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SAR Analysis of Body Wearable Microstrip Patch Antenna Using Different Substrate Materials

Jaget Singh[1]

[1]University Institute of Engineering & Technology, Panjab University Chandigarh, India

Author's Mail Id: jaget_singh80@yahoo.co.in

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***Abstract*— ** Specific absorption rate (SAR) of antenna is observed when antenna is placed on body surface. For body surface a phantom model of body having dielectric characteristics of fat, skin and muscle is designed. Four textile antennas with different substrates are designed and simulated. Textile material like wash cotton, curtain cotton, polyester and polycot having different dielectric constant and thickness is used to design the patch antenna. Designed antenna simulated using CST software and analyzed on the basis of performance parameters like return loss, bandwidth and gain on flat body surface and curved surface also.

***Keywords*—**Specific absorption rate (SAR), Electromagnetic band gap (EBG), body phantom, body wearable antenna, ISM band.

I. INTRODUCTION

Body wearable antenna is supposed to be placed on the human body. Human body is having high conductivity and high 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, back radiated power will be absorbed by the body tissues. These back radiated radiations are measured in terms of specific absorption rate (SAR) [1]. SAR is measured in watt per kilogram (W/kg). SAR can be represented in term of absorbed rate of electric field at a point.

$$SAR = \frac{\sigma|E|^2}{\rho} \text{ W/kg} \quad (1)$$

Where, ρ, is mass density of tissue (Kg/m3), σ, is the conductivity of the tissue (S/m), and E, is the root mean square (r.m.s) of electric field strength (V/m). When antenna is used with mobile phones, due to absorbed back radiation by the body, there is a rise in body temperature. This rate of change of temperature can be measured in terms of specific absorption rate also [2]. 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 [3]. SAR (specific absorption rate) can be represented as [23]

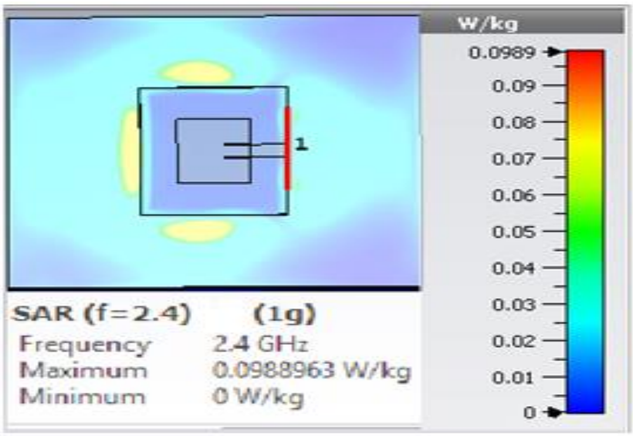
$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho(dV)}\right) \quad (2)$$

$$SAR = \frac{1}{\rho}\left(\frac{dW}{dt}\right) \quad (3)$$

Where dV is elemental volume, dm is element mass and dW is the element absorbed energy. A high value of SAR is observed due to unwanted back radiation towards the body. Many researchers have proposed different techniques to reduce the SAR value. Perfect electric conductor (PEC) and ferrite sheet acting as a reflector shields the human body from the patch antenna and back radiation from the body and reduces the SAR value [4][5]. In this paper specific absorption rate (SAR) for all the four antenna using different substrates like wash cotton, curtain cotton, polyester and polycot are calculated and analyzed.

II. SAR OF ANTENNA ON FLAT BODY SURFACE

As body is highly conductive and having different dielectric constant for different layers of body. So due to impedance mismatching there will be reflected waves towards the body. These reflected waves are harmful for the wearer and increases the temperature of body. This rate of change of temperature can be measured in terms of specific absorption rate. SAR of antennas with different substrates is measured for average value of 1 gm and 10 gm of tissues present in body. The SAR of antenna with wash cotton as a substrate is shown in Fig 1.



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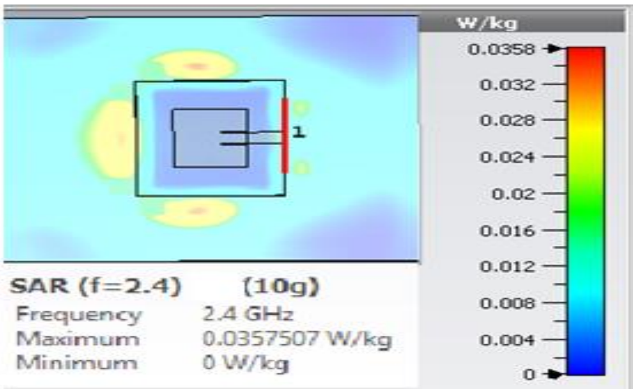

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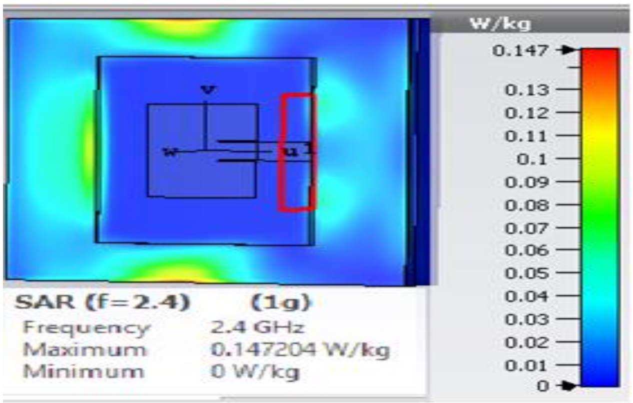
Fig. 1 SAR of antenna with wash cotton substrate (a) 1g (b) 10g

Maximum SAR of antenna with wash cotton substrate is 0.0989 W/kg for 1 g and 0.0358 for 10 g of tissue in the body. SAR for antenna with curtain cotton substrate is shown in Fig 2



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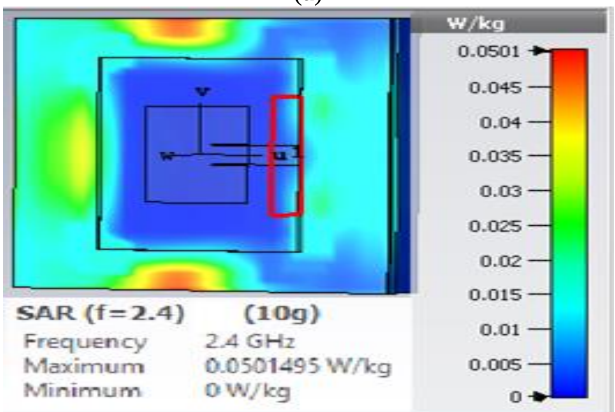

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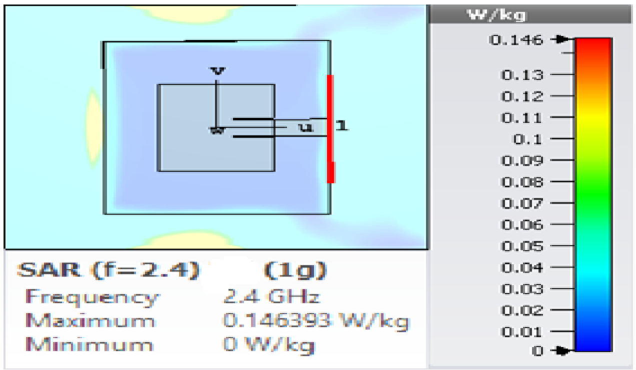
Fig. 2 SAR of antenna with curtain cotton substrate (a) 1g (b) 10g

Similarly SAR for antenna with curtain cotton as a substrate is observed as a 0.147 W/kg and 0.0501 W/kg for 1 g and 10 g of tissues respectively. SAR of antenna with polyester substrate antenna is shown in Fig 3



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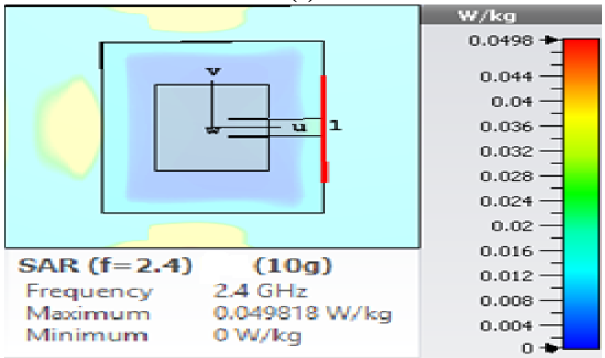

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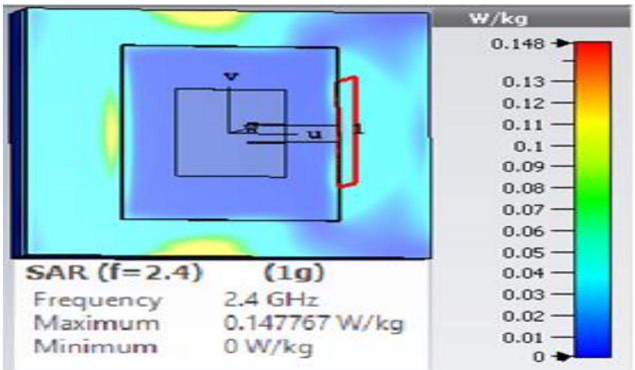
Fig. 3 SAR of antenna with polyester substrate (a) 1g (b) 10g

SAR value for antenna with polyester substrate is 0.146 W/kg and 0.0498 W/kg for 1 g and 10 g tissue respectively. Finally SAR of antenna with polycot substrate is observed and shown in Fig 4. A 0.148 W/kg and 0.0506 W/kg is observed for 1 g and 10 g of tissues respectively.



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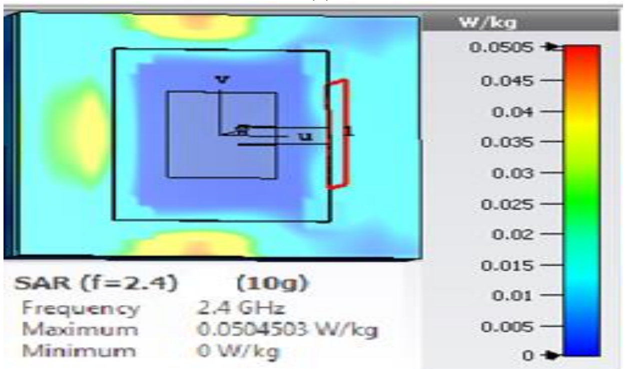

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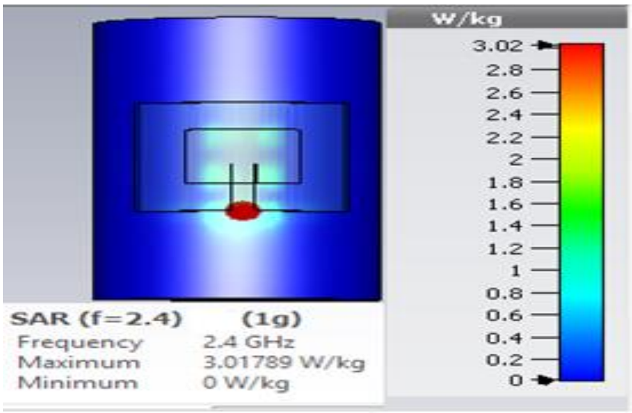
Fig. 4 SAR of antenna with polycot substrate (a) 1g (b) 10g

Specific absorption rate (SAR) observed from all the antennas are very less and designed antennas are not harmful for the wearer. The SAR values are less than maximum values of SAR specified by the international standards. But it is not possible to provide the flat surface for wearable antenna all time. So designed antenna should be analyzed on curved surface also. In this chapter antenna with different substrates are designed and simulated for a diameter of 76.2 mm which is suitable for human hand and leg.

SAR of antenna on bending body phantom

SAR of antenna in bending condition with wash cotton as a substrate is shown in Fig 5 for 1 g and 10 g of tissues. Maximum SAR of antenna with wash cotton substrate is 3.02 W/kg for 1 g and 0.637 for 10 g of tissue in the body. The SAR for 10 g of tissue is well below the required standard (<2 W/kg), but for 1g of tissue it is more than maximum value of SAR decided by US standard which is <1.6 W/kg.



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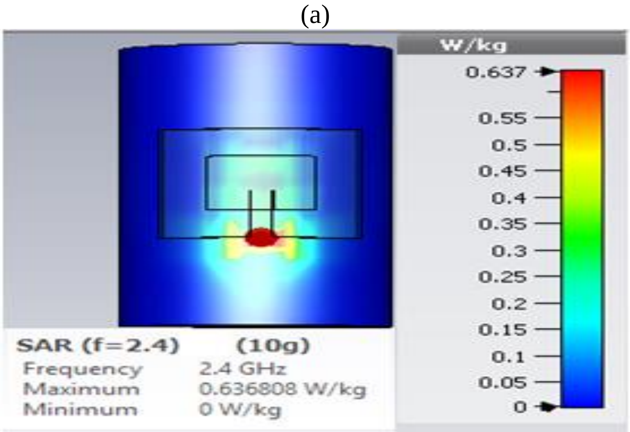

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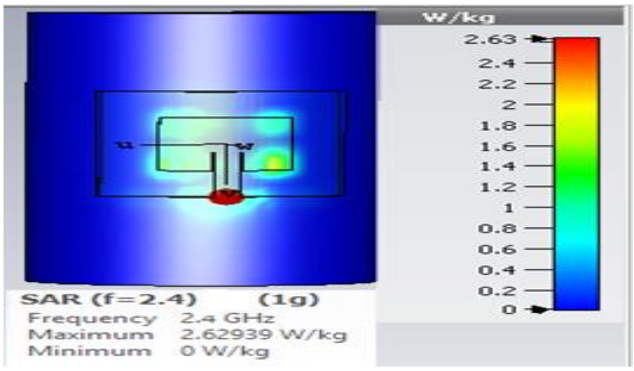
Fig. 5 SAR of antenna with wash cotton substrate (a) 1g (b) 10g

Fig 6 shows the SAR value of antenna with curtain cotton substrate. Maximum SAR of antenna with curtain cotton substrate is 2.63 W/kg for 1 g and 0.55 W/kg for 10 g of tissue in the body. In this case also SAR for 1 g of tissue is more than the maximum value specified by radiation agencies of Europe and US. But 10 g of tissues are in the safe range of SAR value.



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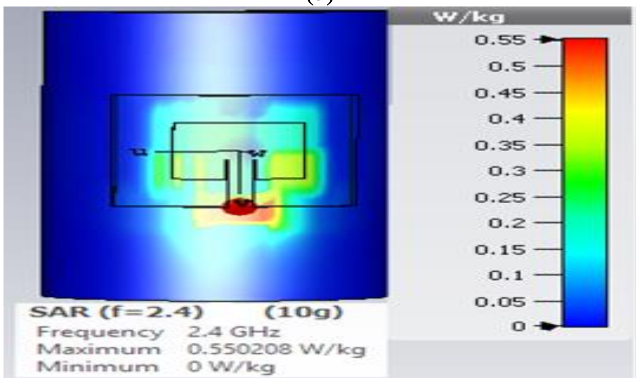

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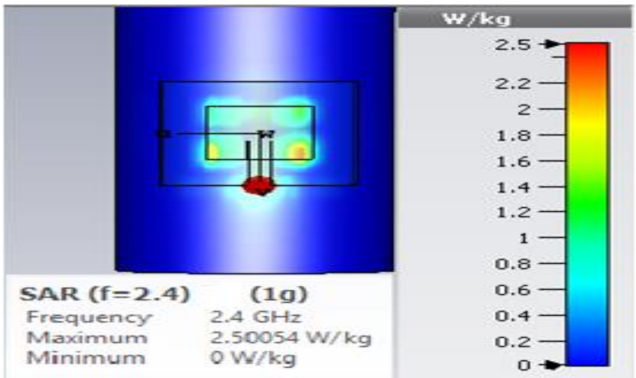
Fig. 6 SAR of antenna with curtain cotton substrate (a) 1g (b) 10g

Fig 7 shows the SAR value of antenna with polyester substrate. Maximum SAR of antenna with curtain cotton substrate is 2.5 W/kg for 1 g and 0.596 W/kg for 10 g of tissue in the body.



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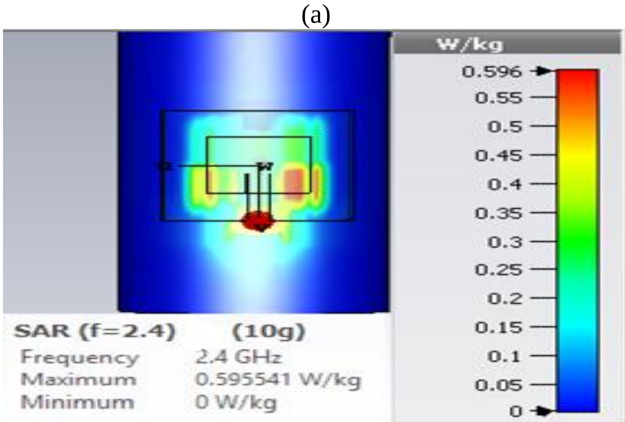
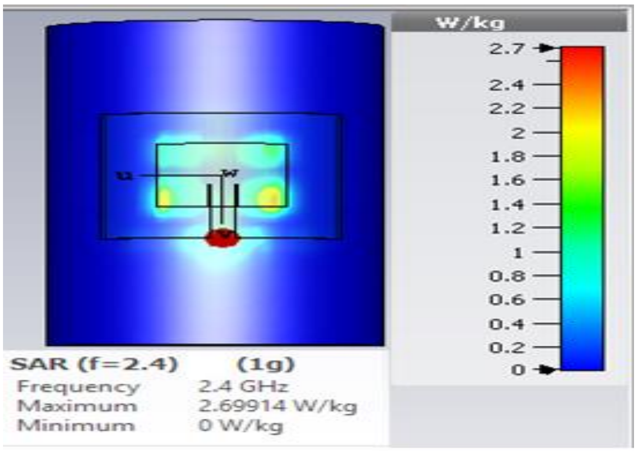


(b)

Fig. 7 SAR of antenna with polyester substrate (a) 1g (b) 10g

Fig 8 shows the SAR value of antenna with polycot substrate. Maximum SAR of antenna with curtain cotton substrate is 2.7 W/kg for 1 g and 0.589 W/kg for 10 g of tissue in the body.



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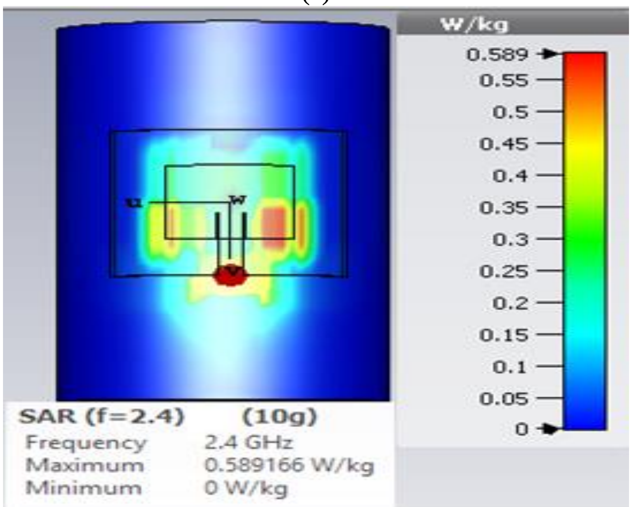

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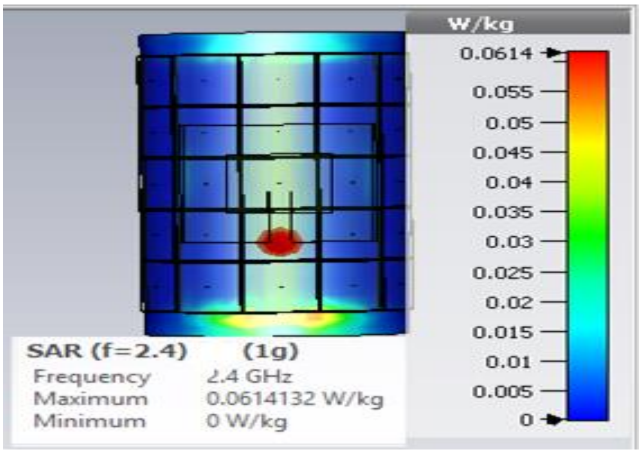
Fig. 8 SAR of antenna with polycot substrate (a) 1g (b) 10g

SAR of antenna with EBG (Electromagnetic Band Gap)

In literature various techniques have been discussed to decrease the back radiation and specific absorption rate also. Use of metamaterial is effective technique to reduce the SAR of antenna. Electromagnetic band gap (EBG) is one of the normally used metamaterial types.

SAR of antenna in bending condition with wash cotton using EBG is shown in Fig 9 for 1 g and 10 g of tissues. Maximum SAR of antenna with wash cotton substrate is 0.0614 W/kg for 1 g and 0.0295 for 10 g of tissue in the body. Now the SAR value haven been reduced from 3.02 W/kg without EBG to 0.0614 W/kg with EBG for 1 g tissue. Now the SAR of antenna is below the maximum SAR defined by international standards.



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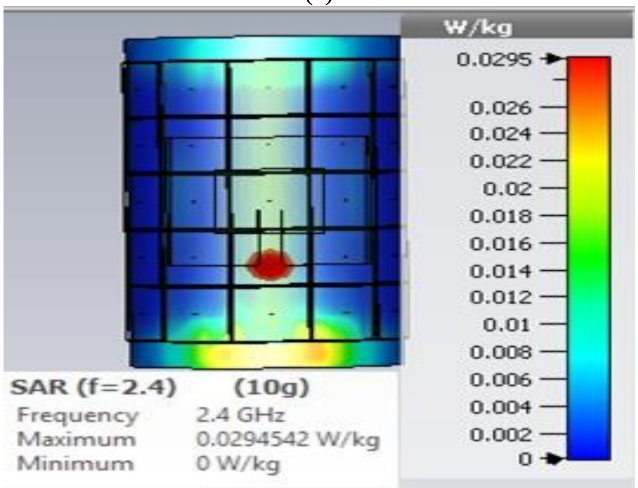

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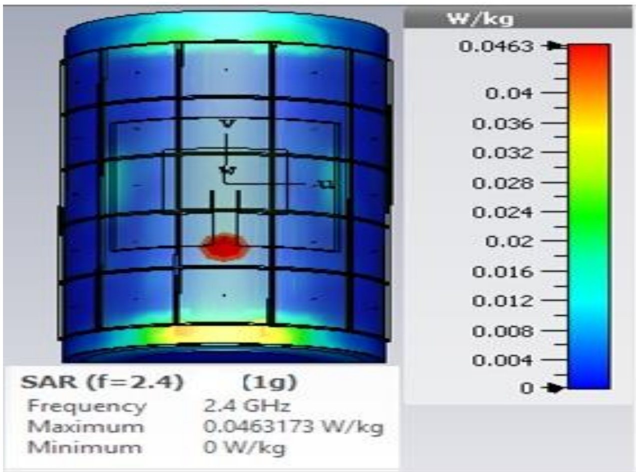
Fig. 9 SAR of antenna with wash cotton substrate (a) 1g (b) 10g

SAR of antenna in bending condition with curtain cotton using EBG is shown in Fig 10 for 1 g and 10 g of tissues. Maximum SAR of antenna with curtain cotton substrate is 0.0463 W/kg for 1 g and 0.0218 for 10 g of tissue in the body. Now the SAR value haven been reduced from 2.63 W/kg without EBG to 0.0463 W/kg with EBG for 1 g tissue. Now the SAR of antenna is below the maximum SAR defined by international standards.



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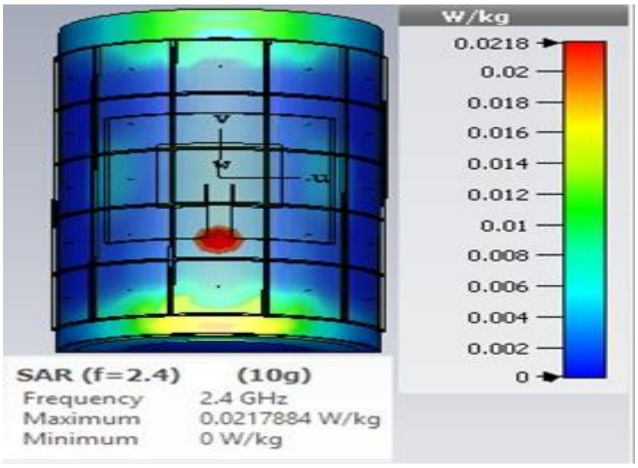

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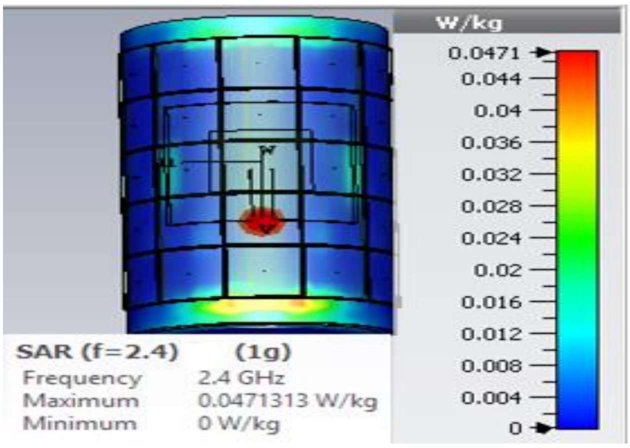
Fig. 10 SAR of antenna with curtain cotton substrate (a) 1g (b) 10g

SAR of antenna in bending condition with polyester cotton using EBG is shown in Fig 11 for 1 g and 10 g of tissues. Maximum SAR of antenna with polyester cotton substrate is 0.0471 W/kg for 1 g and 0.0225 for 10 g of tissue in the body. Now the SAR value haven been reduced from 2.5 W/kg without EBG to 0.0471 W/kg with EBG for 1 g tissue. Now the SAR of antenna is below the maximum SAR defined by international standards.



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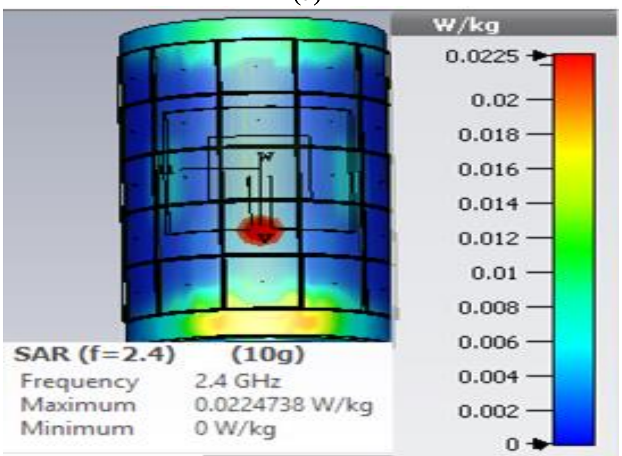
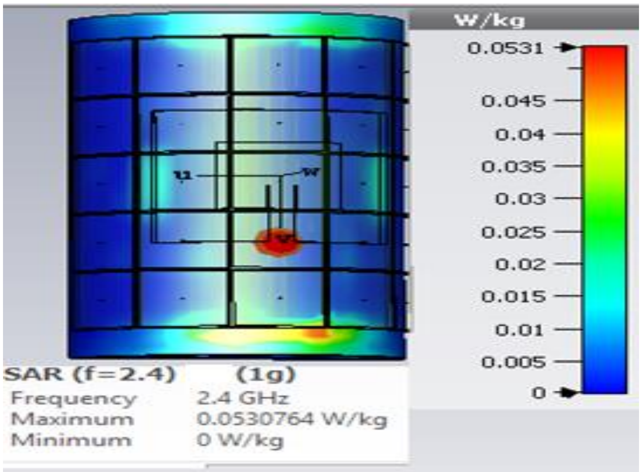


(b)

Fig. 11 SAR of antenna with polyester substrate (a) 1g (b) 10g

SAR of antenna in bending condition with polycot using EBG is shown in Fig 12 for 1 g and 10 g of tissues. Maximum SAR of antenna with polycot cotton substrate is 0.0531 W/kg for 1 g and 0.0253 for 10 g of tissue in the body. Now the SAR value haven been reduced from 2.7 W/kg without EBG to 0.0531 W/kg with EBG for 1 g tissue. Now the SAR of antenna is below the maximum SAR defined by international standards.



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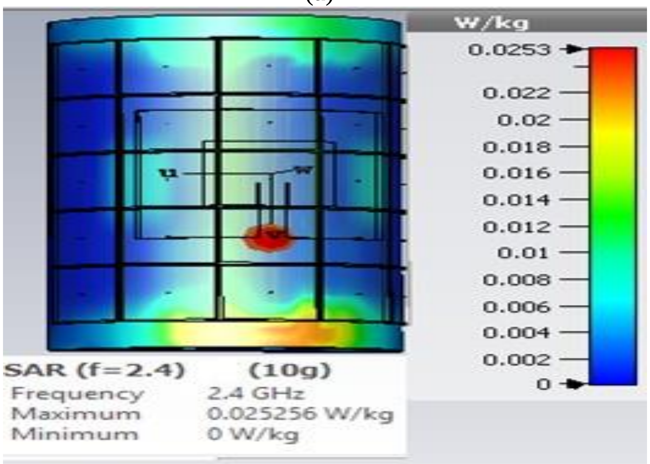


(b)

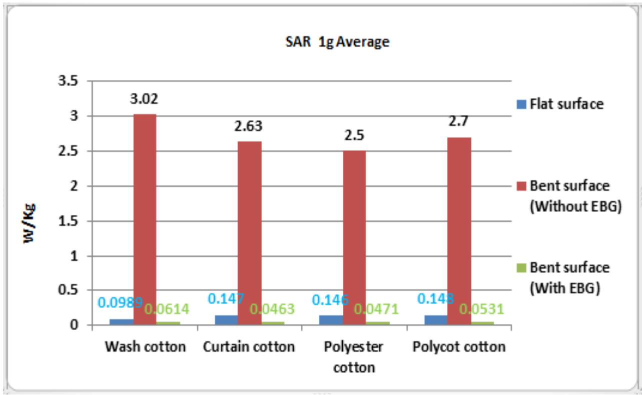
Fig. 12 SAR of antenna with polycot substrate (a) 1g (b) 10g

For better analysis of antenna with different substrate materials, SAR values of antennas are given in table 1

Table 1: SAR (Specific Absorption Rate)

	Flat phantom		**Bent phantom (Without EBG)**		**With EBG**	
	1 gm (W/kg)	**10 gm (W/kg)**	**1 gm (W/kg)**	**10 gm (W/kg)**	**1 gm (W/kg)**	**10 gm (W/kg)**
Wash cotton	0.0989	0.0358	3.02	0.637	0.0614	0.0295
Curtain cotton	0.147	0.0501	2.63	0.55	0.0463	0.0218
Polyester cotton	0.146	0.0498	2.5	0.596	0.0471	0.0225
Polycot cotton	0.148	0.0505	2.7	0.589	0.0531	0.0253

From the table 1, comparative bar graphs of different antennas are shown in Fig 13



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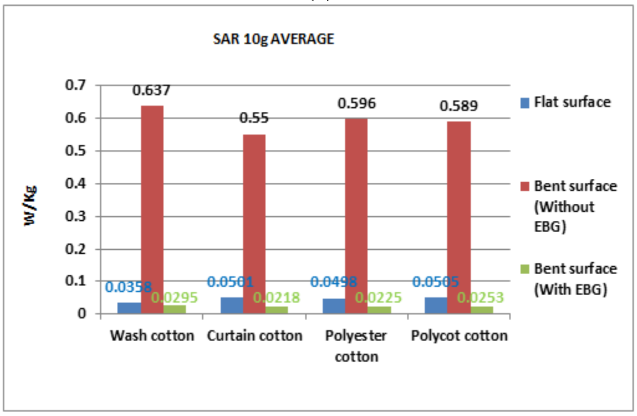

(b)

Fig 13 Comparative bar graphs of different antennas (a) 1g (b) 10g tissue

III. RESULT ANALYSIS

The SAR (specific absorption rate) of antenna on flat surface is less than the 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. It means in case of flat surface ground plane is sufficient to block the back radiations towards the body and no more power is absorbed by the body. But it is not possible to provide the flat surface on body all time to mount the antenna. So antenna should be tested for bending body surface also. The designed antenna is bent at the radius of 76.2 mm, which is suitable for human leg and hand. The SAR (specific absorption rate) of antenna in bending condition is more than in flat one. In flat surface, only a small portion of body comes in contact with antenna, so back radiations towards the body are less as compared to antenna in bending condition and SAR is reduced. In bending antenna more portion of the body surface is covered by antenna and radiations towards body also increased, which also increases the SAR value. In case of bending antenna EBG is used to decrease the back radiation and an improved SAR is observed. EBG is acting as a high impedance surface at the designed frequency and blocks the back radiations toward the body and directs maximum radiations in desired direction. By using the EBG material with ground plane SAR value of antenna have been reduced by approximately 98% of its value without EBG. Now the SAR value is much less than the maximum value decided by international standards and antenna is useful for wearable applications.

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