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Design & Performance of Wearable Ultra Wide Band Textile Antenna for Medical Applications

Abstract: The concept of wearable products such as textile antenna are being developed which are capable of monitoring, alerting and demanding attention whenever hospital emergency is needed, hence minimizing labour and resource. In the proposed work by using textile material as a substrate the ultra wideband antenna is designed especially for medical applications.Simulated and measured results here shows that the proposed antenna design meets the requirements of wide working bandwidth and provides 13.08 GHz bandwidth with very small size, washable (if using conductive thread for conductive parts) and flexible materials. Results in terms of bandwidth, radiation pattern, return loss as well as gain and efficiency are presented to validate the usefulness of the current proposed design. The work done here has many implications for future research and it could help patients with such flexible and comfortable medical monitoring techniques.

Keywords: Textile antenna, ultra wide band, efficiency, wearable antenna, return loss

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1 Introduction about textile antenna

Textile materials generally have a very low dielectric constant, which reduces the surface wave losses and improves the impedance bandwidth of the antenna. In comparison with high dielectric substrates, textile antennas are physically larger. Textile material is generally classified into two categories: Man Made fibers and Natural fibers. Synthetic fiber is subcategory of manmade fibers being polymer from their molecular structure. The important properties of the antenna such as return loss called S_{11}, gain and radiation pattern can be calculated using numerical simulation software CST microwave studio and other software's like FEKO. Recently, possibilities of connecting completely independent appliances with the textile have emerged. Full success however will be achieved only when antennas and all related components are entirely converted into 100% textile materials. Therefore, by embedding antennas in garments a patient-friendly stand alone suit can be obtained. Moreover, the use of embedded textile components guarantees washing of the suit and accordingly reuse of it. On the other hand, the commercial use of frequency bands from 3.1 to 10.6 GHz was approved for ultra-wideband (UWB) systems by the Federal Communications Commission (FCC) in 2002 [4, 5]. UWB transmission antennas do not need to radiate or transmit a high-power signal to the receiver and can have a larger battery. By using UWB technology with wearable technology an UWB antenna using 100% textile materials using flannel as substrate [9]. Unlike previous textile antennas, the present work is found to be capable of meeting the important requirements of wearable electronic devices such as being robust, consumes less amount of power, being comfortable to wear [6–8].

A wearable antenna can be used as clothing used for communication purposes, which includes tracking and navigation, mobile computing, public safety and wireless communication. By using Wireless Body Sensor Networks for healthcare applications, the design of wearable antennas offers the possibility of ubiquitous monitoring, communication and energy harvesting and storage. Basic requirements for wearable antennas are a planar structure and flexible construction materials. Material's several properties influence the working of the antenna [9–11].

In addition, the current manuscript materials used can guarantee washing of the wearable device if the conductive part is made up from conductive thread available in market and accordingly reuse of it. The measured results of the present antenna designs are compared with simulations, and good agreement is observed. The main benefits of the textile antennas are summarized:

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- Lightweight,
- Not expensive & Robust
- Very Low maintenance,.
- Unnoticeable in military purpose.

2 Overview and different application

Important features of designed antenna:

- Ultra wide bandwidth = 13.08 GHz
- Measured S11 at 9.700800 GHz = −18.910 dB
- Gain of antenna at 9.7008 GHz = approx 3.8 dB
- Antenna is UWB between 8.866400 GHz to 21.946400 GHz
- Antenna working for medical monitoring is taken at 9.700800 GHz

Hardware Antenna can also work on:

- Frequency 04.116600 GHz for Wi-Max apllications
- Frequency 9.700800 GHz for radar applications and medical monitoring
- Frequency 13.0131400 GHz for microwave fixed systems
- Frequency 17.991400 GHz for wireless body area network sensor applications

3 Design of proposed antenna

The practical use of textile antennas is most convenient when they are integrated into clothing. As this can be accomplished conveniently and unobtrusively, the integration of such an antenna system into a rescue worker's garment is not hindering for the operations being performed. So the necessary requirements of wearable antenna designing are planar structure, flexible conductive materials in the patch and ground plane, and flexible dielectric materials [12–15].

Table 1: Designed Parameters.

Material	Values
Thickness, h [mm]	1
Relative permittivity (ε_r)	1.7
Loss Tangent	0.025

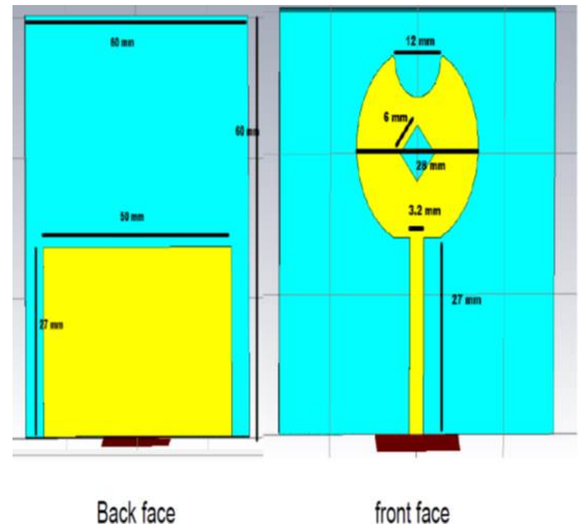

Figure 1: Particle size distribution.

In this paper, an improved design has been proposed and analysed. To find the proposed design parameters such as the radius (a) of radiating element were calculated from the equation (1). Where a is the radius of the circular patch antenna in millimetre, f_r is the resonance frequency in GHz and ε_r is the relative permittivity of the textile substrate material.
The shape of the proposed antenna is given in Figure 1. Height of substrate is taken 3 mm and height of conductive sheet is taken 0.03 mm but it can be a maximum of 0.1 mm. In Figure 1 the dimensions of proposed antenna from back face and front face are given. The Figure 1 shown below is a snapshot from CST studio and waveguide port is used to input signal to antenna. The ground plane of designed antenna is made of copper tape with a thickness of 0.03 mm. The simulations were carried out using CST Microwave Studio software and the antenna characteristics were studied.

$$a = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \tag{1}$$

4 Results and discussions of proposed antenna

4.1 S parameters and VSWR of desired antenna

From Figure 2 and Table 3 we can have gain and S_{11} parameters at desired frequencies after simulation on CST studio

Table 2: Designed Parameters.

Substrate thickness [mm]	3
Substrate dimension [mm]	60 ×60
Patch radius [mm]	14
Partial ground plane [mm]	50 ×27
Upper circular slot radius [mm]	6
Centre Square slot Dimensions [mm]	6 × 6
Microstrip feed line	27×3.2

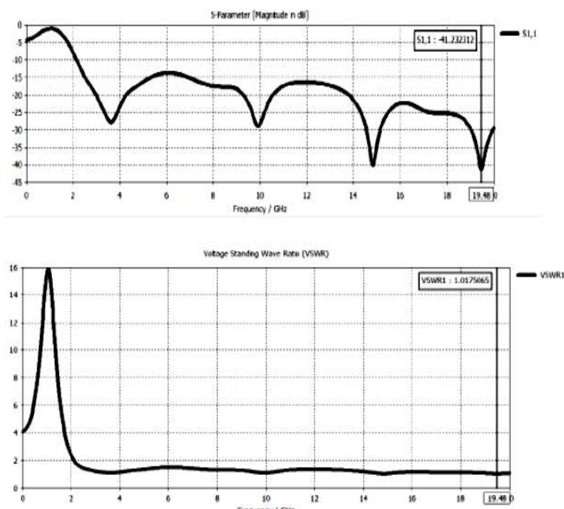

Figure 2: S_{11}-parameter and VSWR Vs Frequency

and also total efficiency is also measured from simulated results of desired antenna.

4.2 Radiation Pattern of desired antenna

In Figure 3 it is clear that radiation pattern is different at different frequencies and we can choose that radiation pattern which is suitable for our application. At frequency 3.64 GHz radiation pattern is somewhat omnidirectional which is good for a device working for medical purpose but frequency is not supporting for medical monitoring applications. Thus we have used second Figure 3 which is also omnidirectional and best fit in form of frequency and radiation pattern for medical monitoring applications. At frequency 19.48 GHz which can be used for wearable wireless body area network sensor applications in the military because it is directional in nature and fits its property for military applications but does not fit for medical monitoring applications which needs omnidirectional radiation pattern.

Table 3: Simulated Results of proposed antenna.

Frequency	Gain	S_{11}	Total Efficiency
19.480 GHz	6.365 dB	−41.232312 dB	87.21%
14.829 GHz	4.762 dB	−40.10772 dB	87.09%
9.92 GHz	3.888 dB	−28.99 dB	89.06%
3.64 GHz	3.173 dB	−27.8699 dB	91.0%

tern. Also efficiency at 9.92 GHz is 89.06% which is quite impressive and with gain of 3.8 dB and S_{11} of -28.99 dB. From Table 3 it can easily be judged that efficiency is highest at lowest frequency of S11 plot given in Figure 3. And S_{11} is also highest i.e. -27.86 dB which is good but at highest frequency at 19.48 GHz S11 is -41.232312 dB which is quite impressive can be used for other applications inspite of medical monitoring.

4.3 Radiated power and total efficiency of desired antenna

In Figure 4, radiated power is given at different frequencies and this result is from simulation of desired antenna. In Figure 5 total efficiency is given at different frequencies and also the results of efficiency in Table 1 is also taken for this plot only. All the observations can be made from these plots.

4.4 Directivity of desired antenna

Figure 6 shows the omnidirectional plot at 3.64 GHz and 9.92 GHz and at frequency 14.829 GHz. The pattern is disturbed from an omnidirectional pattern to spread out pattern and at frequency 19.48 GHz the pattern become pure directional with its side lobes, so at frequency 19.48 GHz this antenna can be used where directional antenna is needed i.e. in point to point communication with station and with other members or clients using station as base which is pure directional system.

5 Antenna fabrication on textile

In Figure 7, Photograph of hardware of proposed antenna with SMA connector soldered carefully on conductive patch. Flannel substrate is taken as substrate as it is formed of 99% cotton and easily available and the cheap-

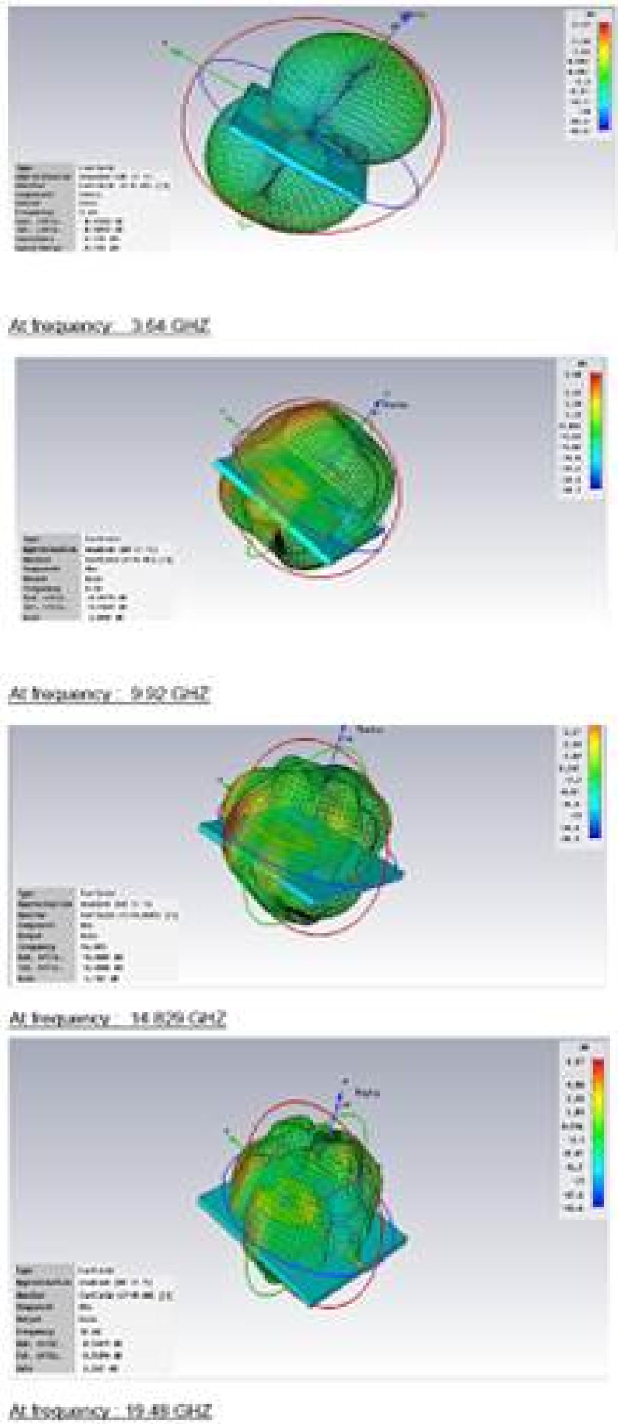

Figure 3: Radiation pattern on different frequencies.

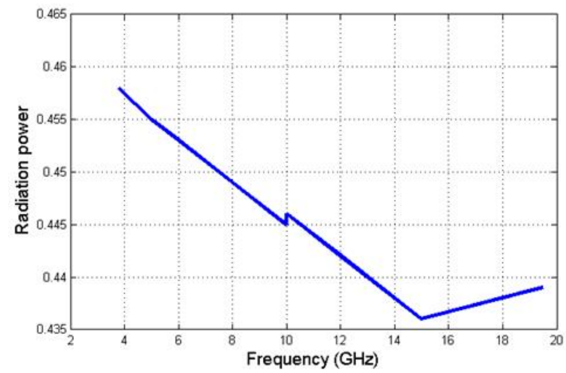

Figure 4: Proposed antenna while measuring results on vector network analyser in IIT Kanpur lab.

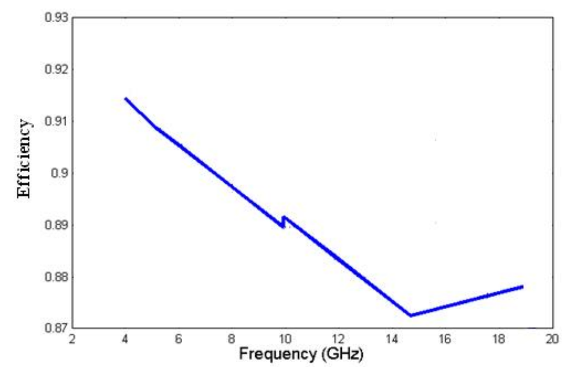

Figure 5: Total efficiency Vs Frequency.

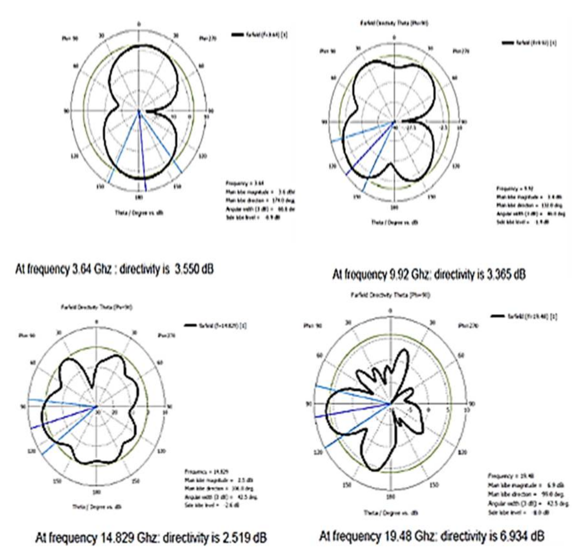

Figure 6: Simulated directivity at 3.64 GHz, 9.92 GHz 14.829 GHz and 19.48 GHz.

(a)

(b)

Figure 7: Hardware implementation of proposed antenna using textile substrate and conductive fabric (a) Front Face, (b) Back Face.

est clothing material available on the market. Conductive fabric is a copper fabric purchased from the market. It is a cloth of conductive threads which makes it robust for use it wherever necessary.

Antenna is kept straight with transmission line of vector network analyser due to continuous fluctuations in results on screen due to change in its orientation with slight movement as shown in Figure 8, Due to textile nature and its flexibility these fluctuations can be ignored. As shown in Figure 9 the antenna is placed or integrated on wearable clothing on arm or on any part of your wearable clothing which is comfortable and convenient. The omnidirectional pattern is needed because when we are wearing an antenna it can be in any orientation during sleep or if a patient is wearing it, it might not be directional towards base

Figure 8: Proposed antenna while measuring results on vector network analyser in IIT Kanpur lab.

Figure 9: Desired hardware antenna on T-shirt.

station as it is impossible for a human to be in single orientation 24 hours. So omni directional pattern is chosen.

5.1 Description of hardware and software used

Hardware requirement is a copper sheet which should be a textile i.e. a conductive cloth which can act as a conductive part of the antenna or in other words can be used as patch and ground for the required antenna. Substrate must also be textile. It can be cotton or polyester but we prefer to use flannel textile as per requirement. Cotton textile can also be used as some works are also done on cotton sheet also. About software we are using 'CST studio 2012' (Computer Simulation Tool) for antenna designing virtually and using new material of dielectric 1.7 and loss tangent 0.025 at 2.4 GHZ. CST studio is used with new material as substrate to calculate results and simulations and to get idea of expected output after formation of hardware. FEKO also be used but better results are expected on CST STUDIO 2012.

6 Simulated and measured results

Figure 10 shows a comparison of both simulated and measured results in terms of return loss and bandwidth of proposed textile antenna. The slight change between simulated and measured result is due to flexibility of textile material, fabrication tolerance, humidity and temperature effect on cotton and also using of three layer stack cotton fabric without bonding agent. However, simulated and measured results show a good correlation. Important features of designed antenna are given as below

- Ultra wide bandwidth = 13.08 GHz
- Measured S11 at 9.700800 GHz = −18.910 dB
- Gain of antenna at 9.700800 GHz =approx 3.8 dB
- Antenna is UWB between 8.866400 GHz to 21.946400 GHz
- Antenna working for medical monitoring is taken at 9.700800 GHz
- Frequency 4.116600 GHz for Wi-max apllications
- Frequency 9.700800 GHz for radar applications and medical monitoring
- Frequency 13.0131400 GHz for microwave fixed systems
- Frequency 17.991400 GHz for wireless body area network sensor applications.

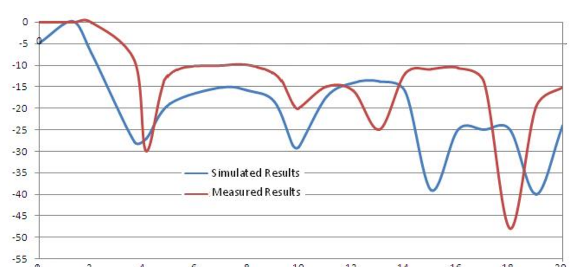

Figure 10: Comparison of measured and simulated results of desired antenna on vector network analyser.

Table 4: Comparison of measured and simulated results.

	Simulated Results		Measured Results	
	S_{11} (dB)	Frequency (GHz)	S_{11} (dB)	Frequency (GHz)
First deep	-27.87	3.64	-31.545	4.12
Second deep	- 28.99	9.92	-18.910	9.70
Third deep	- 40.11	14.83	-25.412	13.01
Fourth deep	- 41.23	19.48	-47.263	17.99

7 Conclusion

In this paper it has been concluded that the textile wearable antenna with major applications of monitoring a human body with data transmission functions is achieved by using a textile substrate and the wearable antenna is useful for off body communication in personal area networks. The developed wearable antenna can be used for wearable wireless body area network sensor applications in the military because it is directional in nature and fits its property for military applications. The proposed design consists of a partial ground plane, modified circular patch with jeans substrate textile material that has made the proposed antenna design suitable for wearable applications. A second layer of jeans textile material was placed on the top of the microstrip feed line to hide the feeding on the clothing. The proposed antenna design was successfully fabricated, and measured. The simulated and measured results showed that the proposed antenna has constant gain, high efficiency and constant radiation pattern over its whole frequency band. In addition, the compact size of the antenna further confirms its suitability for portable UWB devices.

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