Ultra Wideband Indoor Antenna for Medical Deviceswith Minimized Interference from Wireless Local Area Network

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Abstract: The design and analysis of a compact planar monopole ultra-wide band (UWB) antenna for medical devices that rejects interfering frequencies of $5.15-5.825\ GHz$ from wireless local area network (WLAN) is presented. The violin shaped antenna is fed through a handle which acts as a $50\ \Omega$ microstrip transmission line. A U-shaped slot has been etched on the antenna face which can generate a band notch that can eliminate the WLAN radiation. The antenna is fabricated on $28\times18\times1.6mm^3$, FR4 substrate,which has a dielectric constant value of 4.3. The simulated and measured results are in good agreement and analyses show that the antenna has very good radiation as well as frequency and time domain characteristics.

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1. INTRODUCTION

Among other advantages it offers, the ultra-wideband (UWB) frequency can support high data rate and multimedia transmission essential for medical devices, which is not possible in narrow band systems. Hence the design of UWB antennas has gained popularity among researchers of wireless applications. For UMB applications, the Federal Communication Commission (FCC) has allocated the $3.1-10.6\ GHz$frequency band. However, due to the already existence of the wireless standard IEEE 802.11a operating in the band $5.15-5.825\ GHz$, UWB antennas with band rejection characteristics have been proposed to prevent interference with the existing standard, without inserting band stop filters inside UWB gadgets. Addition of band stop filters not only costs more, it also complicates the design requirements of the receivers. Alternate solutions, therefore, have been suggested by researchers that can help in the development of UWB antenna technologies, while minimizing the interference of WLAN for indoor applications.

Since the size reduction is one of the important issues in UWB systems, some antenna characteristics have been sacrificed to design small UWB antenna that can be inserted inside any UWB gadget [1-3]. The wide deployment of the UWB applications has motivated the researchers to design some complex designs having many optimization parameters to accomplish the requirements of special kind of applications such as Radio Frequency Identification (RFID) [4] and cognitive radio [5], widen the antenna band width [6], or improve the radiation characteristics [7]. Some researchers try to keep the antenna characteristics as high as possible by designing relatively large antennas [8], [9]. Flexible relatively large UWB antenna has been produced by utilizing flexible dielectric material as a substrate for the antenna to resist bending and angular positioning as well as maintaining the antenna characteristic [10].For band rejection purposes, researchers have embedded slots either on the antenna patch or through the ground plane to generate single band notch to filter out the existing Wireless Local Area Network (WLAN) band to generate robust indoor UWB antenna [11], [12]. To design UWB antennas that can be utilized for outdoor applications, dual band notches [13], [14] and even triple band notches [15], [16] have been introduced to get rid of interference with WiMax, WLAN, and X-band satellite communications.

In this paper, we design, fabricate, and analyze a simple, planar monopole UWB antenna with band notch for filtering. It is violin-like in shape, formed by overlapping circular patch with an elliptical patch and splitting two circular cuts on the circular patch. The elliptical patch and the circular cuts decrease the lower frequency edge without increasing the antenna size significantly. On the other hand, the length of the ground plane has been optimized to improve the bandwidth by increasing the high frequency edge and reducing the return loss at the middle frequencies. A U-shaped slot has been embedded on the antenna to produce a band notch centered at $5.5GHz$ so that the antenna has no interference with the already existing WLAN applications. The simulated and measured results show that the proposed antenna covers UWB frequency band specified by FCC, has very good radiation characteristics and gain, and has satisfactory time domain characteristics. The antenna small size and performance make it a very good candidate to be attached inside the medical devices. Following this brief introduction, the antenna design is presented in Section 2, while its characteristics are discussed in Section 3. Section 4 discusses the antenna fabrication and experimental result, with conclusions in Section 5.

2. ANTENNA DESIGN

The designed antenna is shaped like a violin, having a circular patch overlapped by an elliptical patch as the major components, and is etched on $28 \times 18 \times 1.6\,mm^3$ FR4 substrate of dielectric constant $\varepsilon_r = 4.3$ with a loss tangent of 0.025. On the other side of the substrate, the ground plane is etched. A microstrip line, $1.8\,mm$ in width and characteristic impedance of $50\,\Omega$, feeds the antenna. Figure 1(a) shows the antenna geometry and other dimensions (in mm), with the front side without the slot, while the antenna with the embedded U-shaped slot and its exact position and dimensions is shown in Figure 1(b). The length of the U-shaped slot is optimized to get the band notch coincident with the IEEE 802.11a frequency band. Figure 1(c) shows the back view of the antenna which includes the ground plane.

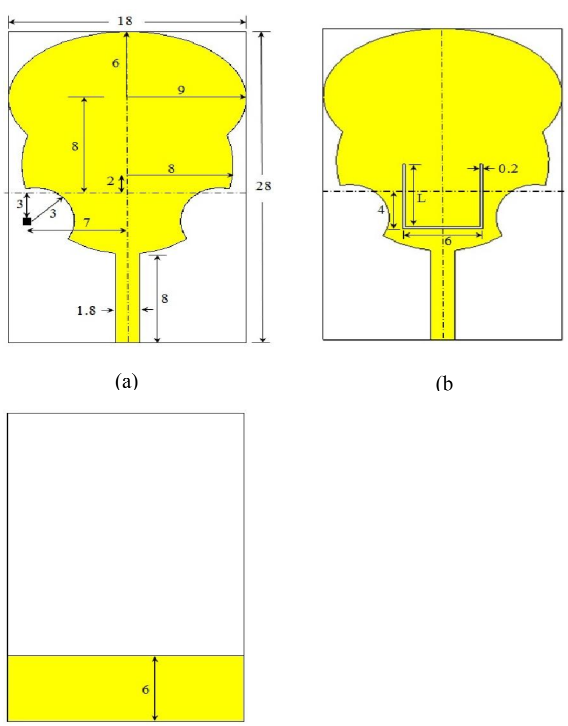


Figure 1. The geometry of the proposed violin-like monopole antenna (a) front view without slot, (b) front view with slot, and (c) back view (All dimensions are in mm).

3. STUDY OF ANTENNA CHARACTERISTICS

The antennas were studied using CST Microwave Studio, an industry standard, commercially available simulation suite. The following subsections present the design and analysis of the violin-shaped antenna with and without the band notch using the simulation package.

3.1 Violin-Shaped Antenna without Band Notch

By varying the circular cut radius and the minor axis of the elliptical patch the lower edge of the antenna bandwidth was set to $3.1GHz$ which is equivalent to that of UWB band. Subsequently, the length of the ground plane has been optimized to reduce the return loss in the middle frequencies and to increase the upper frequency edge of the proposed antenna. The width of the ground plane can be considered as an inductor, and the lower edge of the antenna and the upper edge of the ground plane can be assumed as parallel plates of a capacitor [17]. Consequently, varying the length of the ground plane can leads to different capacitance value, and hence different resonant circuits. Figure. 2 shows the return loss of the proposed antenna after the optimization of the dimensions stated earlier.

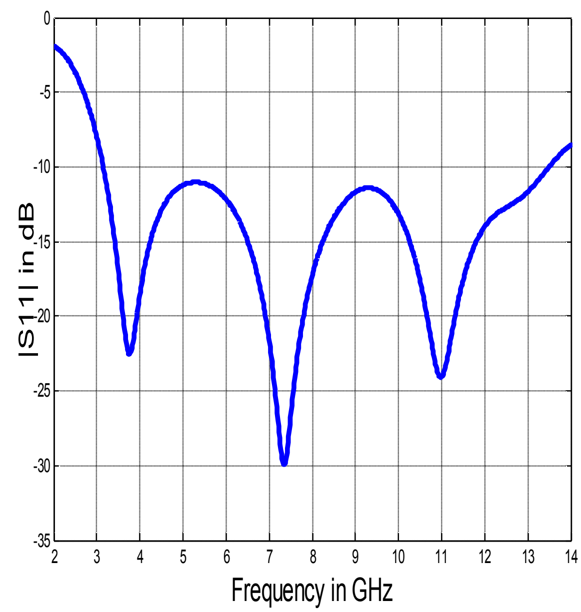


Figure 2. The return loss of the proposed antenna without band notch.

The Radiation characteristics of the violin-shaped antenna can be shown through the radiation pattern at the three resonant frequencies (3.75, 7.34, and $11GHz$). Figure 3 illustrates the E-plane and H-plane power patterns of the proposed antenna at the three frequencies. The H-plane power pattern is approximately omni-directional for the three frequencies, making the antenna suitable for portable medical devices. On the other hand, the E-plane power pattern follows the doughnut shape, which is favorable for UWB applications. Some distortion in the radiation pattern appears in the higher harmonics because the current is concentrated at different positions of the antenna and this will lead to generate radiation pattern in harmony with this concentration.

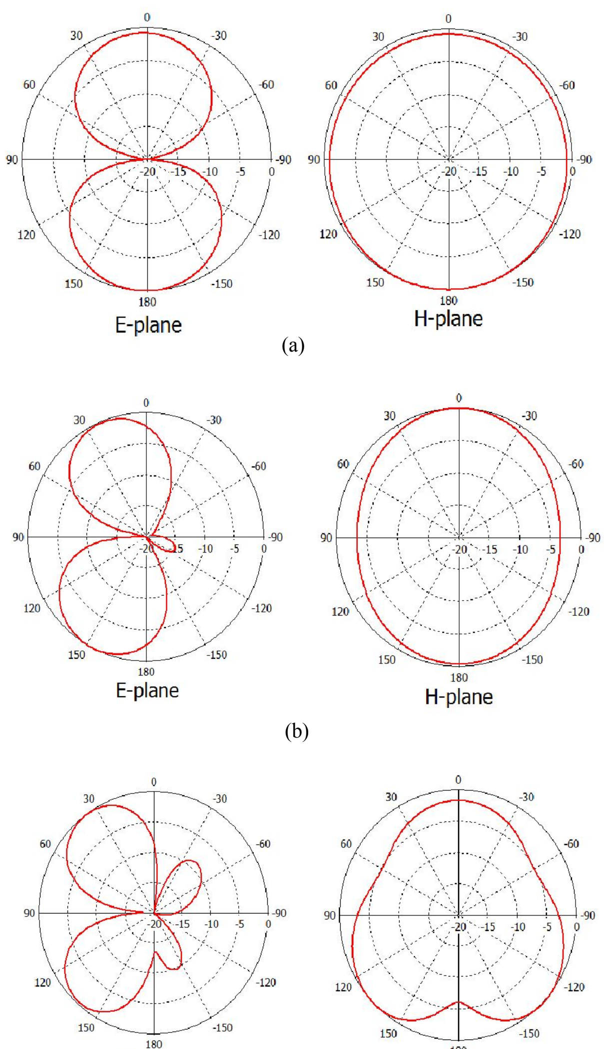


Figure 3.The power pattern of the proposed antenna at (a) 3.76GHz, (b) 7.34GHz, and (c) 11GHz.

3.2 Violin-Shaped Antenna with Band Notch

After embedding a U-shaped slot on the antenna face, the band notch characteristics begins to show up. Bychanging the values of theU-shaped slot arms' length (L), the band notch center frequency occupies different positions. Figure 4 shows the Voltage Standing Wave Ration (VSWR) of the proposed antenna at different values of L. The optimal value of the slot arms length is found to be $5.8\,mm$ which leads to total slot length equal to $17.6\,mm$. This verifies the formula for the center frequency of the notch (f_{notch}) given as [11]:

$$f_{notch} = \frac{c}{2L_{slot}\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

where$c$ is the speed of light in freespace, and L_{slot} is the slot length.

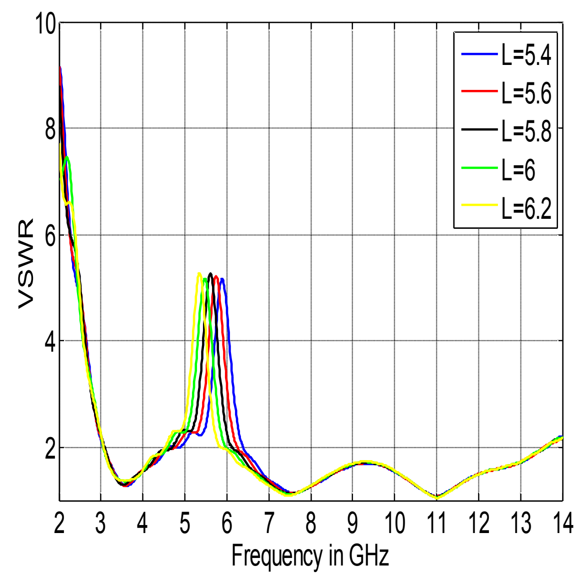


Figure 4. The VSWR of the proposed antenna with band notch for different slot arms lengths.

It can clearly be seen that at slot length equal to $17.6\,mm$ the VSWR curve has a value less than 2 for the frequency band extended from $3.1GHz$ to $13.5GHz$ except the WLAN frequency band at which the value of the VSWR exceed the nominal value. For this reason, this antenna can be used for indoor ultra-wide band medical applications even with the presence of $5.5GHz$ WLAN devices.

Figure 5 illustrates the surface current distribution of the antenna at the band notch center frequency $5.5G\,Hz$ and another at $7.34\,GHz$. It is clear that at $5.5\,GHz$ the current is distributed around the U-shaped slot, so the current tends to rotate rather than radiate. Therefore, the antenna cannot radiate energy within the band notch frequencies. However, at $7.34\,GHz$ the current concentrates at the antenna lower edge and the sides.

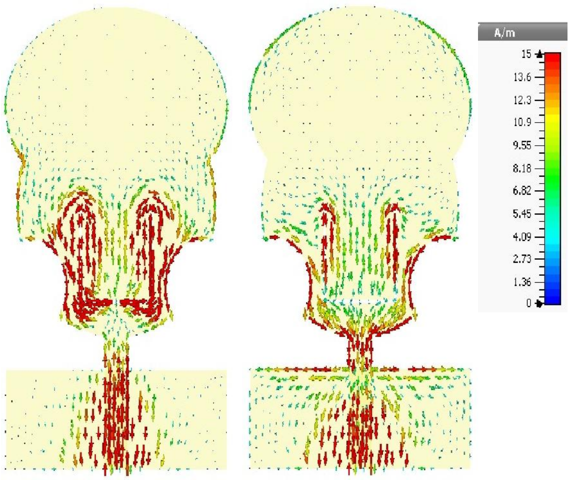


Figure 5. The surface current distribution of the proposed antenna with band notch at (a) 5.5GHz and (b) 7.34GHz.

Generally, the embedded slot on the antenna does not affect the antenna characteristics outside the rejected band. This can be verified through the VSWR curve of the two antennas, as illustrated in Figure 6. This figure demonstrates that the two curves coincide with each other at all frequencies outside the notch. Figure 7 shows the gain in dBi of both antennas, which again demonstrates that the antennas keep its radiation performance outside the rejected band. In effect the antenna gain is abruptly dropped within the rejected band, which confirms the inability of the antenna to transmit or receive electromagnetic waves at the notched frequency band.

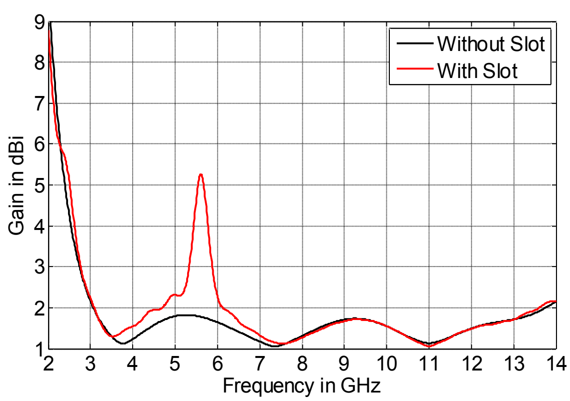


Figure 6.The VSWR curves of the proposed antenna with and without the U-shaped slot.

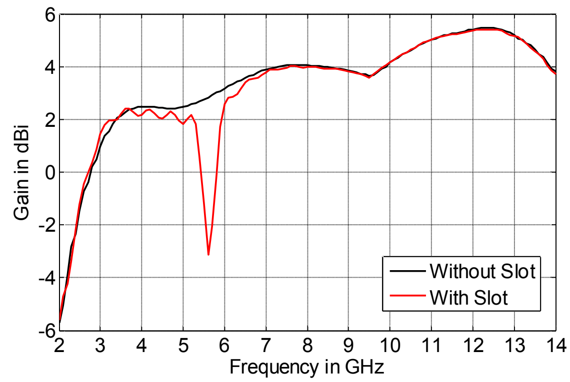


Figure 7.The gain of the proposed antenna with and without the U-shaped slot.

4. FABRICATION AND MEASURED RESULTS

Figure 8 is a picture of the fabricated violin like antenna with and without slot. A comparison between the simulated and measured return loss for the two antenna types is shown in Figure 9. The measurements were done using HEWLETT PACKARD 8719A Vector Network Analyzer at University of Missouri. Three overlapped resonant frequencies appear in both simulated and measured return loss. The simulated band width is found to be equal to $10.4GHz$ extended along the frequency range $3.1-13.5GHz$, whereas the measured band width is equal to $10.1GHz$ extended from $2.9GHz$ to $13GHz$ which has the frequency range wider than that specified to UWB applications. Deviation in results may be due to factors such as fabrication tolerance, imperfect SMA connector soldering which causes close loop path between the feed line and the connector, and the irregular dielectric constant variations over the frequency range.

Figure 8.The prototype of the proposed antenna with and without slot.

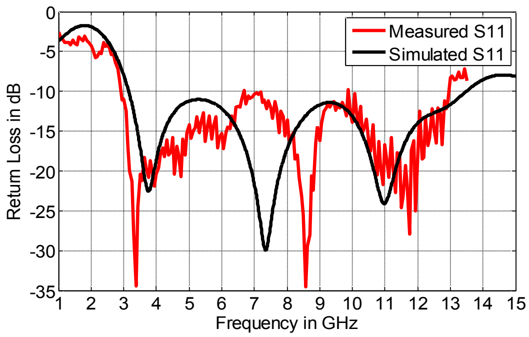


Figure 9.The measured and simulated return losses of the proposed antenna without slot.

Figure 10 shows the simulated and measured VSWR of the antenna with the etched U-shaped slot. The simulated band notch is centered at $5.5 GHz$ and extends from $4.9\ GHz$to $6\ GHz$. However, the etching process of U-shaped slot involves large amount of toleration in the slot dimensions and this causes clear discrepancy between the measured and the simulated results. The measured band notch is centered at $5.8\ GHz$ extended along the frequency range $5.5 - 6.6\ GHz$.

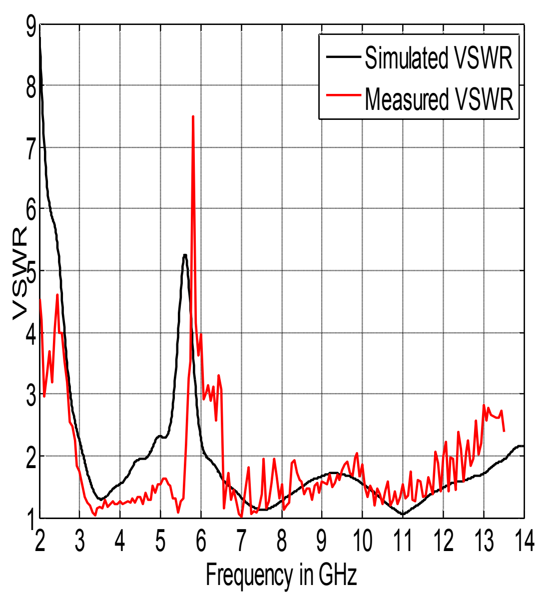
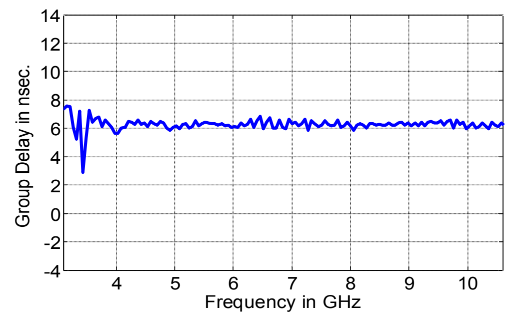
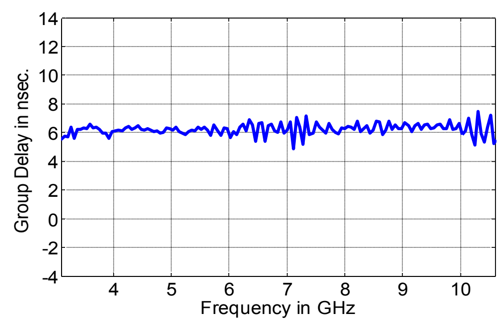


Figure 10.The measured and simulated return losses of the proposed antenna with band notch characteristics.

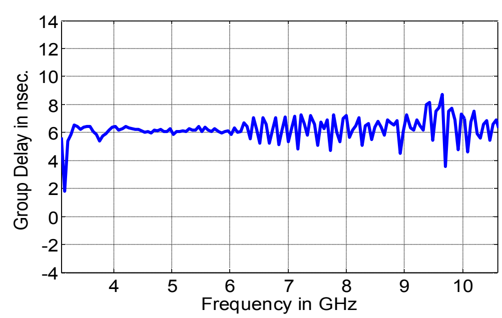
In order to understand the time domain characteristics of the proposed antenna, the antenna group delay is measured by aligning two antennas inside anechoic chamber in three different alignment schemes Face-to-Face, Face-to-Side, and Side-to-Side. Figure 11 illustrates the group delay of the antenna at the three different alignments along the UWB frequency band specified by FCC ($3.1 - 10.6\ GHz$). In general, the group delay represents the first derivative of the phase of the transmission parameter S_{11}. The mean value of the goup delay for the three schemes is $6.2\ nsec$ with very small deviation at Face-to-Face and Face-to-Side alignments; however, Side-to-Side alignment has a deviation in the group delay value approaching only $1\ nsec$. These values of group delay verify that the transmitted frequency components are transferred to the receiver approximately at the same instant, so the proposed antenna does not accumulate much distortion to the input pulse.



(a)



(b)



(c)

Figure 11.The measured group delay of two of the proposed antenna aligned (a) Face-to-Face, (b) Face-to-Side, and (c) Side-to-Side.

In fact, the measured results confirm that the proposed antenna is a very good candidate for medical devices since these devices requires antennas with insensible distortion in addition to small size antenna. The antenna also can be used without slot if WLAN applications are not available in the field of the device usage.

5. CONCLUSION

A small violin-shaped antenna with and without band notch characteristics is designed and analyzed in this paper. The antenna covers the FCC frequency band specified for UWB applications, and its small size enable it to be attached to any UWB medical gadget. The band notch characteristics are presented by embedding a U-shaped slot on the antenna face. The simulated and measured results show that the proposed antenna has a bandwidth larger than the one specified for UWB applications. The designed antenna has good time domain characteristics since the antenna do not accumulate much distortion to the input signal since there is a small deviation in the group delay. It has satisfactory radiation characteristics because the antenna has an omni-directional radiation pattern in the H-plane which is suitable for portable medical devices. In addition, the presence of the U-shaped slot generates a frequency notch that eliminates WLAN radiation without affecting the antenna characteristics outside this frequency range.

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