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To cite this article: Narbada Prasad Gupta *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **594** 012025

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## Development and performance analysis of conformal UWB wearable antenna under various bending radii

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**Abstract.** Antennas for off-body wearable applications needs to be flexible and its electrical characteristics should be stable in different body postures, different bending or stretching environments. Therefore, the designed antenna should be such that, even if the antenna is bent frequently, it should operate properly. In this paper, a conformal UWB antenna is reported which has been optimized to be conformal to any body shape and size. The proposed antenna has been designed on RT Duroid substrate with dielectric constant of 2.2 and loss tangent 0.0009. The thickness of the material is 0.127 mm. Due to low thickness; it can easily be bent and mounted on curved surfaces. The size of the antenna is 35 × 31 mm<sup>2</sup>. To accomplish the design process, two different bending radii have been considered to bend the proposed antenna. The two bending radii of 25 mm and 50 mm have been chosen; one corresponding to the arm of a healthy child of around 5 years age and another corresponding to a healthy person of age about 35 years with medium built. The simulated radiation efficiency and total antenna efficiency are more than 60% for the bending at 25 mm and 50 mm radii in the UWB frequency range from 3.1 GHz to 10.6 GHz. The gain of the proposed antenna for both the bending radii is changing from 1.4 dB to 5.3 dB. The return loss of the proposed antenna is obtained for 25 mm and 50 mm bending radii of curvatures and it is below 10 dB in UWB range. A prototype of proposed antenna has been fabricated and tested on Rohde & Schwarz 40 GHz VNA. Measured results are in close agreement with simulation results.

### 1. Introduction

Ultra-Wideband (UWB) radio is a potentially revolutionary approach to wireless communication. Recently, the demand for short-range, very high data rate, and video transmission devices has tremendously increased within the wireless user community. Research efforts in this area have exaggerated since the year 2002 when the United States Federal Communication Commission (FCC) allocated the frequency range of 3.1-10.6 GHz for unlicensed UWB indoor wireless communication [1]. A wide variety of antennas has been reported by many authors for off-body wearable applications [2]-[6]. There are two primary requirements for antennas in off-body communication. First, the antenna should be insensitive to the proximity of the body; and second, the antenna should have radiation properties like gain, directivity, etc., which always remain same for different body postures. The impedance matching of the antenna is naturally affected by the proximity of the body. A number of techniques are available for adaptively matching antenna impedance. It is important to note that if antenna is to be used for off-body wearable applications, it must be flexible and its electrical characteristics should be stable in different body postures, different bending or stretching environments [7]. Wearable antennas should have flexible substrates for their practical implementation. Therefore, the designed antenna should be such that, even if the antenna is bent frequently, it should operate properly. The variation in the dimensions due to bending or stretching affects the electromagnetic properties of the antenna [8]. Major effects are as follows:

- Changes in the length of antenna detune its operating frequency.
- Changes in the substrate thickness change the operating frequency.



- Changes in the substrate thickness also affect input impedance bandwidth.

In this paper, the flexible UWB antenna reported in [9] has been optimized to be conformal to any body shape. Design details are provided in [9] along with its parametric results. To accomplish the design process of this conformal UWB antenna, two different bending radii have been considered to bend the flexible UWB antenna reported in [9]. The two bending radii of 25 mm and 50 mm have been chosen; one corresponding to the arm of a healthy child of around 5 years age and another corresponding to a healthy person of age about 35 years with medium built. Simulation results of the conformal UWB antenna obtained from CST EM Simulator v.12 for the two bending radii have been compared with results of the flexible UWB antenna keeping it flat. The return loss of conformal UWB antenna bent at two different radii has been measured on Agilent E5071C 20 GHz VNA after design of the prototype. Section-II provides design and parametric simulation results of the proposed antenna. Section-III provides the detail of prototype designed and measured results. Also, measurement results are compiled in this section. Concluding remarks on the comparison of simulated and measured results are provided in section –IV.

## 2. Design of conformal UWB wearable antenna

Usually, wearable antennas for off-body applications are worn on arms, biceps, and thigh etc. All mentioned body parts are in general cylindrical in shape. So, two cylinders of radius 25 mm and 50 mm have been considered for the design of conformal antennas. These antennas are conformed to the surface of the corresponding cylinder to obtain a particular bending radius. Figure 1 shows the proposed antenna design bent at two radii 25 mm and 50 mm.

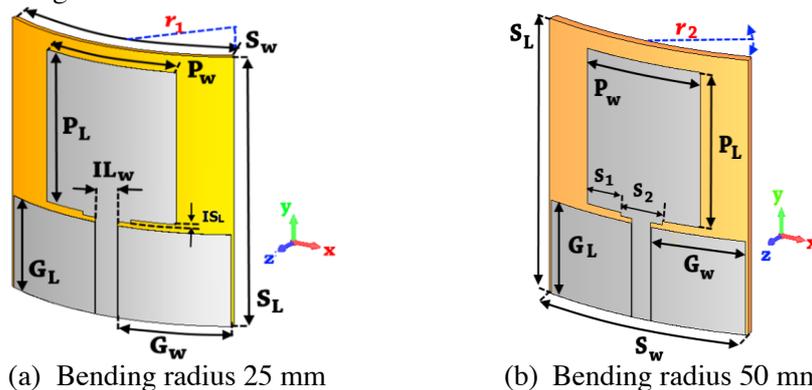
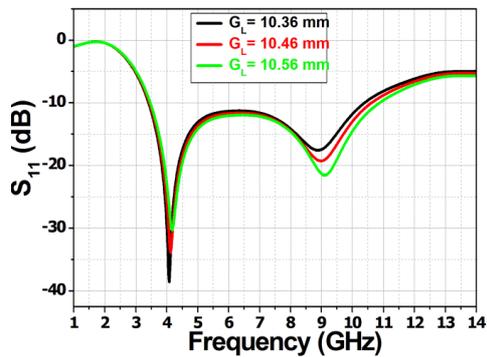
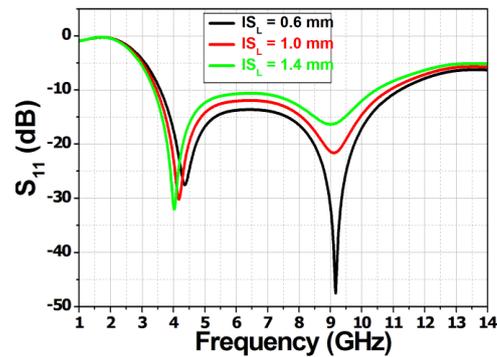


Figure 1 Structure of conformal UWB antenna for bending radius of  $r_1=25$  mm and  $r_2=50$  mm

The material used to model the antenna is RT Duroid with relative permittivity 2.2 and loss tangent 0.0009. The thickness of the material is 0.127 mm.

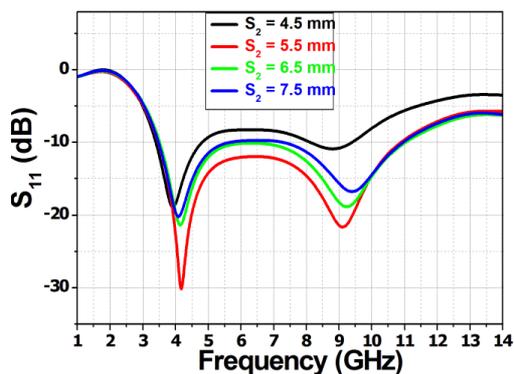
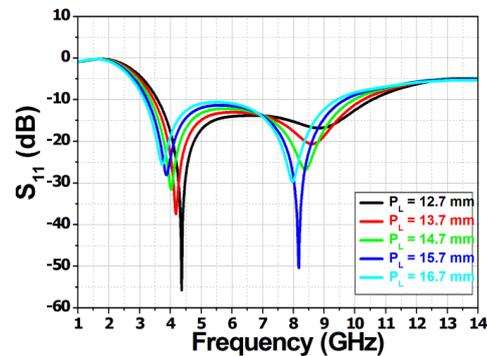
### 2.1. Parametric study and optimization

The conformal antenna shows a different response when it is bent. In the parametric study, 25 mm bending radius has been considered. Figure 2 represents the parametric results of ground length ( $G_L$ ) varied from 10.36 mm to 10.56 mm in three steps of 0.1 mm. It is shown that increasing the ground length increases upper frequency to some extent but no significant change is observed in lower frequency. Parametric results for the step length ( $IS_L$ ) are provided in Figure 3. The step length was varied between 0.6 mm to 1.4 mm in three steps of 0.4 mm. It was observed that if step length is varied, matching of the antenna in the lower as well as the upper frequency band is affected. More effect has been seen in upper frequency compared with lower frequency. Return loss is greatly increased in the middle UWB frequency range if step length is made larger.

Figure 2 Parametric study of ground length ( $G_L$ )Figure 3 Parametric study of input step length ( $IS_L$ )

Similarly, the step width which is again a very important parameter while finalizing the parameter value of the antenna has been varied from 4.5 mm to 7.5 mm in four steps of 1 mm as shown in Figure 4. Performance of the antenna is greatly affected in the middle of UWB range when step width is altered. It also affects the impedance bandwidth. In fact, when step width is reduced to 4.5 mm, the return loss is above 10 dB in the middle UWB frequency range and entire operating band is disturbed at the step width of 4.5 mm. Parametric results for patch length ( $P_L$ ) varied from 12.7 mm to 16.7 mm in five steps of 1 mm are shown in

Figure 5.

Figure 4 Parametric study of Input step width ( $IS_w$ )Figure 5 Parametric study of patch length ( $P_L$ )

It was observed that if patch length is changed, the upper, as well as lower frequency, are changed, which affect the impedance bandwidth of the conformal UWB antenna. The return loss comes closer to the 10-dB mark in the middle frequency band of around 6 GHz. It is evident that the proposed conformal UWB antenna works perfectly for patch length of 13.7 mm as the return loss bandwidth is 3.5 GHz to 10.5 GHz. So, the optimum value of the patch length is taken as 13.7 mm. Figure 6 represents the parametric results of the patch width ( $P_w$ ), which was varied from 13.9 mm to 17.9 mm in five steps of 1 mm. Increasing the patch width results in decrease of upper frequency. At the same time, return loss in the middle UWB range of frequency is improved but impedance bandwidth is reduced significantly. Change in the patch width doesn't affect the lower frequency much but a very small decrease is observed in lower frequency also. The optimized value of patch width is taken as 14.9 mm.

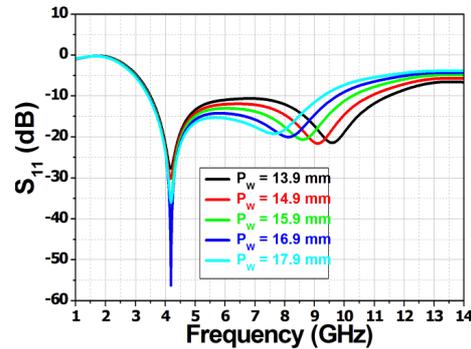
Figure 6 Parametric study of patch width ( $P_w$ )

Figure 7 and Figure 8 compares the return loss of conformal UWB antenna respectively bent at 25 mm and 50 mm radius with planar flexible UWB antenna reported in [9].

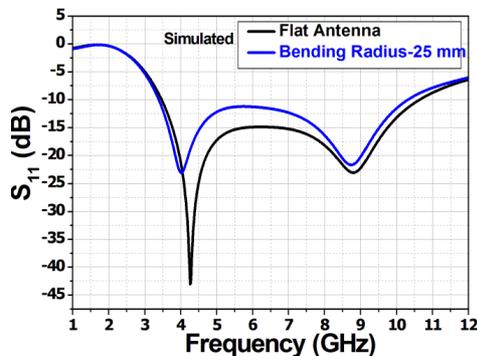


Figure 7 Return loss of flat antenna [9] and proposed antenna bent at 25 mm radius

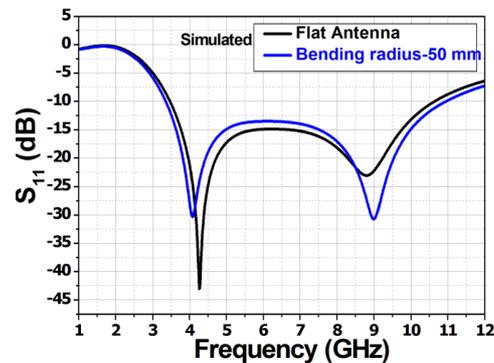


Figure 8 Return loss of flat antenna [9] and proposed antenna bent at 50 mm radius

Results show that planar antenna and conformal antenna have almost similar performance in the UWB range. There is only a little variation in the higher frequency as shown in Figure 7 and Figure 8. There is no much variation in the lower frequency due to bending of the conformal antenna. The return loss remains almost at the same level for the two bending radii. The parameters optimized for planar flexible UWB antenna as well as conformal UWB antenna are shown in Table 1.

Table 1 Optimized parameters of conformal UWB antenna

S. No.	Parameter Description	Dimension (mm)
1	Ground length ( $G_l$ )	10.56
2	Ground width ( $G_w$ )	11.66
3	Input line width ( $IL_w$ )	2.48
4	Step length ( $IS_l$ )	1.00
5	Step width ( $S_s$ )	5.50
6	Substrate length ( $S_l$ )	31.00
7	Substrate width ( $S_w$ )	26.00
8	Patch length ( $P_l$ )	13.70
9	Patch width ( $P_w$ )	14.90

After the antenna parameters were optimized for the proposed conformal antenna, these parameters were tested on the flexible UWB antenna proposed by [9] to confirm the design parameters.

Figure 9 shows return loss characteristics of the flexible UWB antenna keeping it flat and conformal UWB antennas with bending radius of 25 mm and 50 mm. There is very little variation observed in the lower and upper frequencies. But the change is not significant. Still, the antenna is valid for UWB range between 3.2 GHz to 10.6 GHz.

Figure 10 shows the antenna efficiency and radiation efficiency of the conformal UWB antenna bent at 25 mm radius.

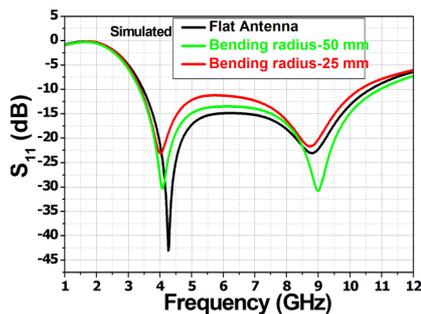


Figure 9 Return loss characteristics of flexible UWB antenna and conformal UWB antennas

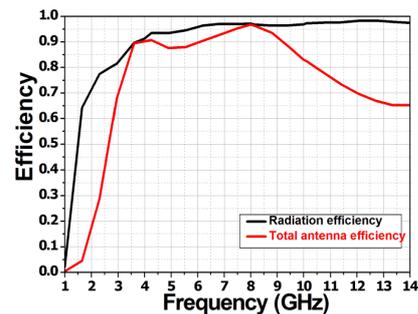


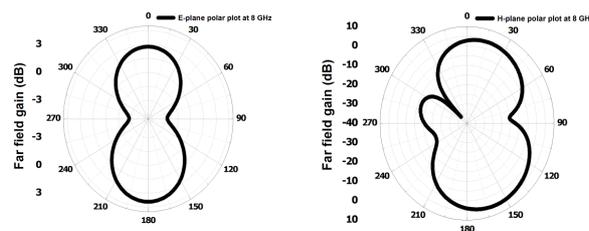
Figure 10 Efficiency of conformal UWB antenna for 25 mm bending radius

The radiation efficiency and total antenna efficiencies are more than 60% in the UWB range. Total antenna efficiency is shown to be ranging from 60% to 97.4% and radiation efficiency is ranging from 80% to 98.5% in the UWB frequency range from 3.1 GHz to 10.6 GHz. Figure 11, Figure 12, and Figure 13 show the far field radiation patterns of conformal UWB antenna bent at the radius of 25 mm at three different frequencies of 4GHz, 8 GHz and 10 GHz. Table 2 provides all the radiation properties of the proposed antenna bent at 25 mm radius.



(a) E-plane pattern (b) H-plane pattern

Figure 11 E-plane and H-plane radiation patterns at 4 GHz for 25 mm bending radius



(a) E-plane pattern (b) H-plane pattern

Figure 12 E-plane and H-plane radiation patterns at 8 GHz for 25 mm bending radius

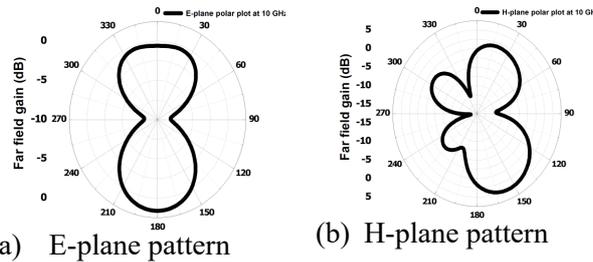


Figure 13 E-plane and H-plane radiation patterns at 10 GHz for 25 mm bending radius

Table 2 Radiation properties of proposed antenna bent at 25 mm radius

S. No.	Frequency (GHz)	Main lobe direction	Main lobe magnitude (dB)	Beam width	Gain (dB)
1	4	180°	2.2	89.2°	2.219
2	8	180°	3.9	92.6°	5.34
3	10	180°	1.6	77.2°	4.93

Figure 14 depict the gain of the conformal UWB antenna for the bending radius of 25 mm. Figure 15 represents the radiation efficiency and total antenna efficiency of conformal UWB antenna bent at 50 mm radius. It is shown that the radiation efficiency varies between 86.1-97% and total antenna efficiency is varying between 71.8-94.3% in the UWB range from 3.1 GHz to 10.6 GHz.

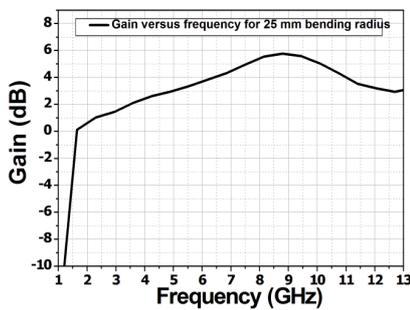


Figure 14 Gain of conformal UWB antenna bent at 25 mm radius

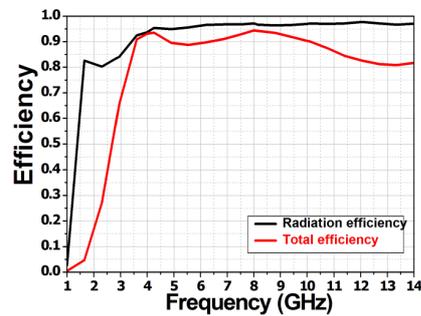


Figure 15 Efficiency of conformal UWB antenna for 50 mm bending radius

Figure 16, Figure 17, and Figure 18 depict E-plane and H-plane far field radiation patterns of conformal antenna bent at 50 mm radius. Table 3 provides all the radiation properties of the proposed antenna bent at 50 mm radius. Variation in the gain of conformal UWB antenna bent at 50 mm radius is shown in Figure 19. The gain is varying between 1.6 dB to 5.3 dB in UWB frequency range from 3.1 GHz to 10.6 GHz.

Table 3 Radiation properties of proposed antenna bent at 50 mm radius

S. No	Frequency (GHz)	Main lobe direction	Main lobe magnitude (dB)	Beam width	Gain (dB)
1	4	180°	2.6	82.2°	2.17
2	8	180°	2.6	94.9°	5.1
3	10	180°	1.0	94.5°	4.2

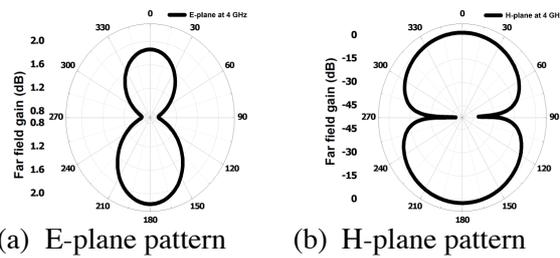


Figure 16 E-plane and H-plane radiation patterns at 4 GHz for 50 mm bending radius

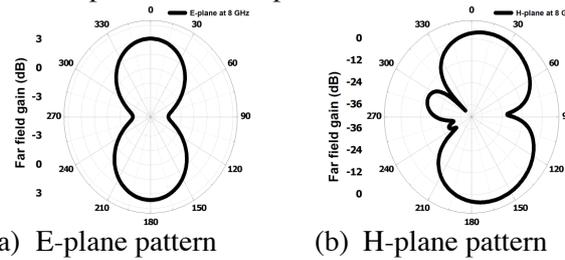


Figure 17 E-plane and H-plane radiation patterns at 8 GHz for 50 mm bending radius

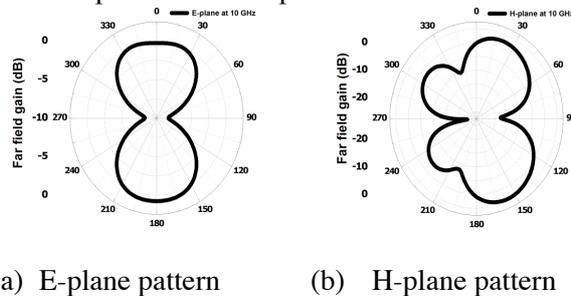


Figure 18 E-plane and H-plane radiation patterns at 10 GHz for 50 mm bending radius

The proposed conformal UWB antenna exhibits the UWB properties and as far as simulations results are concerned it is suitable for conformal applications. Next section represents the measurement results for conformal UWB antenna, which was bent at two different radii. All measurements have been done on Agilent E5071C 20 GHz VNA.

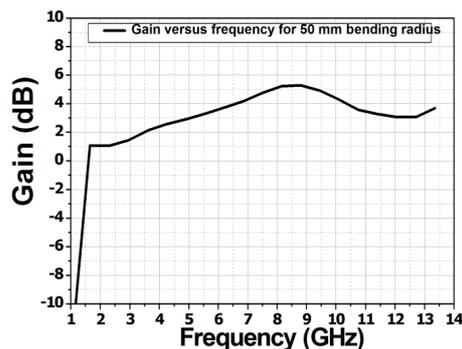


Figure 19 Gain of conformal UWB antenna bent at 50 mm radius

### 3. Measurement results

Figure 20 shows the measurement setup used for the measurement of return loss at bending radius of 50 mm. A flexible cardboard has been used to provide 50 mm bending radius. The antenna has been rolled on the cardboard to measure the return loss as shown in the Figure 20.

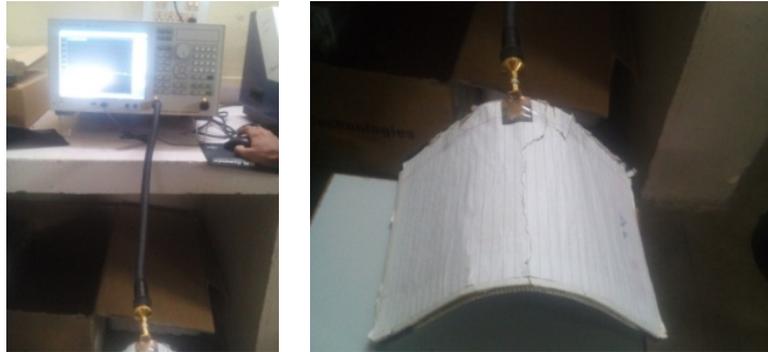


Figure 20 Measurement setup for conformal UWB antenna (bending radius- 50 mm)

Figure 21 compares the measured return loss of flexible UWB antenna in two different conditions when it was kept flat and when it was bent at the radius of 50 mm. Both the measured results closely matched. Almost the same response is observed in both the conditions. The measured lower and upper frequency is 2.9 GHz and 10 GHz respectively, for the conformal UWB antenna which is bent at the radius of 50 mm. The return loss is more around the frequency 8.4 GHz compared to the return loss measured for the flexible antenna in flat condition.

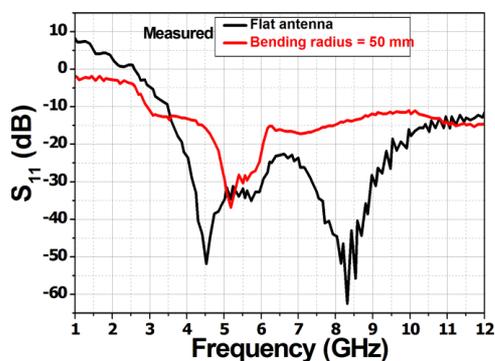


Figure 21 Measured return loss of conformal UWB antenna bent at 50 mm radius



Figure 22 Measurement setup for conformal UWB antenna (bending radius- 25 mm)

The shift in resonance frequency and deterioration in the return loss may be due to the use of cardboard, which was not present during the simulation. Also, the inaccurate 50 mm bending radius may contribute to the deterioration in the return loss. Figure 22 and Figure 23 respectively represent measurement setup to test the conformal antenna for 25 mm bending radius and measured return loss. It is clear from the graph shown in Figure 23 that the proposed conformal UWB antenna exhibits good conformal characteristics in the UWB range from 3 GHz to 10 GHz. The effect of bending the antenna at two different radii does not affect antenna performance much.

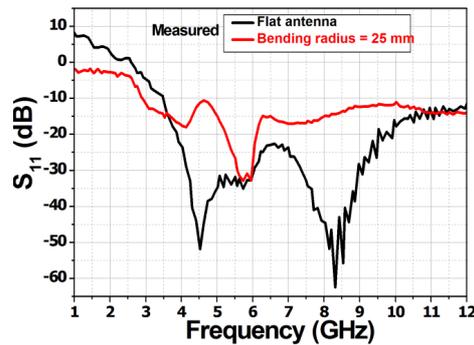


Figure 23 Measured return loss of conformal UWB antenna bent at 25 mm radius

There is only a little frequency shift observed in the result but it doesn't affect its UWB range. There is small variation observed in the measured results. This variation in the result may be due to cardboard in which the antenna has been wrapped for conformity test. The cardboard itself may have certain dielectric properties which certainly affect the frequency of operation. The material used to fix the antenna over the cardboard may also affect its performance. So, considering all these conditions, the return loss of the antenna is still maintained below 10 dB for UWB range, which provides the flexibility to neglect these effects. Therefore, the proposed conformal UWB antenna is perfectly working for UWB wearable applications and can easily be conformed to any bent surface.

#### 4. Summary and conclusions

A conformal UWB antenna designed on RT Duroid flexible substrate with 0.127 mm thickness and relative permittivity of 2.2 has been tested for 25 mm and 50 mm bending radii. The size of the antenna is  $35 \times 31 \text{ mm}^2$ . The radius of 25 mm corresponds to the arm of a medium built healthy child around 5 years age and 50 mm corresponds to a medium built healthy person of age about 35 years. Measured results are in close agreement with simulation results.

The simulated radiation efficiency and total antenna efficiency, gain, lower and upper frequencies are compiled in Table 4

Table 4 Simulated parameters for bending radius 25 mm and 50 mm

Bending Radius	25 mm	50 mm
Radiation Efficiency	80 to 98.5	86.1-97
Total antenna efficiency (%)	60 to 97.4	71.8 - 94.3
Gain (dB)	1.4 to 5.3	1.6 to 5.3
Lower frequency	2.9 GHz	2.9 GHz
Upper frequency	10 GHz	10 GHz

As far as return loss of the conformal UWB antenna is concerned, an equivalent response is obtained for the different radii of curvatures as shown in Figure 24. Return loss is below 10 dB for the UWB range for both the bending radii 25 mm and 50 mm.

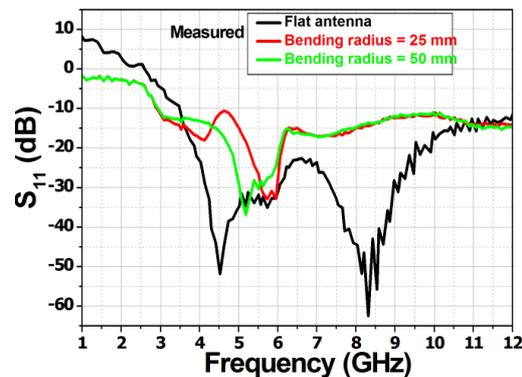


Figure 24 Comparison of flexible UWB antenna (planar) and conformal antennas

It was observed that the impedance bandwidth is between 3 GHz to 10 GHz for both the bending radii. There is only a little shift in frequency which is seen when the antenna is bent. Also, the return loss is more around the frequency of 8 GHz. Due to less thickness and flexibility of the substrate, the proposed antenna is easy to conform to any shape and radius. So, it can easily be employed for UWB wearable applications.

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