Design and Analysis of a Low Cost, Flexible Soft Wear Antenna for an ISM Band Working in Different Bending Environment

I. Rexiline Sheeba and T. Jayanthy

Abstract A low cost, flexible software antenna for ISM band is presented. The Novel antenna is proposed for ISM Band applications. Pure 100 % Cotton is used as dielectric substrate material with dielectric constant 1.6. This antenna is flexible and suitable for wearable applications. The designed antenna resonates at ISM (Industrial, Scientific, and medicine) band with a return loss of more than −25 dB. The simulated and measured results show the performance in terms of Return Loss, Radiation pattern which shows the efficiency of the proposed antenna and this flexible softwear antenna is measured in various bending environments are presented in this paper. Investigation focuses on an ordinary cotton cloth with 3 mm thickness, used as its substrate, and the patch and ground plane are made up of copper as conducting material together to form a flexible textile antenna. Proposed antenna is tested in various bending condition. Such Textile antenna designed for an ISM Band 2.45 GHz. Its radiation characteristics, return loss, gain, polarization have been examined which are the issues when it is used as a wearable antenna for medical purpose. Since it is a flexible textile antenna it bends for any condition. Observations were done for various diameter PVC pipes which is equivalent to the human body organs like arm, elbow, forearm, wrist or in the leg, ankle, knee, thigh and its resonant frequencies were noted. One of the advantages of these characteristics is once the antenna is flexible and bends in any condition then the specific absorption rate can be reduced, when this antenna is placed on the human body.

Keywords Softwear antenna · ISM band · Soft substrate · Bending environment · Flexible textile antenna · Human body physical structure

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1 Introduction

Wireless communication devices and techniques are flourishing, convalescing and escalating nowadays. The improvement of such devices should assemble precise requirements miniature dimension, light weight, low cost with attractive appearance. To improve the characteristic of wearable microstrip antennas many techniques were developed. In recent years, wearable devices are getting popular and dominating in electronic industries. By using suitable materials such as textiles and foams, the electronic systems can be integrated into clothing. These smart textile systems can be deployed in different fields, and have been shown to function in garments. This low profile antenna is suitable for wearable applications and microstrip patch antenna topology is chosen. An Electronic Device Worn by a person said to be a Wearable contrivance. If it is a wearable one, then it should expect to be a light weight, low profile. One such device worn by a person for communication purposes such as navigation, monitoring health issues and is widely used in military and medical application said to be a wearable microstrip antenna. They enable the integration of flexible, robust conductive textiles to form the radiator and ground plane. Textile antennas already have been successfully implemented with satisfactory performance. Conductive textiles, metal foils can be used as the radiating element [1–3]. In 1993; FCC allocated 40 MHz of unlicensed band in the 1890–1930 MHz band. Several years later, the FCC also unlicensed the 5.15–5.35 GHz and 5.725–5.825 GHz frequencies considered as the existing 5 GHz ISM band.

The proposed Softwear antenna uses soft substrates in the microstrip patch antenna. Moreover this softwear microstrip patch antenna is used as a wearable one because of its compact size, light weight and ease of integration in clothes. So Textile substrates are used as soft substrates in this softwear antenna, wearable and textile antenna properties are in two dimensions. The Combination of textile antenna and wearable properties referred as softwear antenna in which it is 2-D flexible along two planes also it is optimized to perform proximity of the human body [1]. Researchers are focusing on such type of antenna because of its wearable system technology. User body and the characteristics of the antenna should be maximized for the coupling of antenna and human body interaction, treatment of malignant tumour can be found by using patch radiator and its operation is simple in microstrip patch antenna, strip line is separated with a separation which is flexible used to measure the human body temperature [2]. Several wearable antennas have been developed in the form of flexible metal patches on soft substrates which uses textile material. A new Hexagonal patch is proposed which is operating in industrial, scientific and medical frequency band at 2.45 GHz and was verified by the numerical techniques like Finite Element Method (FEM) and the method of moments (MOM) and the effect on the human body is known by its resonance frequency and gain. For Simulation human tissue is modelled as multi-layer's, for skin, fat, and muscle, various ε_r and σ value have been investigated to create a model of human tissue [3]. General scenarios of wireless body centric communication are namely, off-Body, in-body and on body. Also the Intra body and Interbody communications also explained in this review which deals Wireless Body Area Network (WBAN). IEEE 802.15.1 (Bluetooth) in (PAN) personal Area Networks (WPAN) is widely used, which extends the propagation range. Efficiency and gain of the antenna can be analysed in 3 parameters like Antenna-distance from the body, Location on the body and the type of the antenna, also the dispersive electrical properties of the human body is lossy at higher frequencies presence of human body changes the operating frequency of the antenna [4]. Normally human body is composed of water with dielectric constant and conductivity. When the metal based antenna placed on the skin, it reflects from the body. When EM waves coincide on the skin, a then there is a change in its resonant frequency. Electromagnetic Interference (EMI) between the human body and the antenna is calculated by Specific Absorption Rate, it is the rate of heat generated by the antenna and was sensitized as heat on the body surface. High dielectric constant increases surface wave losses and Bandwidth of the antenna decreases the impedance Bandwidth [5]. In medical application when a patient is to carry such radiator which constantly communicates the outside world can use this wearable technology working in various bending environments. In on body environment to keep the wearable antenna flat all the time is difficult when a patient worn on clothing. Due to the patient's body movement there is a possibility of bending the antenna in any condition. Also, this bending may modify the characteristics of the antenna like resonant frequency, Magnitude, return Loss etc. In general diameter of the human body organs are different; it also depends on the age factor. When this antenna is placed on the organs such as arm, elbow forearm, wrist or in leg, ankle, knee, thigh it is flexible and works in any pliable situation. This paper proposed some of the key features related to the wearable antenna design process include Textile material selection, material conductivity, antenna performance on various bending environment. Simulation and investigational interpretation were made on the performance characteristics of this Flexible softwear microstrip antenna are also explained rest of the section shows the bending performance of the antenna in various diameter using PVC pipes which represents the diameter of the human arm, forearm elbow, wrist, ankle foot, and also wherever bending is possible in human body according to the body movement.

1.1 Substrate Material

Pure 100 % cotton material is chosen with a firm and smooth surface and it is suitable for wearable applications. Thickness of this material is 0.3 mm. The electrical evaluations should be performed before the establishment of any kind of soft substrate material. It is important to know the dielectric permittivity of the chosen cotton material. If the dielectric constant is more, then gain, directivity, and efficiency increases. To Perform the effect of textile material Relative permittivity ε_r = 1.6 cotton material is selected. Comparing with other cotton materials like

Wash cotton, curtain cotton, poly cotton and Jean cotton the relative dielectric permittivity value is more [6]. If the dielectric permittivity value is more then performance of the antenna is more. Low dielectric constant in textile substrate reduces the surface loss and improves the impedance bandwidth of the antenna.

1.2 Conducting Material

To establish the communication system a conducting material with its electrical characteristics are required for the ground plane as well as the patch of the antenna. Material conduction should satisfy several requirements such as having a low and stable electrical resistance (1 Ω/square) in order to minimize losses [2, 7–9]. Variance of the resistance throughout the area should be small. Also conducting material should be flexible when it is worn, also when the antenna is deformed to any radius. The material used in such type of antenna should be in elastic because of bending, stretching and compression is possible when it is worn or integrated within the cloth [3, 4, 10–13]. Conducting properties of various materials plays major role in achieving the desired performance of antenna designs and also in fabrication. An impedance matching element controls the impedance bandwidth of the patch. In this flexible softwear antenna ground plane acts as an impedance matching element which create a capacitive load neutralizes the inductive nature of the patch to produce pure resistive input impedance. The proposed work focused on copper which is used as the conducting material because of its flexibility on the substrate. Copper has good flexibility and surface resistivity used in both patch and ground plane. One end of the patch is made up of copper and the other end conducting plane is also made up of copper. This is flexible for any bending radius which is possible when integrated in cloth or worn by the user.

1.3 Relationship Between Permittivity ε and Conductivity σ

Permittivity ε and conductivity σ are complex quantities expressed in real and imaginary parts as

$$\varepsilon = \varepsilon' - j\varepsilon'' \tag{1}$$

$$\sigma = \sigma' - j\sigma'' \tag{2}$$

Effective permittivity ε_e and the effective conductivity σ_e are defined as

$$\varepsilon_e = \varepsilon' - \sigma''/\omega \tag{3}$$

$$\sigma_e = \sigma' + \omega\varepsilon'' \tag{4}$$

Loss due to conductivity is expressed in dissipation factor or it is said to be tangent tan δ, which is defined as

$$\tan\delta = \frac{\mathrm{Im}[\varepsilon_e]}{\mathrm{Re}[\varepsilon_e]} = \frac{\sigma_e}{\omega\varepsilon_e} \tag{5}$$

Refraction Index of a substrate and patch includes both parameters

$$n = \sqrt{\varepsilon_r \mu_r} \tag{6}$$

ε_r Relative permittivity,
μ_r Relative Permeability

Ratio of space-wave radiation to surface wave radiation can be found for any small antenna mounted on the substrate and it can be applied to a patch. To achieve efficiency and high Gain dielectric constant should be decreased so that it increases the spatial waves which increase the bandwidth of the antenna. The Relative permittivity ε_r value changes as bandwidth changes. Dielectric constant thickness determines the bandwidth and efficiency performance of this planar textile softwear antenna. Low relative permittivity results in a wide patch and a thin substrate results in smaller patch.

2 Antenna Design Consideration

To have a low profile planar antenna this can be integrated into clothing. One of the familiar topology of microstrip antenna is preferred. This ensures radiation away from the body with sufficient bandwidth for a good coverage. Here the Use of 100 % cotton material is used as the dielectric substrate with a ε_r value of 1.6. Copper metal in the patch is acting as the radiating surface with a thickness of 0.1 mm. HFSS software is used for the design of the proposed antenna and the results were simulated for the antenna with the final dimensions in mm. L1 = 54.8 mm, L2 = 47.1 mm, h = 3 mm. Due to the larger physical area and higher bandwidth and ease of fabrication rectangular microstrip antenna is chosen. A 50 Ω microstrip feed line was provided for the antenna feed and SMA connector is the feeder for the microwave power.

$$w = \frac{c}{2f_r\sqrt{2/(\varepsilon_r + 1)}} \tag{7}$$

C Velocity of Electromagnetic wave
ε_r Relative permittivity of the cotton Textile material
f_r Resonant frequency

Microstrip patch lies between dielectric material and air, thus electromagnetic waves related to effective permittivity (ε_{reff}) given by the expression introduced by Balanis [14], as shown in Eq. 8

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r + 1}{2}\right] + \left[\frac{\varepsilon_r - 1}{2}\right][1 + 12h/w]^{-1/2} \quad (8)$$

where, h-Height of the substrate

Because of the narrow bandwidth of the patch, the resonant frequency depends on the length of the patch; design value of L is given by

$$L = \left[\frac{c}{2f_r\sqrt{\varepsilon_{reff}}}\right] - 2\Delta L \quad (9)$$

ε_{reff}-effective permittivity, additional line length ΔL and effect of fringing fields

$$\frac{\Delta \mathrm{L}}{\mathrm{h}} = 0.412\left[\frac{[\varepsilon_{\mathrm{reff}} + 0.3]}{[\varepsilon_{\mathrm{reff}} - 0.258]}\right]\left[\frac{\mathrm{w}}{\mathrm{h}}\right] + \frac{0.264}{\frac{w}{h}} + 0.8 \quad (10)$$

Effective patch length L_{eff} is given by

$$L_{eff} = L + 2\Delta L \quad (11)$$

Resonant Frequency of a planar rectangular patch antenna determines W and L, thickness t and permittivity ε_{reff} of the dielectric

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_{eff}}}[(m/L)^2 + (n/W)^2] \quad (12)$$

m, n-mode numbers when an antenna curved in an arc along its length

$$L = R\theta \quad (13)$$

R-Radius of curvature, θ-angle subtended by the patch length.

Equation (1) can be modified with the variation in the effective length by assuming the new length lies along an arc midway through the dielectric material, by ignoring the changes to the fringing field, new length can be given as

$$L_{eff} = \left(\frac{L}{\theta} - \frac{t}{2}\right)\theta = L - \frac{t\theta}{2} \quad (14)$$

Effective length L_{eff} becomes L in [14] and $\theta = 0$

A change in antenna performance reflects both increased and decreased frequencies depending on the bending environment. The curvature effect of the antenna on its resonant frequency was given by Krowne [15, 16] as

$$(f_r)_{mn} = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{(\frac{m}{2\theta a})^2 + (\frac{n}{2b})^2} \quad (15)$$

2b-length of the patch antenna, a-radius of the cylinder, 2θ-angle bounded the patch width, ε, μ-permittivity, permeability.

2.1 Results and Discussion

Proposed softwear microstrip rectangular patch antenna has been modelled using HFSS (Fig. 1). HFSS is a commercial finite element method solver for EM structures. This software is provided with a linear circuit simulator with an integrated optimetrics for electrical network design. The geometrical construction and its material properties and also the desired output frequency should be specified. HFSS integrates an automated solution process HFSS automatically generates an appropriate and accurate mesh analysis for the given geometry [17].

Antenna geometry using HFSS have been shown in Fig. 1. Which shows the geometric construction of the flexible softwear antenna. Simulated │S11│ parameter in dB. (20Log10 │S11│) also said to be │S11│, the radiation pattern of the softwear antenna and the directivity are shown in Figs. 2, 3 and 4 respectively. Performance of the antenna depends on the return loss. As the return loss increases antenna performance also increases. More than −25 dB was achieved in the above observation.

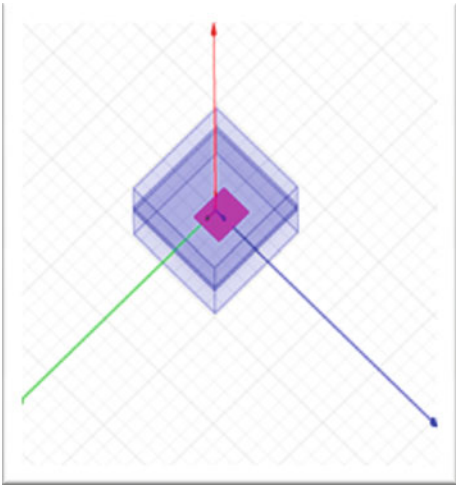


Fig. 1 Simulated softwear antenna

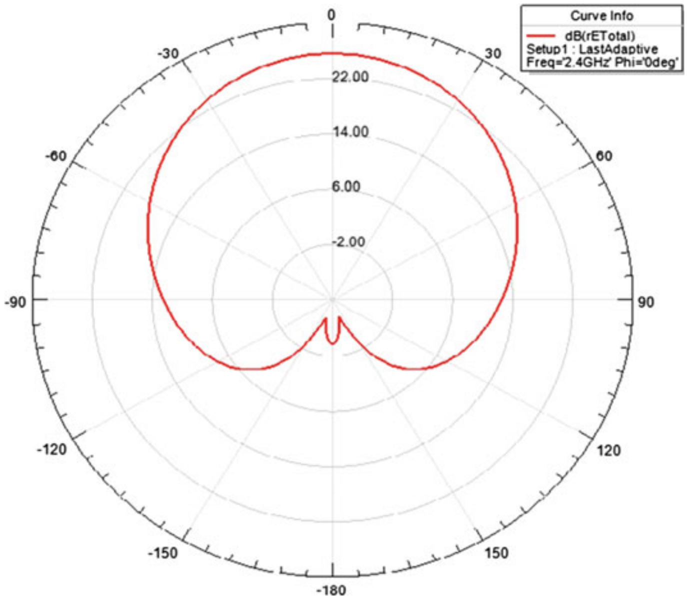
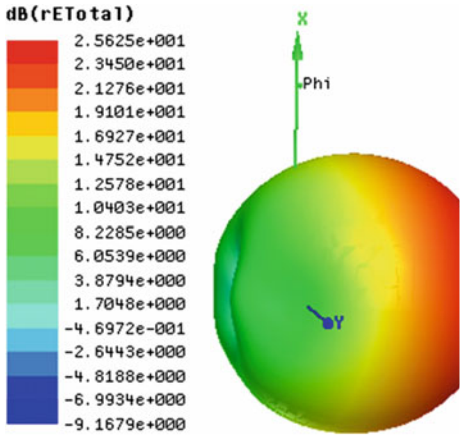


Fig. 2 Radiation pattern of the sofwear antenna

Fig. 3 Directivity



Above snapshot Figs. 5 and 6 shows the front and back side of the fabricated flexible softwear antenna. Measured S11 parameter using a Network Analyzer have been shown in Figs. 7 and 8.

The simulated and measured results shows the performance of the proposed flexible softwear antenna The proposed antenna is working in the frequency of 2.39 GHz, which is almost near to the simulated output of 2.4 GHz shown in

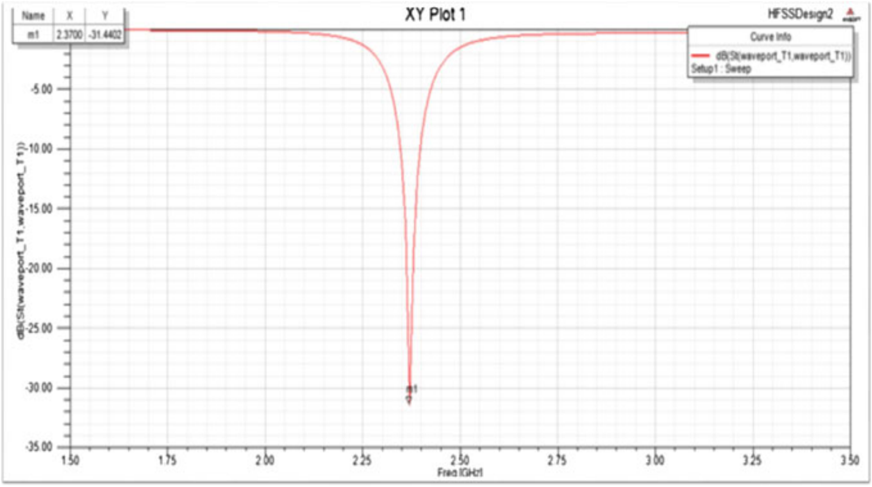


Fig. 4 Return loss of the proposed antenna

Fig. 5 Photographs of the front and back side of the flexible soft wear antenna

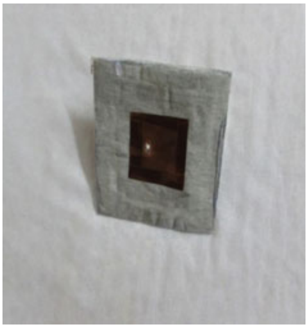


Fig. 6 Photographs of the front and back side of the flexible soft wear antenna

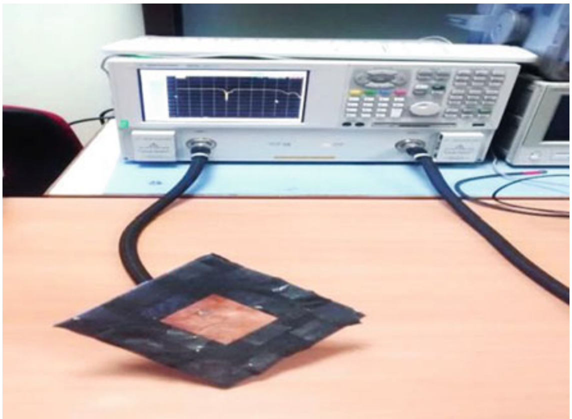


Fig. 7 Snapshot of the measurement of S_{11} using network analyzer

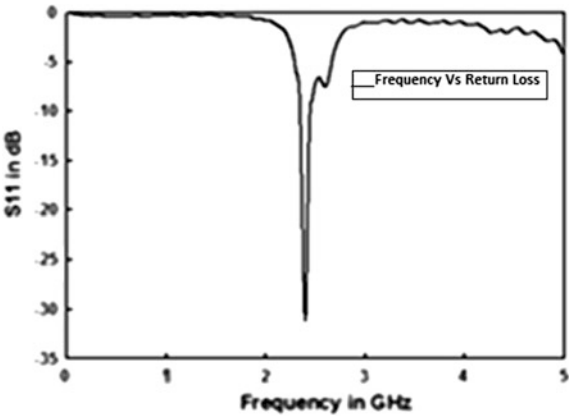


Fig. 8 Flexible softwear antenna measured result

Table 1. When this flexible softwear is tested in various pliable condition different frequencies were obtained which evidences, the proposed softwear antenna is flexible and working in various meandering environment.

The measured return loss (s11) characteristics of the antenna under different bending condition on the poly vinyl chloride (PVC) pipes of radii 11, 5, and 3 cm respectively. Which is shown in above Figs. 9, 10, 11 and 12. When the flexible softwear antenna is bent on the pipe of radius 11 cm, it resonates at 5.59 GHz with the magnitude of (−12.414) dB as shown in Fig. 9. Similarly when the antenna bent on the pipe radius of 5 cm the resonant frequency of the antenna shifted to

Table 1 Simulated and measured output

Simulated output	Measured output
2.45 GHz	2.39 GHz

Fig. 9 Flexible softwear antenna placed on PVC pipe

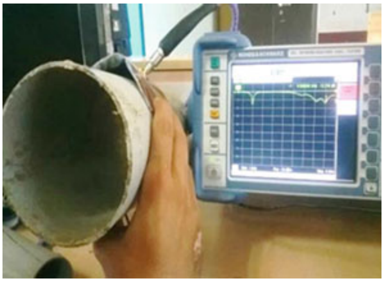


Fig. 10 Antenna under bending on 11 cm dia PVC pipe

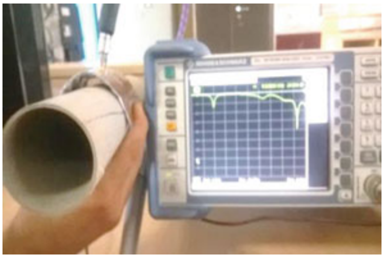


Fig. 11 Antenna under bending on 5 cm dia PVC pipe

(5.62 GHz) with the magnitude of (−36.9) dB and when the bending radius is about 3 cm then the resonant frequency is shifted to 5.7 GHz with the magnitude of (−29 dB). Experimental results shows in any bending condition resonant frequency of the proposed antenna increases as diameter decreases. It shows when more or less bending taking place while this flexible softwear antenna is placed on any of the above said organ of the human body then the resonant frequency oscillate in and around of the corresponding Resonant frequency. Also it was observed that when the pipe is kept in horizontal or vertical position same resonant frequencies and the corresponding magnitudes are obtained. The resonant frequency obtained from the sample diameters of the PVC pipes are coming under the ISM band between 5.5

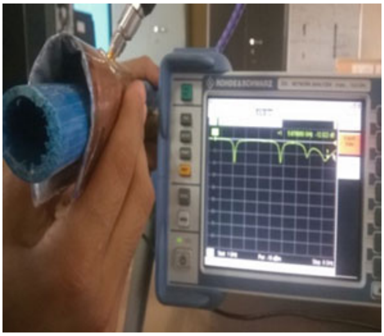


Fig. 12 Antenna under bending on 3 cm dia PVC pipe

and 5.7 GHz. which shows the proposed flexible softwear antenna is working in ISM band.

Diameter of the circle is the longest distance in a circle, when the flexible softwear antenna is placed on PVC pipes with different diameter, shown Shift in its resonant frequency and its magnitude in dB shown in Table 2. The measured results show as the diameter increases resonant frequency decreases, and magnitude increases, it shows the resonant frequencies oscillates within the ISM band.

Figure 13 shows the geometry of flexible soft wear antenna on a PVC pipe. This shows the xz direction in which radiation is possible. By decreasing the radius of curvature, the strength of the Electric field increases [15], the magnitude value of the electric field depends on the effective dielectric constant and the same depends on the radius of curvature. Magnitude increases with decrease in curvature is shown in above Table 2.

Table 2 Measured result on placement of flexible softwear antenna on PVC pipes

Diameter of the PVC pipes (cm)	Resonant frequency (GHz)	Magnitude in dB
11	5.59	−12.414
5	5.62	−36.9
3	5.7	−29

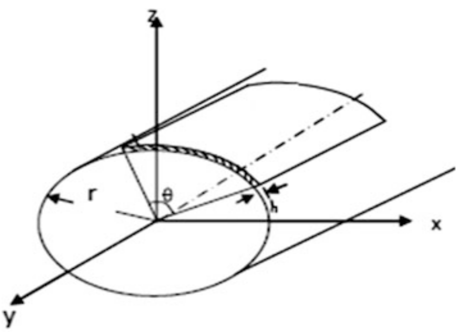


Fig. 13 Geometry of flexible softwear antenna on a PVC pipe

2.2 Experimental Observation and Concern on Bending Effects

Once the antenna is installed as an integrated part of the clothing on different parts of the human body like arm, elbow, forearm wrist, thigh, ankle and wherever human body movement is possible. This study examines the bending effect and the frequency resonance of proposed softwear antenna under various bending environment. In this experiment human body organs like thigh, knee, arm, forearm, wrist etc. are realised by the curved surfaces of 3 different diameter PVC pipes of its various internal radiuses. The diameter is almost similar to the above said humanbody organs. Hence different diameter shows different resonant frequency. As diameter increases frequency decreases which was tabulated above. Normally a cylindrical bend is more precise when compared to V-shape bends in clothing [12]. Proposed antenna is tested by properly bending it on the surface of PVC pipes.

While bending fringing fields should be taken into deliberation, due to this performance of the antenna has great consequence. At the Centre of the patch E-field is null. The fringing field between the margin of the patch and the ground plane guide the radiation. The thickness of the substrate plays major role for the amount of the fringing field. By using Eqs. (8–12) the resonant frequency of the antenna and all the parameters can be calculated.

3 Conclusion

The proposed Antenna performance depends on its structure. Using HFSS the proposed flexible softwear antenna was modelled with a soft substrate. The resonant frequency depends on the dimension of the patch shape, type of the substrate material and also the feed line technique. Variation of these parameters influences the resonant frequency. In this work when this novel antenna is placed on human organs with various diameter resonant frequency oscillates and shift to various frequency and this variation belongs to the ISM band was observed. This soft wear antenna is very cheap and is flexible for any bending Radiuses. By this observation the amount of heat generated on the human body can be reduced, while it was implanted on the human body organs with various diameters. Also the textile substrate used in this proposed antenna is 100 % cotton which absorbs water accordingly the performance also get changed and to be validated for future enhancement.

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