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Design of Wearable Textile Antenna for ISM Band with Low SAR

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***ABSTRACT**:- Antennas which can be worn on human body as part of clothing are known as Wearable Antennas. Wearable Textile antennas have been greatly investigated over the past years due to the progress of wireless communication and their usage in different fields. Such antennas are easy to fabricate and have a very light weight since they are made up of flexible textile materials. The paper explains the design of textile antenna using inset feeding for Industrial, Scientific and Medical (ISM) applications from 2.4-2.4835GHz. The Electromagnetic Band Gap structure is utilized to improve the return loss, gain and Bandwidth. The performance of the antenna is observed when it is bent on tube and when placed on wrist. Since Textile antenna is being used very near the human body, SAR (Specific Absorption Rate) computation is also done. Simulation is carried out using IE3D and CST MW Studio. Simulated and measurement results are compared.*

***Keywords**:- Wearable Textile Antennas, ISM Band, Electromagnetic Bandgap Structure, Specific Absorption Rate (SAR.)*

I. INTRODUCTION

Antenna is a crucial part of any communication system in wireless applications [1]. Wearable textile antenna is an interesting field of research in the context of improved communication efficiency and safety during interventions in major disasters. Wearable textile antennas are required to transmit and receive data between a wearable system and a base station [2]. Patch antennas are suitable candidates for textile antennas because of their low profile, low cost and low volume. They do not hinder the wearer's comfort and the presence of ground plane protects the body from radiation [3].

A textile microstrip antenna presented in [4] operating for WLAN applications used both copper and electro textile as conducting parts. E-shape patch antenna made out of electro textile material was designed at GPS frequencies L1 (1.227GHz) and L2 (1.575GHz) [5]. A fully textile UWB circular wearable antenna [6] is designed and analyzed. The proposed antenna designs are made from flannel fabric substrate material along with two types of conducting materials Copper and Sheidit. The performance of a dual band coplanar patch antenna integrated with EBG Substrate as band gap array of 3 x 3 elements is presented [7]. The antenna with EBG structure exhibits operating bandwidths of 4% at 45GHz and 16% at 5.5GHz respectively. A dual band wearable textile antenna consisting of circular patch operating for ISM Band at 2.4GHz and 5.2GHz is presented in [8]. The Antenna is integrated with EBG elements arranged in a circular pattern by similar six elements surrounding the patch. The EBG structure has relatively reduced the radiation in back direction.

The Specific Absorption Rate (SAR) is defined as the rate at which RF electromagnetic energy is promulgating to unit mass of biological body. According to IEEE, the limit is 1.6W/kg. An ultra low profile printed monopole antenna integrated with a compact AMC ground plane based on a novel Jerusalem Cross (JC) inclusion operating in ISM Band at 2.45GHz and consequently reduces 64% in SAR [9]. A wearable fractal antenna integrated with an electromagnetic band-gap (EBG) structure [10] was operating at GSM-1800MHz and ISM-2450MHz, SAR analysis using a three-layered rectangular body model is also performed to validate the usefulness of the prototype for wearable applications. In view of the above discussion, an attempt is made to design ISM band antenna with very low SAR value.

II. ANTENNA DESIGN

The textile antenna is designed to provide wireless short range communications in body and personal area networks operating in ISM Band (2.4-2.4835GHz). IE3D Simulator is used to achieve the design of textile antenna using transmission line model. Basically, the essential parameters required to design a patch antenna are: i) operating frequency (f_r), ii) Substrate having dielectric constant (ε_r) and iii) thickness of the substrate (h).

$$W = \frac{c}{2f_r}\left(\sqrt{\frac{2}{\varepsilon_r+1}}\right) \quad \text{...... (1)}$$

Where, W is width of the patch.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{\frac{-1}{2}} \quad \text{..... (2)}$$

Where, ε_{reff} is effective dielectric constant.

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad \text{..... (3)}$$

Where, ΔL is the length extension of the patch.

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad \text{..... (4)}$$

Where, L is the actual length of the patch.

Table 1: Dimensions of the Textile Antenna.

Substrate	Felt Sheet
Dielectric Constant(ε_r)	1.4
Loss tangent (□)	0.02
Thickness (h)	1.1mm
Patch Length (L)	50.812mm
Patch Width (W)	55.89mm
Cut Width (Cw)	7mm
Cut Depth (D)	9.125mm
Feed Length (FL)	20mm
Feed Width (FW)	4.175mm

Using the table1, the antenna is designed in IE3D and is shown in figure1. The dimensions of the antenna with integrated EBG are also computed by using the following above equations (1-4) are tabulated in table 2.

Table 2: Dimensions of the Textile Antenna with EBG Structure

Substrate	Felt Sheet
Dielectric Constant(ε_r)	1.4
Loss tangent (δ)	0.02
Thickness (h)	2.2mm
Patch Length (L)	47.285mm
Patch Width (W)	55.89mm
Cut Width (Cw)	10mm
Cut Depth (D)	7mm
Feed Length (FL)	29.294mm
Feed Width (FW)	5mm
EBG Unit Cell (a x b)	11mm *11mm
Gap between each cell 'g'	2mm

III. SIMULATION RESULTS AND DISCUSSION

The Textile Antenna without EBG Structure is shown in figure 1.

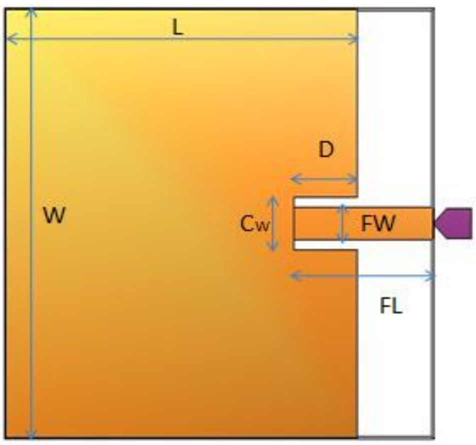


Fig 1: Simple Rectangular Textile Antenna

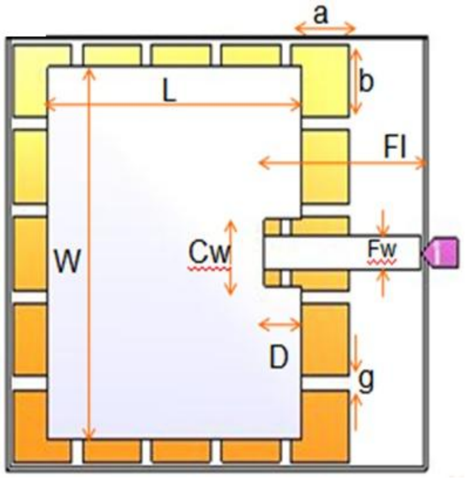


Fig 2: Textile Antenna with EBG Structure

The Textile Antenna integrated with uni-planar EBG Structure is shown in figure 2. The dimensions of the textile antenna with integrated EBG Structure are tabulated in table 2.

The EBG Structure consists of periodic unit cells arranged in array of 5 X 5. Each unit cell having length and width of 11mm and gap between unit cells is 2mm. The return loss plot is shown in figure 3 and return loss improvement from -22.28 to -28.32 is observed. The other parameters like Gain, bandwidth, VSWR are also compared between the antenna with EBG and without EBG Structure are tabulated in table 3. Figure 4 represents the VSWR plot of Antenna with EBG; figure 5 represents the 3D gain plot with EBG. The antenna is fabricated using chemical etching with felt as dielectric material.

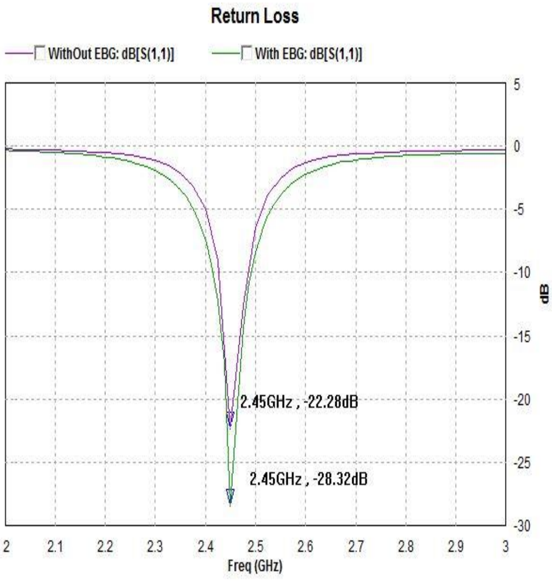


Fig 3: Return Loss Comparison of Antenna with EBG and without EBG.

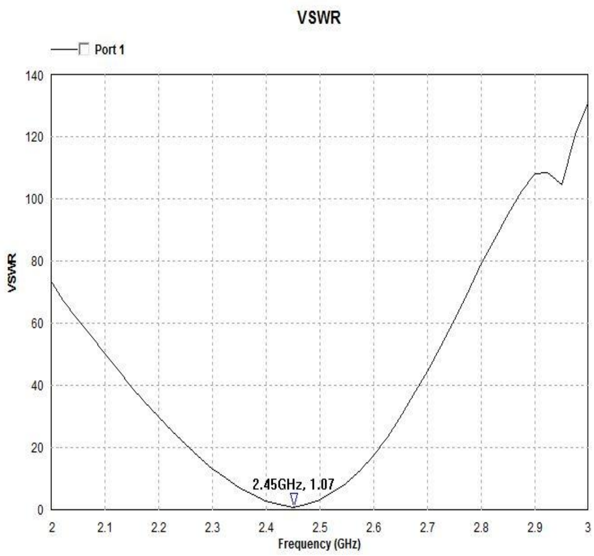
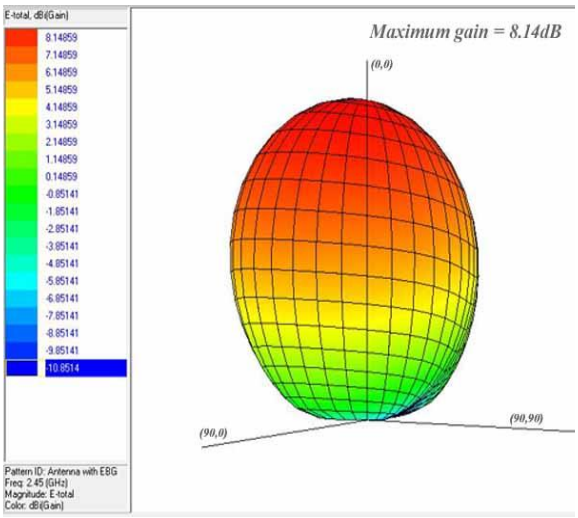


Fig 4. VSWR of Textile Antenna with EBG



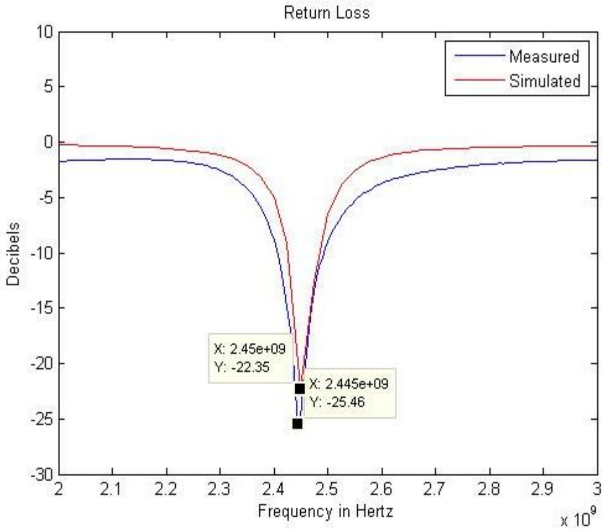


Fig 5.Gain of Textile Antenna with EBG in 3D **Fig 6**.Comparison of simulated and measured results.

The fabricated antenna is tested using vector network analyzer and the comparison of measured and simulated results are depicted in figure 6.

Table 3: Comparison of antenna characteristics with EBG and without EBG.

S. No	Parameters	Simple Textile Antenna	Textile Antenna with EBG Structure
01	Return Loss	-22.28dB	-28.32 Db
02	Gain	7.28dBi	8.14 dBi
03	VSWR	1.17	1.07
04	Bandwidth	58.5MHz	76MHz

The fabricated antenna is also tested when the antenna is bent on a cylindrical tube of diameter 9.4cm to observe the antenna performance and also tested when the antenna placed on the wrist and is shown in figure 7.

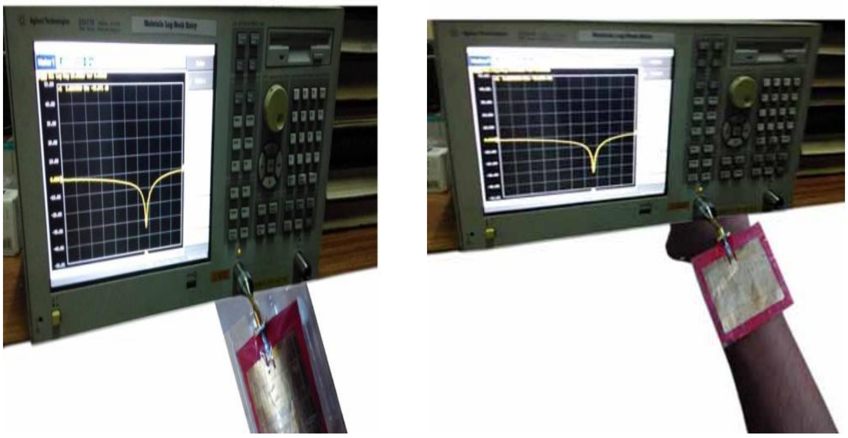
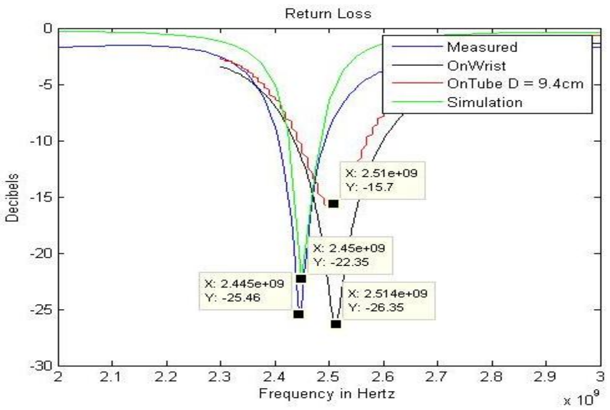


Fig 7. Textile Antenna placed on Ftube and on wrist

The results of simulation, measurement, antenna under bent condition on a tube of diameter 9.4cm and placed near the body are shown in figure 8.



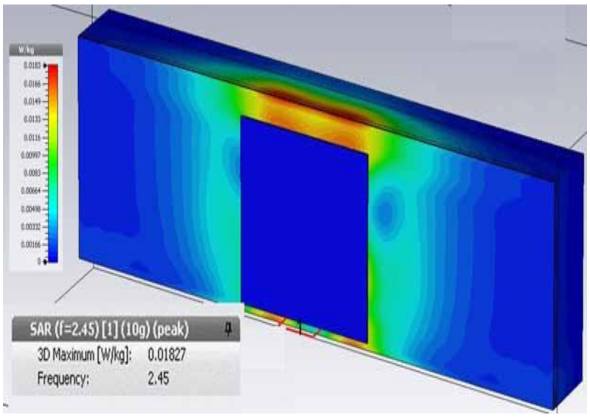


Fig 8.Return loss comparison of antenna under **Fig 9. SAR Calculation different conditions.**

In order to determine the SAR, phantom model of muscle is designed in CST MWS. The Muscle model consists of three layers, muscle having permittivity of 54, conductivity of 1.2S/m and density of 1040Kg./Cu.m. and thickness of 50mm. Next, Fat having permittivity of 5.3, conductivity of 0.11S/m, loss tangent of 0.13 and thickness of 2mm. Lastly, skin having permittivity of 42.8, Conductivity of 1.6S/m, loss tangent of 0.27 and thickness of 1mm. The simulation result of SAR calculation is depicted in figure 9. Table 4 represents the comparison of SAR values of structures in references [10, 11] with proposed structure.

Table 4: SAR Value Comparison

Reference	Frequency Considered	SAR Value(W/Kg)
[09]	2.45GHz	1.88
[10]	2.45GHz	0.14
[Proposed Structure]	2.45GHz	0.01827

IV. CONCLUSION

Textile antenna is successfully designed for ISM Band applications from 2.4-2.4835GHz. When the antenna is integrated with uniplanar EBG Structure, the return loss is improved from -22.28dB to -28.32dB and bandwidth is enhanced from 58MHz to 76MHz, gain is improved from 7.28dB to 8dB. Antenna prototype is fabricated, good agreement is observed between simulated and measured results. While examining the performance of antenna under bending and on wrist, a slight shift of resonant frequency is observed. For the proposed structure, SAR obtained is 0.01827W/Kg well below the recommended value and better than the structures existed.

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