidirectional, so the antenna is very suitable for portable UWB antenna devices. On the other hand, the E-plane power patterns take the doughnut shape which is favorable for UWB applications. The antenna is most suitable for portable UWB applications.

The gain-frequency response of the antenna is illustrated in Figure6 which demonstrates the radiation characteristics as a function of frequency. The gain appears constant over most of the operating frequencies and its value is reasonable for the whole operating frequencies, so the antenna shows approximately the same radiation response over the whole frequency band with low antenna loss.

4. Fabrication and Measured Results

The proposed antenna was fabricated and its parameters analyzed using HEWLETT PACKARD 8719A Vector Network Analyzer at University of Missouri. Figure 7shows the front and the back view of the prototype UWB slot antenna attached to an SMA connector. Figure 8 demonstrates a comparison between the simulated and the measured return loss. The measured return loss has the same response as the simulated antenna, with three overlapping resonances covering frequency band equal to 7.8GHz and extended from 2.9 GHz to 10.7 GHz , while the simulated return loss has a bandwidth of 7.94GHz along the frequency range $3.06 - 11GHz$. This small discrepancy may be caused by the fabrication tolerance, the irregular variation of the dielectric constant for different frequencies, or the imperfect SMA connector soldering which may cause a close loop path between the connector and the feed line. However, both the simulated and the measured return loss cover the whole frequency band specified by FCC for UWB applications ($3.1 - 10.6GHz$).

Figure 7.The prototype of the proposed UWB slot antenna.

To plot the time domain characteristics of the fabricated antenna, the group delay of two identical antennas positioned inside an anechoic chamber was measured. The group delay represents the first derivative of the phase response of the forward transmission parameter S_{21}. The two antennas are aligned Face-to-Face, Face-to-Side, and Side-to-Side, and the group delay of each of these three alignment schemes is illustrated in Figure 9. The average value of the group delay of the three schemes is approximately equal to $6\,nsec.$ with a small deviation around this value especially within the band specified for UWB applications. The interpretation of this small deviation is that the frequency components of the transmitted signal arrive at the receiver within the same time frame. As a result, the antenna does not contribute much distortion to the transmitted signal. A large deviation can clearly be seen outside the operating band width due to the impedance mismatching; however, the UWB transmitted signal spectrum does not undergo this distortion.

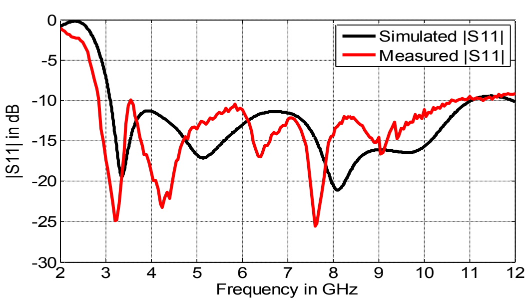


Figure 8. The simulated and measured return loss of the proposed UWB slot antenna.

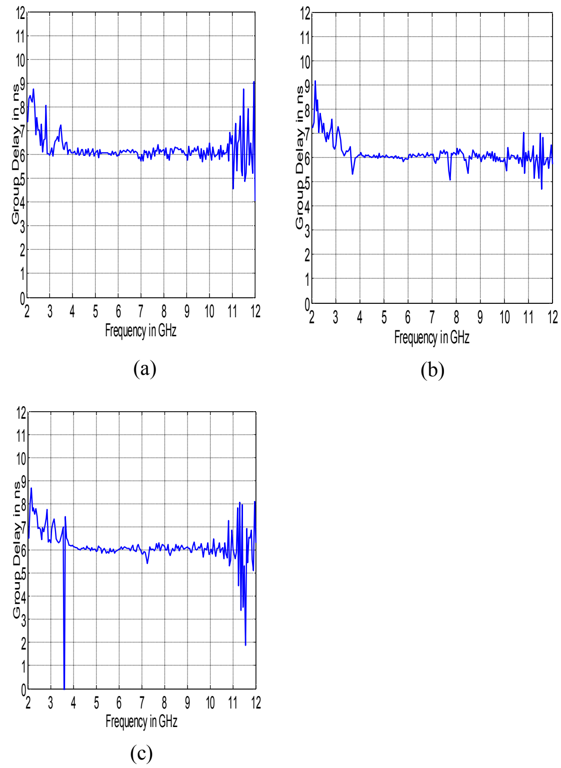


Figure 9. The measured group delay of two of the proposed antenna aligned (a) Face-to-Face, (b) Face-to-Side, and (c) Side-to-Side.

5. CONCLUSION

A small UWB slot antenna with optimized triangular stub and optimized dome shaped slot is analyzed in this paper. The antenna dimensions enable it to fit inside most UWB gadgets. The simulated and measured results show that the antenna has a bandwidth exceeds that specified for UWB applications. The designed antenna has very stable radiation characteristics in the operating frequency range. Moreover, the results show that the antenna has small time domain dispersion since the group delay has small deviation within the bandwidth of the antenna. With an omnidirectional H-plane power and a doughnut E-plane power pattern, the antenna is most suitable for portable UWB devices.

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