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Flexible Ultra Wide Band Antenna for WBAN Applications

Reshma Lakshmanan,Shinoj K. Sukumaran*

MTech student, Department of ECE, RIT, Kottayam, Kerala, India

Assistant Professor, Department Of ECE, RIT, Kottayam, Kerala, India

Abstract

This paper introduces a small-sized, low-profile, planar and flexible ultra-wide band (UWB) antenna using natural rubber as the substrate. It is the primary approach in using natural rubber as the substrate for UWB antenna. The UWB antenna is designed for applications in WBAN, which is the current revolution in wireless sensor networks. The antenna operates from 3.1-10.6 GHz, which is a candidate for WBAN operation. The flexible nature of the antenna makes it convenient for the use as a body worn antenna for WBAN. This paper is a case study of whether rubber can be used as a substrate for UWB antenna and compares the performance using FR4 substrate.

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Keywords: **Flexible UWB Antenna; Rubber substrate; WBAN.**

1. Introduction

Wireless devices and systems based on ultra-wideband (UWB) radio technology, with the frequency allocation of 3.1–10.6 GHz, support low output power and high data rate (110–200 Mb/s) applications over short ranges (4–10 m) [2,8].UWB antennas must be electrically small and inexpensive without compromising on performance. UWB can be effectively used for WBAN due to its ultra-low power consumption, and large bandwidth availability.In February 2004, Federal communications commission (FCC) allocates unlicensed frequency band of 3.1-10.6 GHz for UWB applications. For on-body and off-body communications, [6] IEEE802.15.6 specifies both narrowband and

* Corresponding author. Tel.:7558965910.
E-mail address:lakshmananreshma@gmail.com

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wideband frequency areas, such as industrial, scientific and medical (ISM) at 868 MHz (in the EU), 915 MHz (in the US), 2.4 GHz (in the EU & the US) or UWB at 3.1-10.6 GHz.

Polymer based antennas become a popular topic in the field of flexible antennas.The advantages of using polymers as the flexible substrate are they are inexpensive and able to withstand mechanical strains. Different approaches [3-5] using polymers as flexible substrates have been identified, this included liquid crystal polymer, polydimethylsiloxane [1] employing silicone elastomers or ceramic composites, and high conductivity polymer like carbon nanotube. Polymers such as polydimethylsiloxane (PDMS) and SU-8 have been widely adopted for microwave microsystem fabrication in recent years [1]. PDMS as microwave frequency electronics' Substrate has several promising features, such as good chemical stability and low dielectric constant.

The flexibility of an antenna depends on the flexibility of the substrate. Theflexible antennas are widely used now a day due to their versatility of use. When we thought of flexible material, rubber is the material that first comesto our mind [9]. The mechanical properties of rubber make it a good candidate for this purpose. Rubber can naturally and forcibly retract to its original dimensions after deformation. Flexible antennas are robust, lightweight and can withstand mechanical strains up to a certain extent. In order to make the antenna flexible, alternative materials to replace existing substrates that are rigid have been considered. The basic idea is to lay a thin metal strip on top of a flexible substrate. This metal must maintain their conductivity even when it is stretched.

Many proposals were made in using several materials as substrates for textile antennas and other wearable antennas. Flexible Micro strip Patch Antenna (MPA) using rubber substrate for WBAN Applications [9] is an important work in the field of flexible electronics.It deals with the primary approach in using natural rubber and natural rubber with filler materials added as the substrate for patch antenna.The antenna operates in the ISM band (2.4-2.5) GHz and provides a better performance in the narrow band of WBAN. But it is not suitable for wide range of operations.This work is the first approach to use natural rubber as a substrate for flexible UWB (3.1-10.6 GHz) antenna. Size reduction is one of the advantages of antenna using high dielectric constant substrate (rubber).

The coplanar wave guide (CPW) patch antennas are the best candidates for UWB flexible antennas as they can be easily fabricated and are much reduced in size. The proposed flexible patch antenna is intended to operate in the UWB of Wireless Body Area Network (WBAN) i.e. 3.1 GHz-10.6 GHz.The antenna design for BAN is a challenging problem as the WBAN uses a network of sensors that are operating in the close vicinity of body tissues. [7, 10].It should not harm the human body and should be of low profile and should account for the flexibility in accordance with the bending of the body.

2. UWB antenna architecture and design

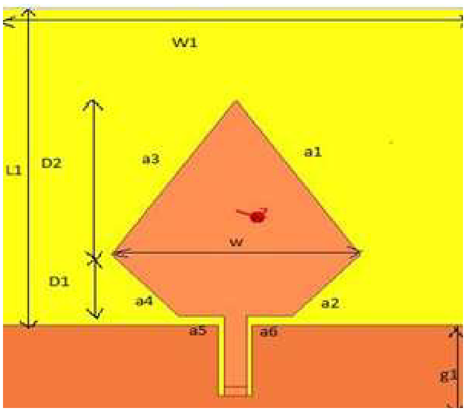


Fig. 1. UWB Antenna using FR4 substrate.

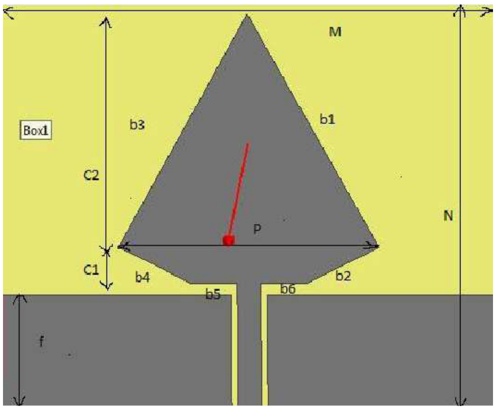


Fig. 2. UWB Antenna using natural rubber substrate.

This section deals with the design of UWB antenna for different substratesi.e. FR4 and natural rubber, based on the resonant frequency (f_r) and dielectricconstant (ε_r).Coplanar waveguide (CPW) is used for this UWB Antenna design. Coplanar waveguide (CPW) is formed from a conductor separated from a pair of ground planes, all on the same plane.The CPW fed antennas have wider bandwidth, better impedance matching and easy integration with active devices or monolithic microwave integrated circuits.

2.2 UWB Antenna using FR4 substrate

The antenna, shown in Fig. 1, was built on a 1mm thick FR4 substrate with a relative permittivity of ε_r = 4.4 and a loss tangent of 0.02. The substrate transverse dimensions are $42 \times 46 mm^2$, and there is no ground metallization underneath the radiator for proper operation. The UWB element of rhomboidal geometry is responsible for the 3.1-10.6 GHz UWB band.The design of the UWB rhomboid antenna [2] starts with choosing D1 and D2. D1 and D2 are critical parameters associated with the upper and lower operating frequencies of the antenna. Accordingly, D1 and D2 are selected to have a reasonable return loss at $f_{\min} = 3.1 GHz$ and $f_{\max} = 10.6 GHz$ which are the lower and upper ends of the UWB band. Good starting points for these dimensions are as follows**:**

$$D1 \cong \frac{\lambda_{e, f_{\max}}}{4} \quad (1)$$

$$D1 + D2 = \frac{\lambda_{e, f_{\min}}}{4} \quad (2)$$

where λ_e is the effective wavelength for the radiation mode in the FR4 substrate with the effective dielectric constant($\varepsilon_{eff} = 2.7$ for the 1mm FR4 substrate) $\lambda_{e, f_{\max}}$ and $\lambda_{e, f_{\min}}$ are the effective wavelengths at the upper and lower UWB frequencies, respectively. Using above equations, calculated values of D1 and D2 are 7mm, 17.5mm respectively. And the width of the patch can be choosing for desired return loss pattern.

Table 1.Optimised antenna dimensions (in mm)

a1	a2	a3	a4	a5	a6	g1	w
20.7	9.6	20.7	9.6	4	4	10	22

2.2 *UWB Antenna using natural rubber substrate*

The antenna, shown in Fig. 2, was built on a 1.2mm thick natural rubber substrate with a relative permittivity of ε_r = 9.3897 [9] and a loss tangent of 0.015.Due high relative permittivity of natural rubber, size of antenna can be reduced. The total length of rhomboidal shape is only 17mm compare to FR4 (24.5mm).The substrate transverse dimensions are $42 \times 34 mm^2$, and there is no ground metallization underneath the radiator for proper operation. The UWB element of rhomboidal geometry is responsible for the 3.1-10.6 GHz UWB band.The design of the UWB rhomboid antenna starts with choosing C1 and C2. C1 and C2 are critical parameters associated with the upper and lower operating frequencies ofthe antenna. Accordingly, C1 and C2 are selected to have a reasonable return loss at $f_{\min} = 2 GHz$ and $f_{\max} = 10.6 GHz$, which are the lower and upper ends of the UWB band. A good starting point for these dimensions is as follows:

$$C1 \cong \frac{\lambda_{e,f_{\max}}}{4} \quad (3)$$

$$C1 + C2 = \frac{\lambda_{e,f_{\min}}}{4} \quad (4)$$

where λ_e is the effective wavelength for the radiation mode in the natural rubber substrate with the effective dielectric constant($\varepsilon_{eff} = 5$ for the 1.2mm natural rubber substrate) $\lambda_{e,f_{\max}}$ and $\lambda_{e,f_{\min}}$ are the effective wavelengths at the upper and lower UWB frequencies, respectively. Using above equations, calculated values of C1 and C2 are 3mm, 14mm respectively. And the width of the patch can be choosing for desired return loss pattern.

Table 2.Optimised antenna dimensions (in mm)

b1	b2	b3	b4	b5	b6	f	p
17.8	6.7	17.8	6.7	4	4	10	22

3.UWB antenna fabrication

Rubber piece have a dimension of $42 \times 34mm^2$. The rubber sample is prepared at Rubber Research Institute of India, Kottayam. The Fig. 3 shows the hydraulic press used for the preparation of natural rubber. The flexible UWB antenna is fabricated by deposition of a thin film of copper on the (patch, feed and ground plane) rubber sample. The masking of rubber for vapour deposition is shown in the Fig. 4.The dimensions of the metal film deposition are same as that obtained in the antenna design.

3.1 *Physical vapour deposition technique techniques of thin films*

Physical vapour deposition technique is also known as thermal evaporation.Because, the technique is done by using thermal energy. The deposition by thermal evaporation method is very convenient and simple and is present most widely used. The process mainly consists of three steps;

- The phase transition of the material (from solid to liquid, liquid to vapour)
- Transmission of vapour material onto the substrate
- Condensation of the vapour material on the substrate

A vacuum evaporation apparatus consist of pumping system, coating chamber and electrical sources. The system used consists of a diffusion pump in conjunction with a backing rotary pump. The ultimate pressure achieved in stain less steel bell jar is of the order of $10^{-6}m$ bar. The measurement of pressure inside the system is done bymean of the pirani and penning vacuum gauges provided within the system. Fig. 6 shows the vacuum coating unit.

Fig. 3. Hydraulic Press for natural rubber preparation.

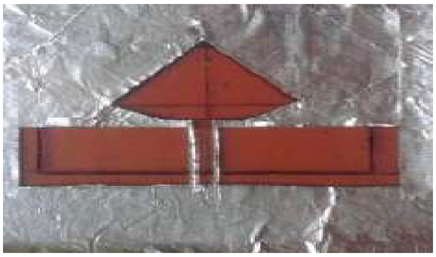


Fig. 4.Mask for Thin film coating using Aluminium foil.

Vacuum technology has undergone major developments primarily as a result of the demand of thin technology for better vacuum.

Fig. 5.Vacuum coating unit.

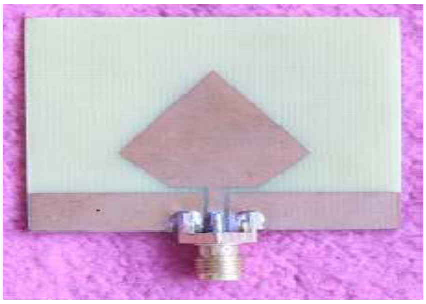


Fig. 6. Fabricated UWB Antenna.

The fig. 6, shows, fabricated small, planar and low cost UWB antenna using FR4 substrate.SMA connector is used as input port for UWB antenna.

4. Results and discussion

The antenna is designed and simulated using the software HFSS (High Frequency Structure Simulator).CorelDraw software is used to draw antenna structure form HFSS files.

4.1 Simulated *Results of UWB antenna using FR4 and flexible natural rubber substrate*

The typically desired value of voltage standing wave ratio (VSWR) to indicate a good impedance match is 2.0 or less, 0r $S11 \leq$ -10dB. VSWR 2 implies that almost 90% power is through to the antenna and only 10% power is reflected back. S11 and VSWR of antennausing FR4 are shown in Fig. 7 and Fig. 9 respectively. S11 and VSWR of antenna using natural rubber are shown in Fig. 8 and Fig .10 respectively. The variations in the values of the return losses are due to the variation in the substrate. The results shows that minimumreturn loss (S11 below -10 dB) is obtained for frequency band 3.1GHz to 10.6 GHz (UWB).The VSWR is also minimum (below 2) at the specified frequency of operation.

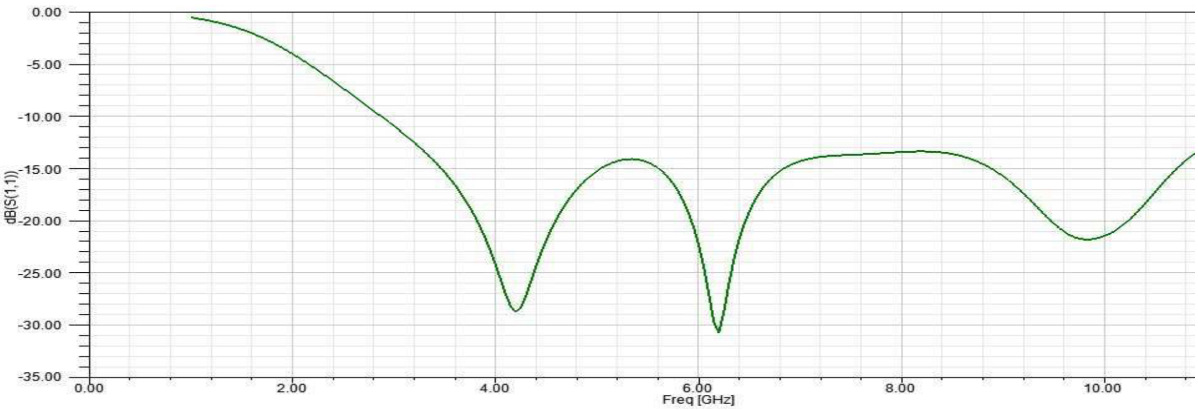


Fig. 7. Return loss of antenna using FR4.

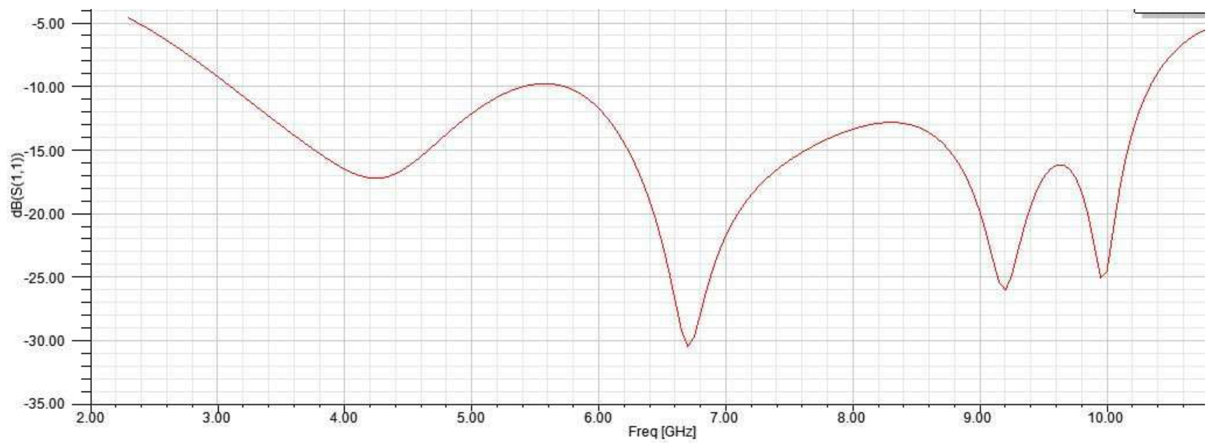


Fig. 8. Return loss of UWB Antenna using natural rubber.

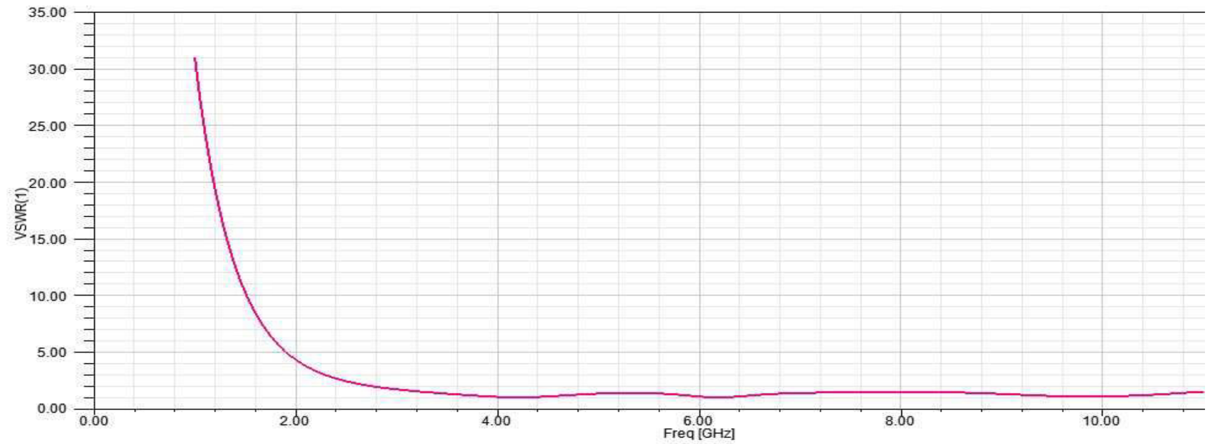


Fig. 9. VSWR of antenna using FR4.

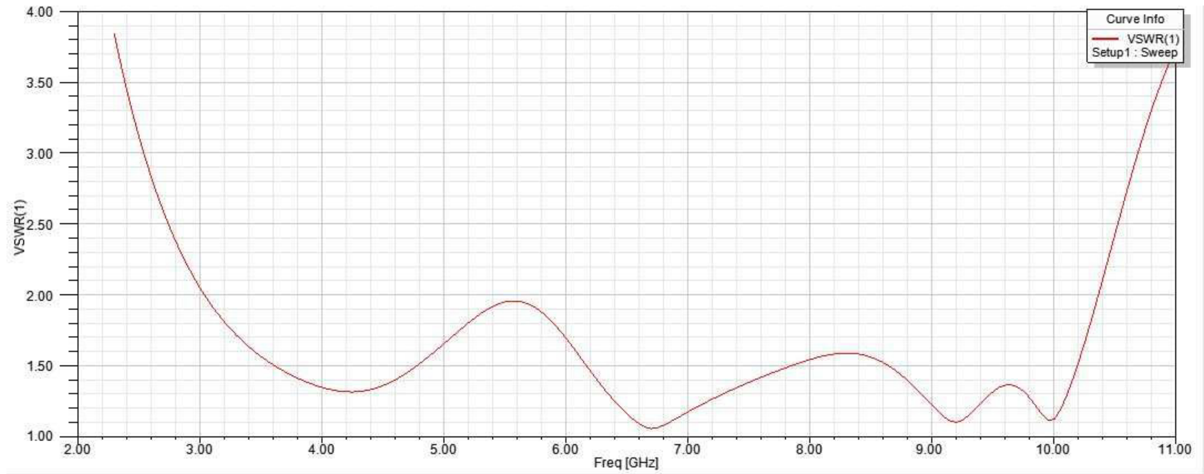
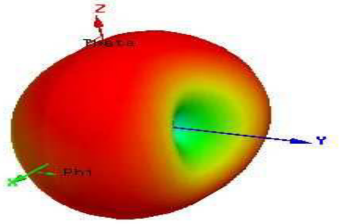


Fig. 10. VSWR of antenna using natural rubber.



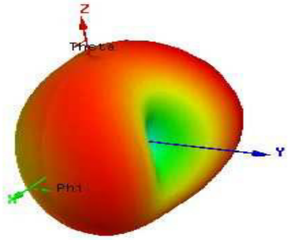
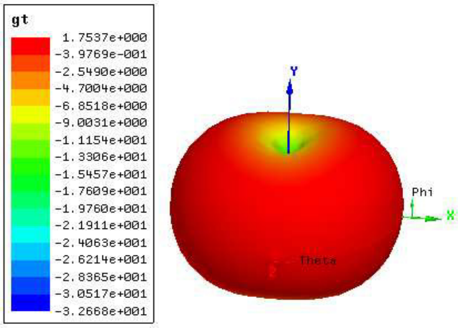


Fig. 11. Radiation pattern of UWB Antenna using FR4   Fig. 12. Radiation pattern of UWB Antenna using natural rubber.



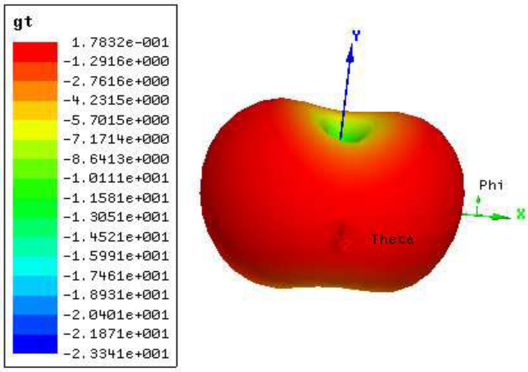
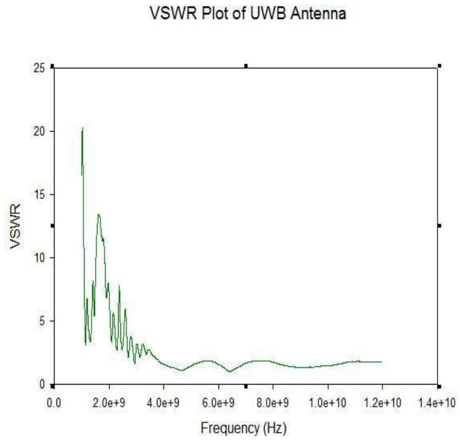


Fig. 13. Gain of antenna using FR4.   Fig. 14.Gain of antenna using natural rubber.

Fig .13 and Fig .14 shows the gain of the UWB antenna using FR4 and natural rubber substrates.The antenna using FR4 have simulated to have a peak gain 1.7dB and 8dB using natural rubber.An omnidirectional radiation patterns are obtained for both UWB antennas.The radiation efficiency is above 90%, and is an important requirement of UWB antenna.The radiation efficiency of UWB antenna using FR4 is 97% and usingnatural rubber is 93%.

UWB antenna testing

The testing of antenna was performed using vector network analyser (VNA). The S11 parameter of the antenna was measured using vector network analyzer. The measured VSWR plot and S11 plot shown in fig. 15 and fig. 16. The band ranges from 3.7-10.6GHz and VSWR is below 2 in this range. Sigma plot V.11 is used for plotting graphs obtained from Vector Network Analyzer.



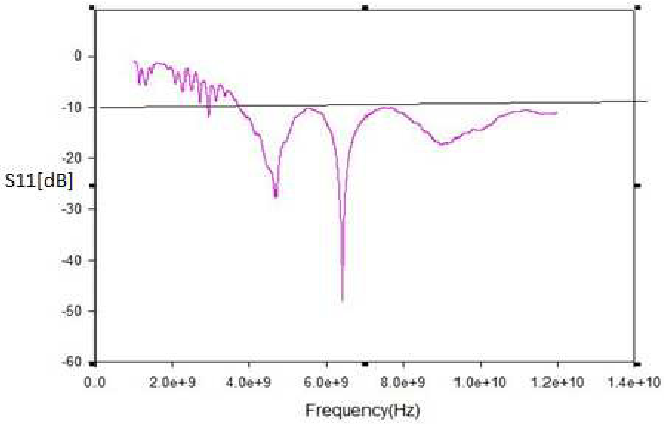


Fig. 15. Measured VSWR of antenna using FR4 substrate. Fig. 16. Measured return loss of antenna using FR4 substrate.

Table 3.Comparison of simulated and tested results using FR4 substrate

Results	Frequency range	VSWR
Simulated results	3.1-10.6GHz	Below 2
Measured results	3.7-10.6GHz	Below 2

6. **Advantages and applications**

The designed flexible UWB antenna using natural rubber as substrate has worth mentioning advantages and applications. As rubber is widely cultivated all over the country especially in the state of Kerala, the raw material is available in plenty. This significantly reduces the cost of antenna.The antenna designed using natural rubber as substrate is reduced in size. This is due to the high relative permittivity (9.3897) of the materials. The size reduction is a major challenge for the antenna design for WBAN also. The antenna justifies its stand as an antenna suitable for WBAN in terms of reduced size.The flexible antenna can beplaced in any portion of the body and it is more versatile to adjust the bendsand curves of the body. Also the antenna is light weight and will not strainthe body.Compare to FR4, natural rubber is not a good flame resistant. But it gives greater resistance to tearing when hot.

7. Conclusion

In this paper, UWB antennas using FR4 and flexible substrate i.e. natural rubber are designed, simulated and fabricated. Antenna parameters such as Return loss, VSWR, Radiation pattern, Radiation efficiency and peak gain analysed.The S11 value below -10dB was obtained for frequency bands and 3.1GHz to 10.6 GHz (UWB).UWB antenna using FR4 substrate was tested using vector network analyzer. Experimental as well as the simulated results have confirmed UWB characteristics of the antennas with nearly stable Omnidirectional radiation properties over the entirefrequency band of interest. The designed antenna meets all the requirements to be used as an antenna for body worn applications.

Acknowledgment

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