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Novel and Compact Ultra-Wideband Wearable Band-Notch Antenna Design for Body Sensor Networks and Mobile Healthcare System †

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Abstract: The development and study of a novel and very miniaturized ultra-wideband (UWB) wearable band-notch antenna for body sensor networks (BSNs) and mobile healthcare system have been presented in this paper. A very user-friendly and reliable software Computer Simulation Technology (CST)™ Microwave Studio was used for the modeling and simulation purpose of this antenna. The antenna is a textile-based UWB notch antenna, as it was printed on jeans' textile substrate. The simulated performance parameters, such as return loss, bandwidth, gain, radiation efficiency and radiation patterns of this antenna are demonstrated and analyzed. The main aim of this paper was to design a textile-based compact UWB antenna with the characteristics of band notch in X-band to reject the down link band (7.25 GHz–7.75 GHz) of satellite communication in the UWB frequency ranges of 3.1 to 10.6 GHz in order to avoid interference. The simulated results show that this antenna has very well band notch characteristics in the frequency range of 7.25–7.75 GHz. The overall dimension of the antenna is 25 mm in length and 16 mm in width, which is very compact. The antenna is printed on 1 mm Jeans' textile with the dielectric constant of 1.7. This antenna shows very good results; it has compact size and is printed on textile material, and has band notch characteristics to avoid interference. Due to all these attractive characteristics, it will be a good candidate for body sensor networks for a mobile healthcare system.

Keywords: novel; compact; body sensor networks; mobile healthcare system; band notch; wearable antenna; ultra-wideband; textile; jeans' textile

1. Introduction

Nowadays, wireless body area network (WBANs) systems are becoming very popular research topic because of the applications of it in the field of medical, real-time health monitoring, entertainments. The low power limit (−44.3 dBm) of ultra-wideband (UWB)systems, high data rate, compact size and large bandwidth attract a wide range of applications in short range communications, wearable applications in sensor networks, body area networks, wireless positioning systems, IoT applications, biomedical imaging and high data rate small range communications. For a small period of UWB pulses, it is simple to persuade a high data rate with small latency [1].

According to Federal Communication Communications (FCC) UWB frequency range is to be from 3.1 GHz to 10.6 GHz [2]. An UWB antenna is the most important element for establishing UWB communications. Important issues remain in terms of interference with narrowband frequency in the UWB frequency regions 3.1–10.6 GHz. UWB experiences from narrow band interference from

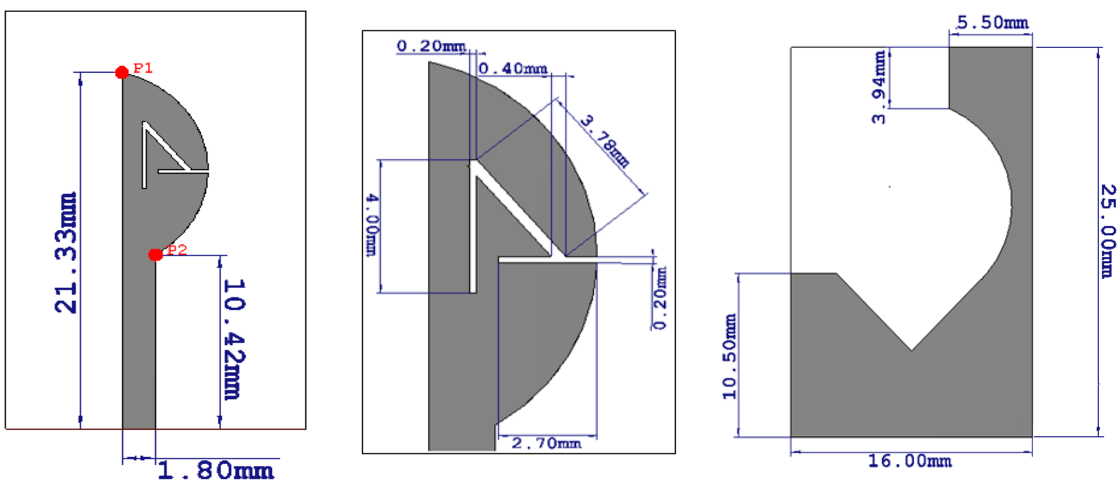
WiMAX, WLAN and X band satellite communication channels. It is very crucial to filter out these unwanted narrowband signals in order to develop a power-efficient UWB communication system for wireless body sensor networks (BSNs). In body area networks, antennas will be integrated with the sensors for health monitoring purposes [1].

Antennae are one of the most important components for any wireless communication system. For the design of an efficient UWB system for BSNs, an antenna needs to meet the special requirements in terms of impedance bandwidth, return loss, radiation efficiency, gain and radiation pattern. Recently, there has been tremendous growing research and interest realized for the design of UWB wearable antennas [3–16]. UWB antenna design and radio channel modeling for WBANs have been presented in [3–9]. Ultra-wideband band north antenna has been pretend in open literature in [12–15]. However, different authors have used various techniques to integrate band notch in UWB antennas [12–15]. Still now, there is no breakthrough in the design of UWB suitable band notch antennas. In some articles, authors used band rejection for WiMAX and WLAN [9–11,14,15]. Band rejection technique has been used in UWB antennas for X-band downlink satellite communication systems (7.25–7.75 GHz) [13,14,16]. However, mostly UWB band notch antenna designs have been focused on FR4 substrate. Some authors were presented with antennas bigger in size, but these may not be suitable for wearable applications.

This paper developed and analyzed a novel and very compact Jeans' textile-based band notch UWB wearable antenna for the health monitoring applications in body sensors networks. The antenna has the band notch characteristics for the rejection of X-band downlink satellite communication systems (7.25–7.75 GHz). Simulation-based results of the antenna, including with the antenna structure, have been presented.

2. Textile UWB Band Notch Antenna Design

Figures 1a–c demonstrate the detail structures of the UWB band notch textile antenna. It shows front and back views of the antenna with detail sizes of each segment and component. This antenna was developed with the help of a Computer Simulation Technology (CST)™ Microwave Studio. The antenna is printed on Jeans' fabric substrate, which has a height of 1 mm, and the relative permittivity of the substrate is used as 1.7. The antenna does not have full ground plane in the rear side, as noticed from Figure 1c. A slit is introduced to the top of the antenna radiating element to obtain the band notch in the X-band frequency range of (7.25 GHz–7.85 GHz) for satellite communication. The antenna is very compact in size as 25 mm in length and 16 mm in width of the full antenna, with substrate and ground plane.



(**a**) (**b**) (**c**)

Figure 1. Ultra-wideband (UWB) band notch textile antenna: (**a**) Front view; (**b**) Front view with details of slit size; and (**c**) Back view with showing ground plane size.

3. Results and Discussions

In this section, performance parameters such as return loss impedance bandwidth, gain, radiation efficiency and radiation pattern of the antenna are presented and analyzed. The results were extracted from the simulation, which was done using CST.

3.1. Return Loss Response

Figure 2 illustrates the return loss curve of the antenna. The return loss result of this antenna was extracted from the simulation result in CST software. From Figure 2, it is noted that the antenna works in the range of UWB frequency band (3.1 GHz to 10.6 GHz), and it shows band notch characteristics in the frequency range of 7 GHz to 7.85 GHz, which was one of the goals of this paper. In the frequency range of 7 GHz to 7.85 GHz, the return loss values are above −2 dB, which will allow interference-free communication in the UWB system for low-power BSNs. The presented return loss results meet the estimated aim of this paper. At other frequency bands, except band notch regions, the return loss values show very good results—especially at a higher frequency.

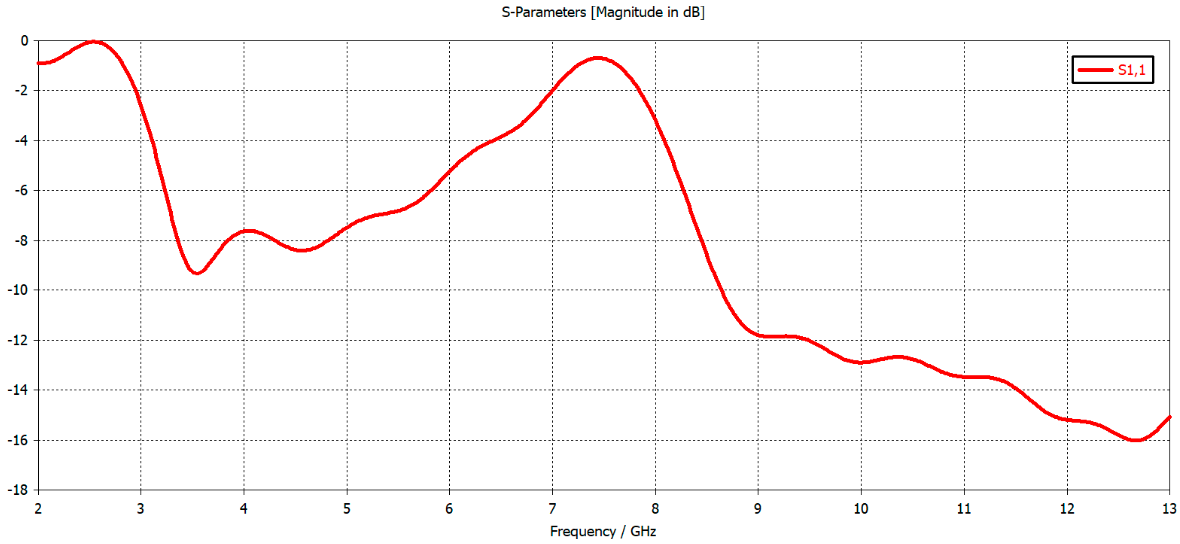


Figure 2. Return loss curve of the UWB notch antenna.

3.2. Radiation Efficiency and Gain

In Table 1, the simulated radiation pattern and gain of the antenna are listed. The simulated gain and radiation efficiency are extracted from the far field simulated results at the frequencies of 3.5 GHz, 5.7 GHz, 7 GHz and 9 GHz. From Table 1, it is shown that antennae show higher radiation efficiency at 3.5 GHz, 5.7 GHz and 9 GHz, as compared to 7 GHz, which is expected due the notch at this frequency. As compared to higher frequency band, this antenna shows better efficiency at lower frequencies. A maximum of 84.3% radiation efficiency is observed at 5.7 GHz for this antenna. The antenna expressed good gain at 3.5 GHz, 5.7 GHz and 9 GHz. The gain is very good at 7 GHz, which is obvious because of noth band here.

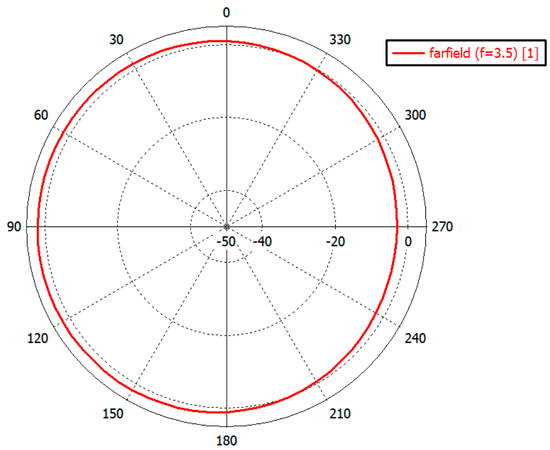
Table 1. Gain and radiation efficiency at various frequencies of the antenna.

Frequency (GHz)	3.5 GHz	5.7 GHz	7 GHz	9 GHz
Gain (dBi)	1.643	1.76	−0.20	2.86
Radiation Efficiency (%)	83.29	84.30	32.00	79.79

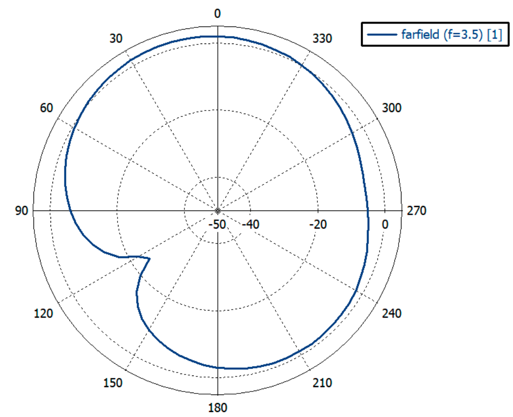
In this study, this antenna shows maximum 2.86 dBi gain at 9 GHz. From the study, it is noticed that higher frequency has higher gain in comparison with the lower frequency band. The lowest gain is noticed at 7 GHz.

3.3. Radioation Patterns

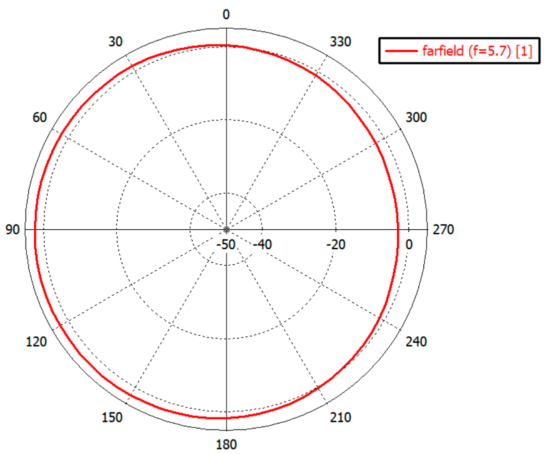
Figures 3a–h demonstrate the simulated radiation patterns of the antennas at 3.5 GHz, 5.7 GHz, 7 GHz and 10 GHz. The radiation patterns have been plotted as plane-wise, such as elevation and azimuth planes.At 3.5 GHz, the antenna radiates omnidirectional in the XY plane, but in the XZ plane there is a null noticed in the 120 degree angle. At 5.7 GHz in the XY plane, the radiation pattern looks the same as the 3.5 GHz, but less null is noticed at the XZ plane in the 120 degree angle in comparison with 3.5 GHz. At higher frequencies such as 9 GHz, the radiation patterns in both planes look more distorted compared with lower frequency bands.



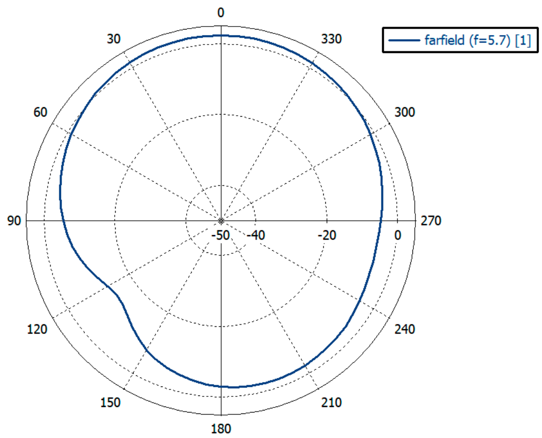
(**a**)



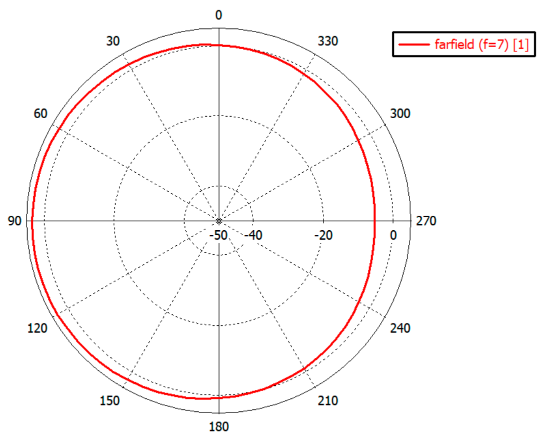
(**b**)



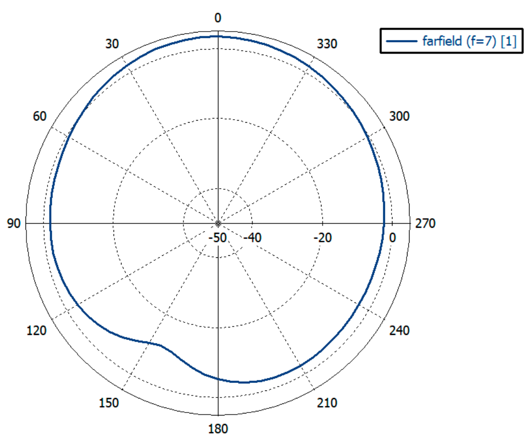
(**c**)



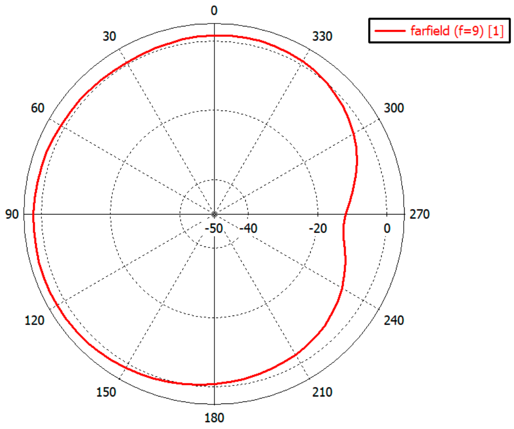
(**d**)



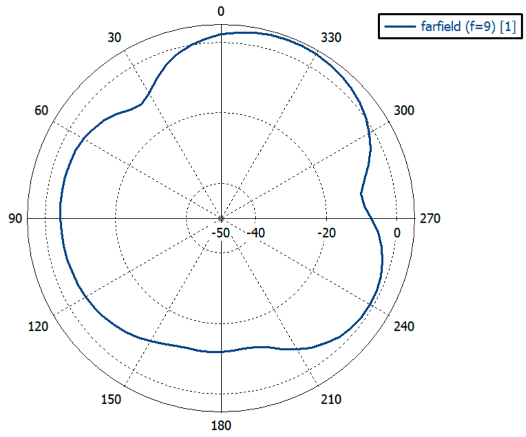
(**e**)



(**f**)



(**g**)



(**h**)

Figure 3. Radiation patterns of the antennas at different frequencies. (**a**) 3.5 GHz, XY Plane; (**b**) 3.5 GHz, XZ Plane; (**c**) 5.7 GHz, XY Plane; (**d**) 5.7 XZ Plane; (**e**) 7 GHz, XY Plane; (**f**) 7 GHz, XZ Plane; (**g**) 9 GHz, XY Plane; and (**h**)9 GHz, XZ Plane.

3.4. Future Work

In future, this compact textile antenna will be fabricated on the jeans' substrate, and performance parameters will be measured. The simulation results will be compared with the measured results. From the experienced of authors, it is noticed that the simulated results using CST are comparable with the measurements. The antenna has already been simulated on three layers (skin, muscle and fat) of the human body model to study the human body's effects on the antenna performance. Due to the page limit, it is not possible to provide the on-body simulated results here in this paper. Some simulation-based parametric studies also have been carried out. Authors of this paper have planned to summarize all the results and write a research article for a MDPI journal soon.

4. Conclusions

A novel compact Jeans' textile wearable UWB band notch antenna for wireless BSNs and a mobile healthcare system is demonstrated. The antenna works in the UWB frequency ranges of 3.1 GHz to 10.6 GHz with the characteristics of band notch in X-band to reject the down link band (7.25–7.75 GHz) of satellite communication with a view to avoid interference. The antenna is very compact in size, and designed on 1 mm Jeans' textile with the dielectric constant of 1.7. The total height of the antenna is 1.07 mm. The antenna shows very bad results at 7 GHz due to band notch characteristics. However, it shows very good preference parameters at other frequency bands of operation. It is illustrated that a maximum 84.3% radiation efficiency and 2.86 dBi gain are noticed at the frequencies of operations for this antenna. The antenna is textile-based, which will be a good option for wearable applications as it can be printed on the users' Jeans. Due to its compact size, novel structure, textile-based band notch characteristics and very good performance parameters, this UWB antenna will be suitable for BSNs and mobile healthcare systems.

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