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Design and Analysis of Textile Patch Antenna

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Abstract: In this paper a rectangular microstrip textile patch antenna for ISM band of frequency has been proposed. For design of this antenna a 3 mm thick curtain cotton having dielectric constant of 1.47 is used as substrate. For conducting part of antenna a 0.04 mm thick copper sheet is used for patch and ground plane. The designed antenna is simulated on a three layered body phantom having characteristics of fat, muscle and skin. The simulation is carried out using a CST STUDIO SUITE 2018. An important parameter specific absorption rate (SAR) is observed and analysed for flat and curved surface of body phantom. In all cases a good bandwidth, return loss and gain are observed and antenna is found useful for wearable application due low value of specific absorption rate. However when antenna is simulated on bending phantom, the SAR value for 1 g of tissue is higher than the safe range specified by international standard. Then an EBG (electromagnetic band gap) material is used and SAR value has been reduced.

Keywords: Textile Patch antenna, Wearable, EBG (Electromagnetic Band Gap), SAR (Specific Absorption Rate)

I. INTRODUCTION

In future the garments will not only provide the protection from the extremes of the nature but they will be helpful to provide the information of state of health of the wearer's. Integration of monitoring system into protective garments increases the safety level and comfort of the wearer [1]. Due to the low mass, high flexibility and easy to integrate into garments textile antennas are useful for wireless communications [2]. When antennas are being used for the on body communication it is not possible to provide the flat surface to mount the antenna all times. So a textile antenna should perform in better way even in the bending the crumpled conditions also. Performance of the wearable antenna is supposed to be change due to presence of human body near the antenna [3]. Due to capacitive coupling of antenna with the body more power absorption is observed by the many researchers in literature [4]. When antenna is placed on human body due to moisture and increase in temperature dielectric properties are also changed, which further detune the impedance matching, shift the resonance frequency and distort the radiation pattern of antenna [5]. Moreover due to mismatching of antenna and human body back lobe radiations are generated and absorbed by the body, which reduces the available power for radiations and reduces the gain of antenna in desired direction. The absorbed power due to back radiations is measured in term of specific absorption rate (SAR) [6]. To reduce the back radiations towards the body an electromagnetic bad gap (EBG) material has been presented [7]. Along with lossy human body a high impedance surface (EBG) reduced the back radiation and further reduced the SAR value also [8] [9].

II. DESIGN METHODOLOGY:

A body wearable textile antenna is designed using an insulating textile substrate bonded with conducting thin copper plate as a ground and patch of antenna. The dimensions of antenna are calculated using the following equations [10].

Step 1: Calculation of the Width of patch (W)

The width of patch is given by (1)

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

Where, c is free space velocity of light. f_r is resonant frequency and is 2.4 GHz for the current design. A3.0 mm thick curtain cotton with relative permittivity of 1.47 [11] is used as a substrate. Due to presence of air between the patch and dielectric the permittivity is changed and known as effective permittivity and given by

Step 2: calculation of effective permittivity

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{2}$$

Where, h is height of the substrate or thickness of the substrate.

Step 3: Calculation of the length extension ΔL, which is given by

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \tag{3}$$

Step 4: Now to calculate the length of patch

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{4}$$

Where ΔL is the additional length on both side of the patch due to fringing fields

$$L_{eff} = L + 2\Delta L \tag{5}$$

L_{eff} is the total length of the patch including the length due to of fringing effect.

III. Design Of Antenna

In this paper a body wearable microstrip patch antenna is proposed and designed. The length and width of antenna is calculated using above formulas and given in the table 1.

Width of patch (W)	56.5 mm
Length of patch (L)	48.70 mm
Width of inset feed line	11 mm
Length of inset feed line	41.23
Height of substrate	3 mm
Dielectric constant of substrate	1.47 mm
Loss tangent of substrate	0.02
Width of inset cut	11 mm
Length of inset cut	17.13 mm

Table: 1

The designed antenna with inset feed is shown in fig.1

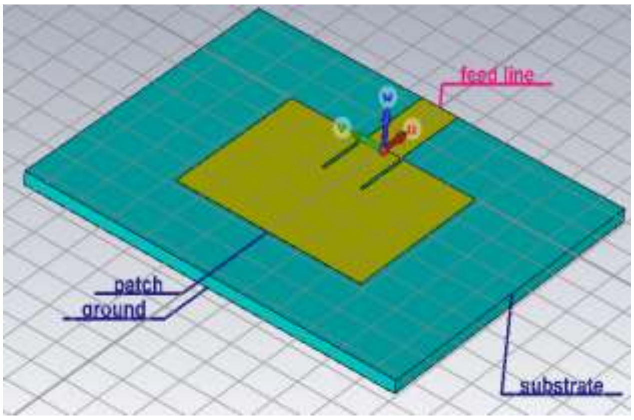

Fig.1 Antenna without body phantom

IV. Results & Discussion:

Return loss: Return loss is the measure of mismatching the input and output ports. If return loss is more it means more power is reflected back which is not desirable. Return loss of –10 dB is acceptable. A plot of return loss versus frequency is shown in fig.2

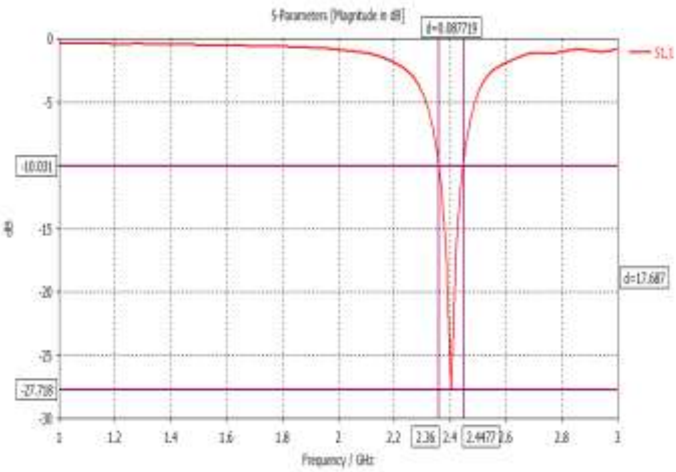

Fig.2 S-parameter without body phantom

From fig.2 a return loss of -27.78 dB is observed at resonant frequency of 2.4 GHz. A bandwidth of 88 MHz is achieved which is useful for body wearable antenna in ISM band of frequency.

Then same antenna is placed on a three layered human body (containing properties of muscles, fat and skin) phantom as shown in fig. 3 and simulate using CST microwave studio suite 2018.

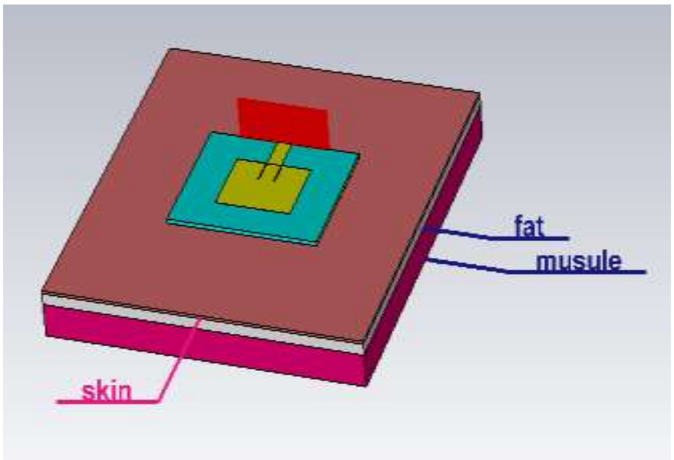

Fig.3 Antenna on body phantom

The return loss of antenna on human body phantom is shown in fig.4

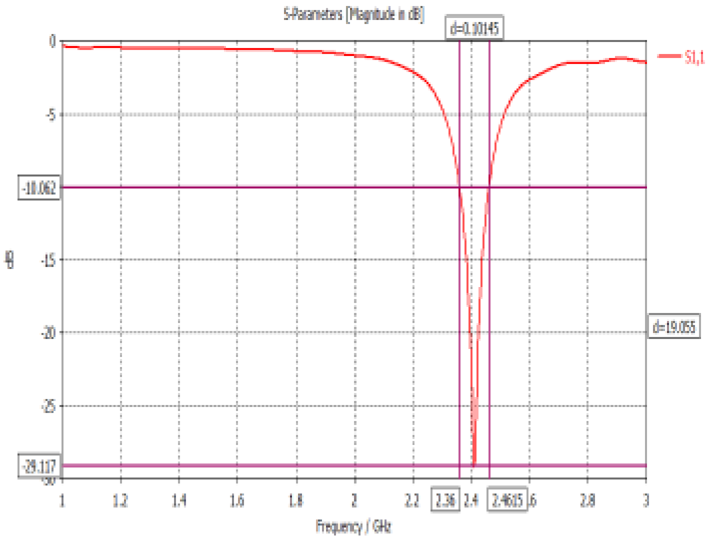

Fig.4. S-parameter with body phantom

When antenna is placed on body phantom model, observed return loss and bandwidth are -29.11 dB and 101 MHz respectively. It means lossy human body increases the return loss and bandwidth of antenna at designed frequency of 2.4 GHz.

It is not possible to provide the flat surface for a wearable antenna at all time. So performance of antenna under bending conditions also should analyze. So the designed antenna, under bending condition with diameter of 76.2 mm is also simulated and return loss are given as below. A bending antenna on body phantom is shown in fig.5

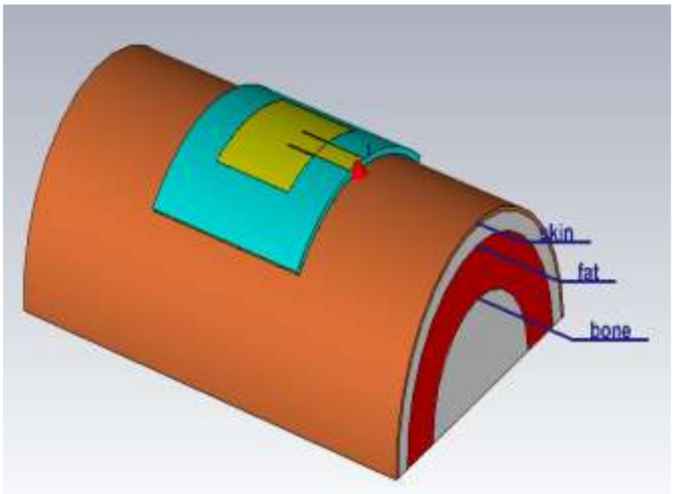

Fig.5. Bent antenna with body phantom

When antenna is worn by the user in bending condition more area of antenna come in. contact with body and more power is being absorbed by the body and return is decreased but bandwidth has been increased. The return loss and bandwidth are -17.18 dB and 133 MHz respectively. A plot of S-parameter under bending condition is shown in fig. 6

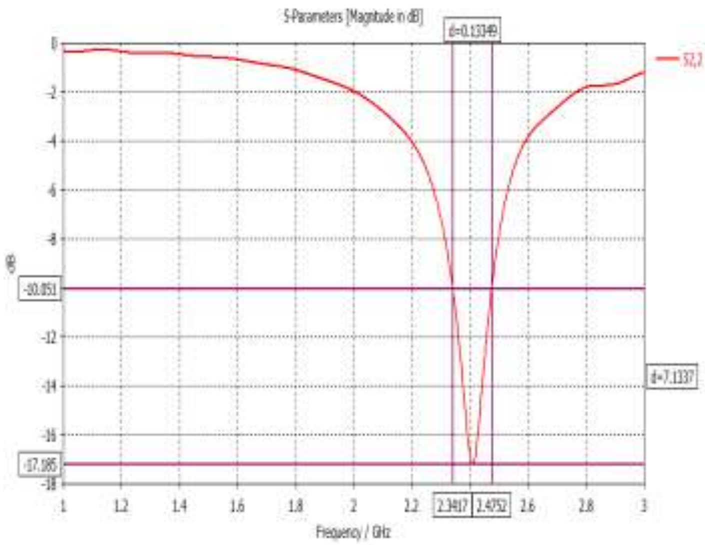

Fig.6 S-parameter of bent antenna with body phantom

Gain and Directivity:

Gain of antenna compares the power radiated by the antenna with respect to the isotropic antenna in that direction. Gain and directivity are same if efficiency of antenna is 100%. Gain and directivity of antenna without body phantom is shown in fig.7 and fig.8

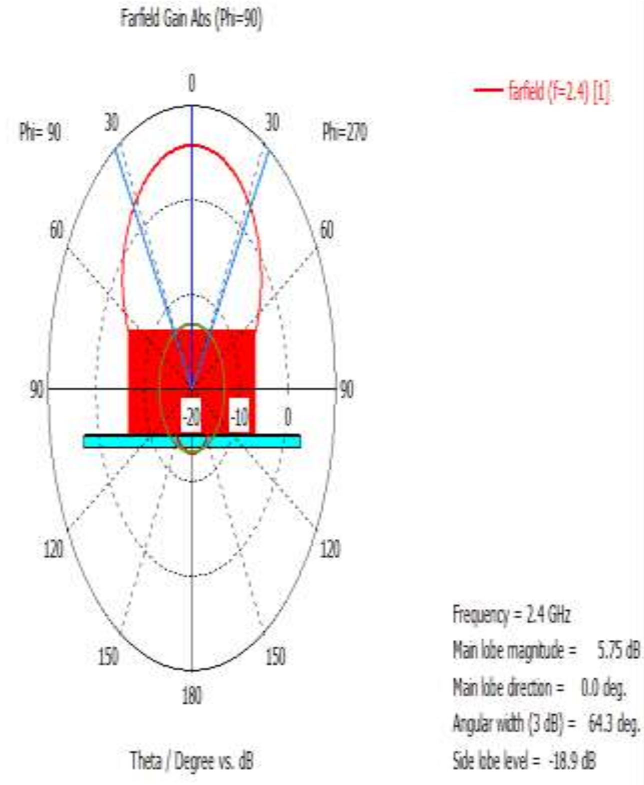

Fig.7 Gain of antenna without body phantom

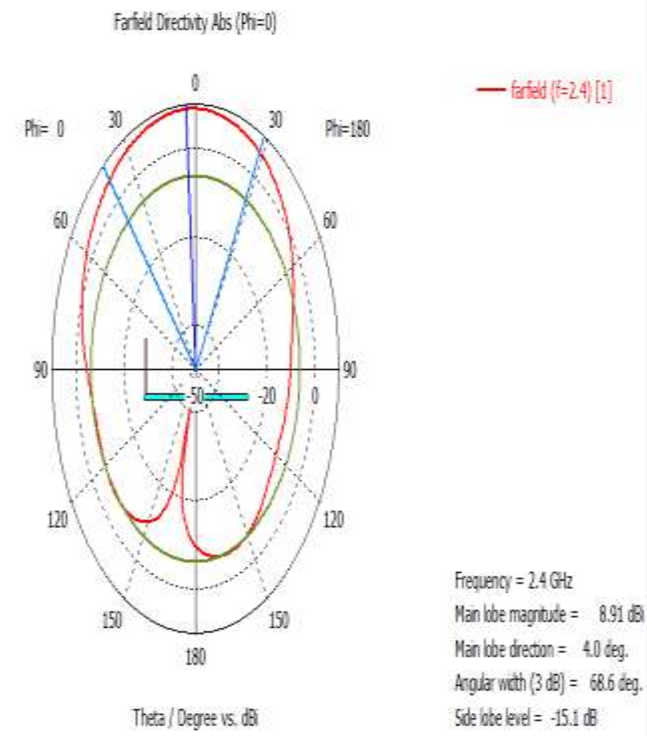

Fig.8 Directivity of off body antenna

The gain and directivity of antenna at 2.4 GHz are 5.75 dB and 8.91 dBi respectively.

Then antenna is placed on a three layered body phantom, gain and directivity of same antenna is shown in fig.9 and fig.10

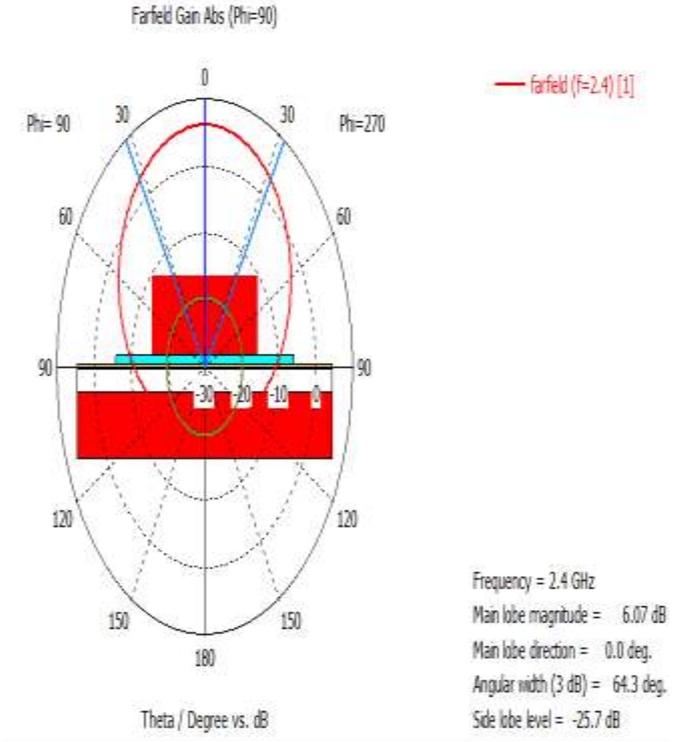

Fig.9 Gain of antenna with flat body phantom

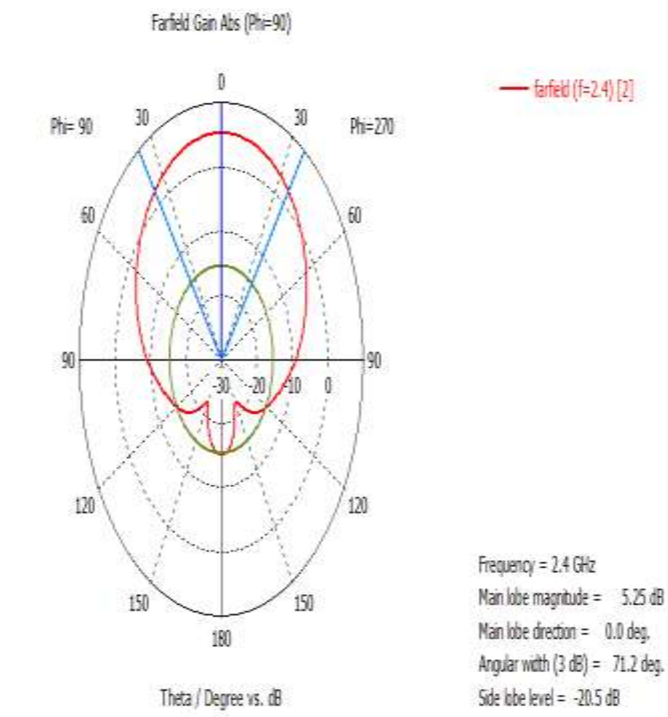

Fig.11. Gain of on body antenna

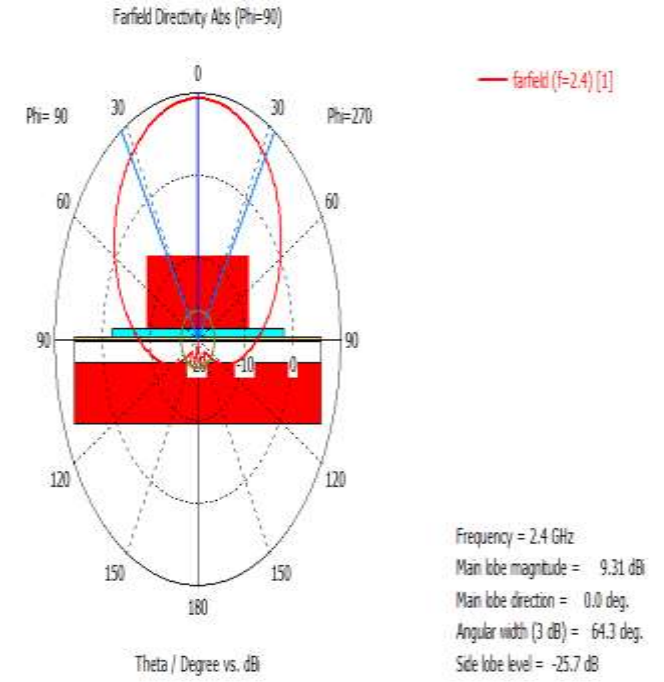

Fig.10 Directivity on flat body phantom

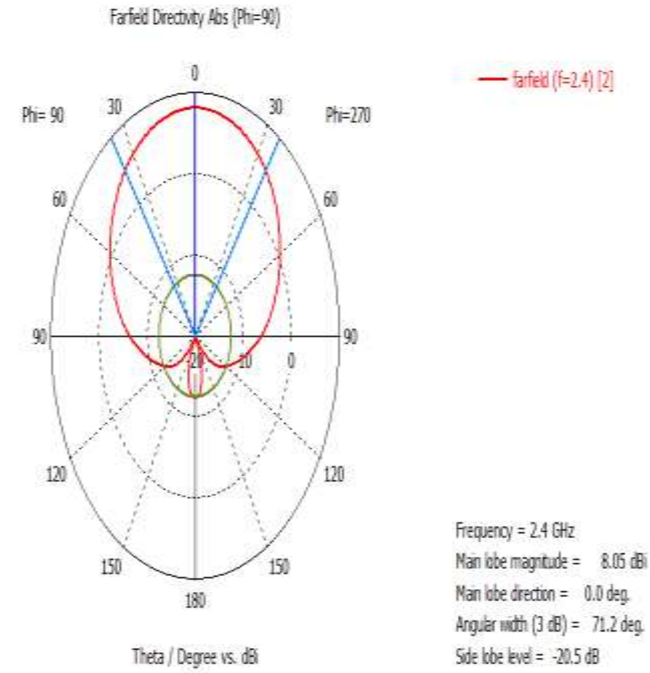

Fig.12. Directivity of on body antenna

Gain and directivity observed on flat body phantom is 6.07 dB and 9.31 dBi respectively, which is higher than the off body antenna. It means human body being a losy medium provides the favorable conditions for body wearable antenna.

Then same antenna is placed on a bending phantom surface and gain and directivity are shown in fig.11 and fig.12.

Due to curved surface of human body more area of antenna cover the body phantom and more power is being absorbed by the body and radiated power is decreased and gain and directivity also decreased. The observed gain and directivity of antenna on curved surface of body is 5.25 dB and 8.05 dBi respectively, which is less than when antenna is place on a flat surface.

Specific Absorption Rate (SAR): Body wearable antenna is placed on the human body. Human body is having high conductivity and dielectric constant which results in change in resonant frequency. When antenna is placed on human body, due to the mismatching of antenna and human body, there will be back radiated power and absorbed by the body tissues. These back radiated radiations are measured in terms of specific absorption rate (SAR). SAR for an antenna with flat phantom is shown in fig. 13 and Fig.14

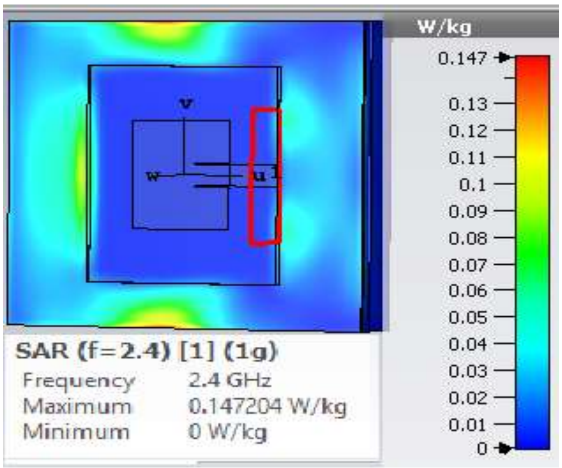

Fig.13 SAR for 1 g of tissue

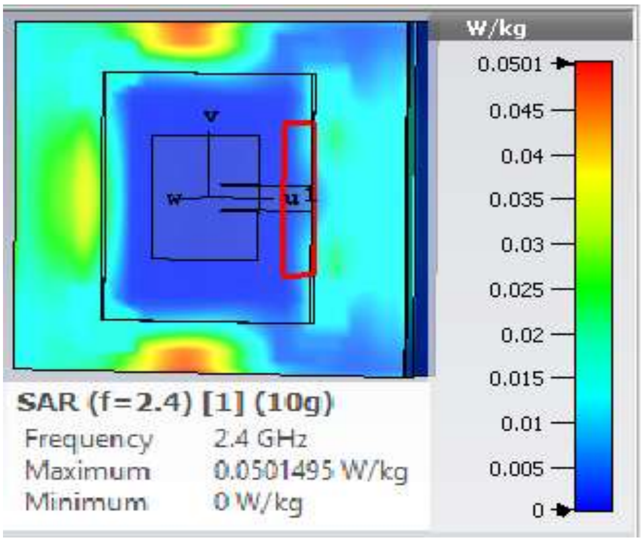

Fig.14 SAR for 10 g of tissue

Specific absorption rate is measured for 1 g and 10 g of tissues in body. Safe values of SAR for these two different types of tissues are specified by international standards. Maximum value of SAR for 10 g of tissue is limited 2 W/kg by the International Commission of Non Ionization Radiation Protection (ICNIRP) of Europe and as per US standard 1.6 W/kg is fixed for 1 g of the tissue. From fig. 13 and fig 14 SAR values are 0.147 W/kg and 0.0501 W/kg. These SAR are within the safe range and so antenna is suitable wearable applications.

When antenna is to worn on the human body, flat surface is not possible at all time. Then the same antenna is placed on the bending phantom and SAR value in bending condition is shown in fig.15 and fig. 16

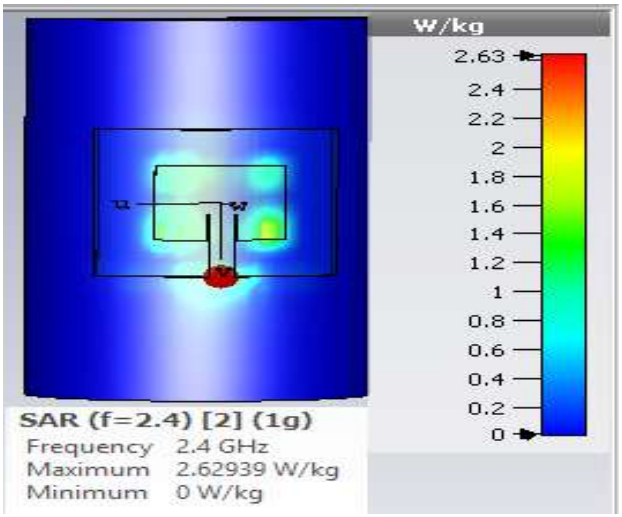

Fig.15 SAR for 1 g of tissue

From the fig.15 SAR value for 1 gm tissue is 2.63 W/Kg but for 10 gm of tissue it is 0.55 W/Kg. So antenna is not suitable for 1 gm of tissue because SAR value is greater than the safe value of radiation (>1.6 W/Kg). In literature various techniques have been proposed for the reduction of SAR value by reducing the back lobe radiations. Use of electromagnetic band gap (EBG) is one of the effective techniques to reduce the back radiations.

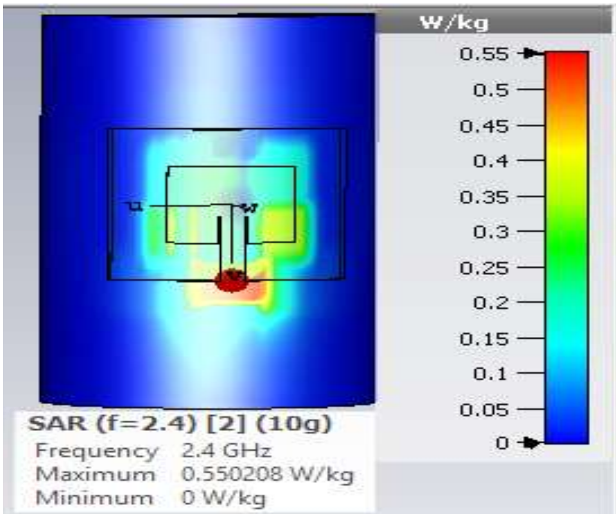

Fig.16 SAR for 10 g of tissue

EBG (Electromagnetic band gap): High impedance surface or electromagnetic band gap (EBG) is used to decrease the back radiation and SAR of antenna. It is having a property to provide high impedance in a designed frequency band [6]. For design of this material an array of 5x5 cells is used.

Fig.17. EBG array

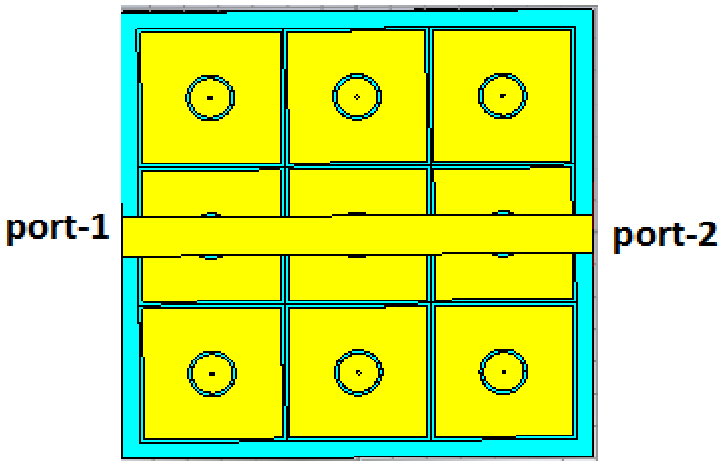

Fig.17. EBG array

The length, width and gap between cells are calculated using the Sievenpiper's surface equation [12]. In this material at designed frequency the reflection coefficient and transmission coefficient are out of phase and material behaves as a metamaterial. The EBG array of 3x3 is shown in fig. 17.

The reflection and transmission coefficient between port 1 and port 2 is observed as shown in fig.18

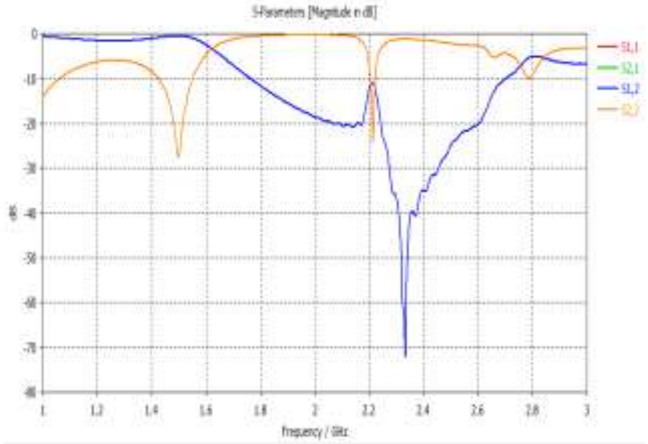

Fig.18 Reflection and Transmission coeeficient

From fig 18 it is clear that reflection coefficient and tranmission coefficient are out of phase at the designed frequency 2.4 GHz.Antenna with EBG is shown in fig. 19.

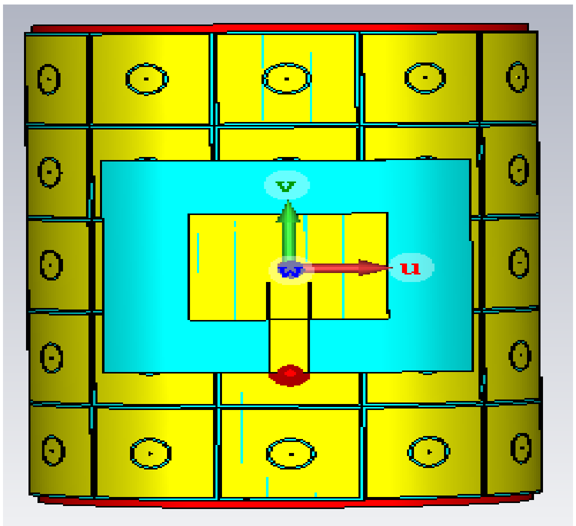

Fig.19 Antenna with EBG on bent body phantom.

The SAR value with EBG for antenna on bending body phantom is shown in fig. 20 and fig. 21

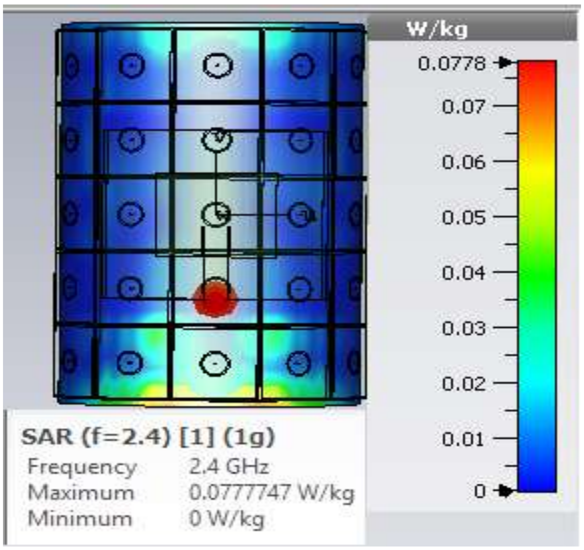

Fig.20 Fig.13 SAR for 1 g of tissue

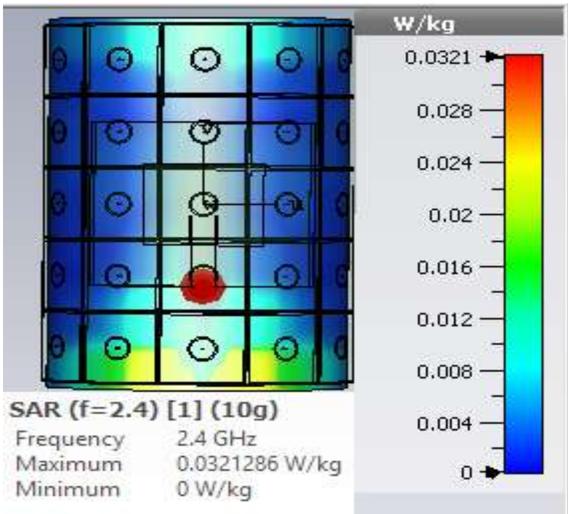

Fig.21 Fig.13 SAR for 10 g of tissue

After using the EBG the SAR value of antenna have been reduced. For 1 g of tissue SAR has been reduced to 0.078 W/kg from 2.63 W/kg without EBG. And for the 10 gm SAR is 0.0321 W/kg. So now the designed antenna is suitable for wearable communications.

V. CONCLUSION

A body wearable antenna operating at 2.4 GHz is designed and analyzed. Further when antenna is placed on losy human body phantom, the back radiations are increased and specific absorption rate also increased. An artificial material, electromagnetic band gap (EBG) is used to decrease the back radiation an also decreases the SAR value for the designed antenna at designed frequency.

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