Design of Wearable Textile Patch Antenna Using C-Shape Etching Slot

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Abstract—With today's advanced technology microstrip patch antennas are more flexible and stronger than ever before. These antennas can work on various frequencies ranging from low to high for a huge variety of applications including medical, military and quite a few more. This paper presents the textile antennas those are designed for Wi-MAX application with the frequency range of 3.09–3.94 GHz, fifth generation (5G) lower band with the resonant frequency of 4.23–5.65 GHz and UWB 4.62–10.74 GHz applications. This work also introducing a single C-shape etching slot (CSES) in a rectangular patch antenna. The textile substrate (jeans) has been applied to reduce the surface wave losses and design a wearable textile antenna using microstrip line feed technology. Bending effect up to 750 and radiation effect on human tissue as specific absorption rate (SAR) are analyzed using Computer Simulation Technology (CST) tools. Textile antennas for multiple band applications can be created using CSES which can be attributed to cotton, denim cotton and polyester.

Keywords—textile antenna, multiple bands applications, C-shape etching slot (CSES), bending effect, radiation effect on human tissue

1 Introduction

This is a significant consideration now that smart gadgets and body-based communication have both greatly advanced in recent years. It is crucial to thoroughly investigate the standards of different wireless communication when designing wearable device [1], [2]. In order to satisfy these communication needs wearable multi operating band antennas that can utilize several frequencies are required. These antennas are designed for use in the following bands of UWB, Wi-MAX, ISM, WLAN and 5G communication. Because of this the biggest issue of UWB, 5G, and Wi-MAX antennas will have to deal with the body absorption and loss especially concerning people [3]. In order to overcome these conditions, wireless communication requires an antenna that is very efficient in within a reasonable distance of the human body.

It has investigated the different types of antennas such as the slot antenna which has made a significant contribution in the field of wireless communications [4]. It has been observed that a polygon-shaped antenna in denim material may operate in dual bands due to circular patches and vertical slots on the surface of the jeans [5] In addition to C, L, U, and F-slots, other shapes have been studied in the context as well [6]. The flat waveguide slot has been illustrated using the simple antenna designs [7]. With the introduction of on-body communication Yagi-Uda antennas operating at 61 GHz are now being used [8] in which the electromagnetic bandgap structure is used to minimize SAR in the bodily tissues while enhancing the antenna's isolation from the human body (EBG). However, most EBG-based antennas are electrically wide greater structural complexity is required due to the electrical conductivity of the front-to-back (FBR) structure [9]. So, it was recommended that a microstrip patch antenna offer improved gain [10].

As part of this study, it is recommended that the Wi-MAX application at the resonant frequency of 3.09–3.94 GHz UWB 4.62–10.74 GHz and 5G at 4.23–5.65 GHz. To obtain resonant bands a CSES based on a Jeans substrate is used along with consistently reduced SAR. Antenna performance is influenced not just by SAR but also by various textiles and bending conditions. Previous published research studies showed a smaller reduction in size with this antenna proposed measurements of $19 \times 18 \times 1$ mm^3. In contrast to earlier studies it has been revealed that there are relatively a small number of research publications on 5G antenna applications for the lower band.

2 Antenna design

When it comes to microwave engineering one sort of low-power communication antenna is known as a microstrip antenna. As part of this study it has been developed a patch antenna on a denim substrate with the following specifications: antenna height is 1 mm; relative permittivity = 1.7, loss tangent = 0.025 and the total dimensions = 18×19 mm^2. Moreover, the patch length Lp = 16 mm, patch width Wf = 3.6 mm, and $\lambda/4$ feed line are used. The radiation patch and ground plane thickness of copper was determined to be 0.035 mm thick. Following the completion of some parametric calculations CST MWS 2021 was utilized for the purpose of design and simulation. To increase the working bandwidth the CSES was only applied to the radiating patch with a ground length of Lg1 = 3.5 mm. Because of this the radius R = 4.5 mm of CSES's circle, in terms of coordinates (x, y) with coordinates x = 3 mm, y = 1.5 mm, 3.5 mm representing Wi-MAX application of 3.09–3.94 GHz, 5G at lower band 4.23–5.65 GHz and for UWB 4.62–10.74 GHz band width where R = 2.5 mm, a = 2 mm, b = 4.45 mm and the coordinate (x, y) = 3 mm, y = 3.5 mm. There were several substrates tried and evaluated to find out if the antenna's performance and effects varied by substrate. Jeans fabric has been employed in this work. In Figure 1 the antennas physical layout is displayed. In Table 1 the various cotton fabric parameters are shown while in Table 2 operational frequencies for various cloth are shown. The S_{11} parametric investigation shows that jeans fabric has a higher impact on the performance than the others. This parametric research is relevant to the 5G and Wi-MAX applications. As shown in Figures 2 and 3 the proposed antenna has a return loss and it is acceptable for use in a body area network (BAN). Antenna performance is more strongly affected by R-value than antenna efficiency. From Figure 4 it's evident that R = 4.5 mm is the most suitable R value for this suggested research activity.

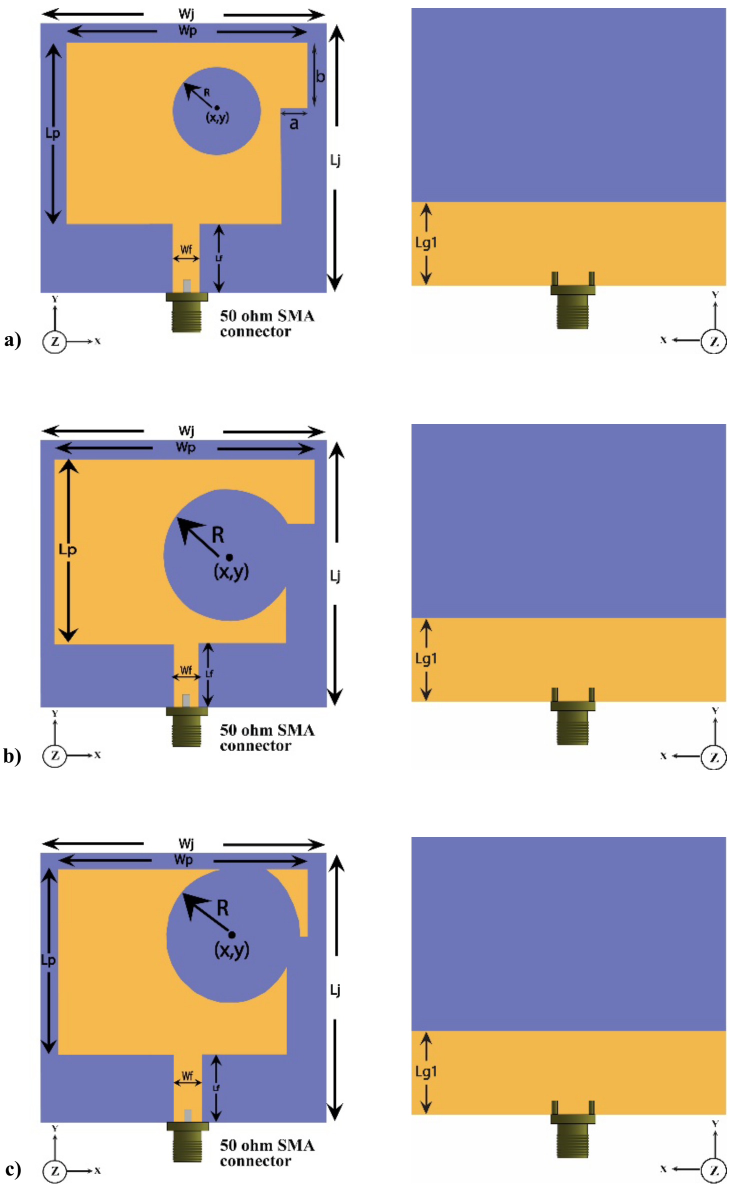


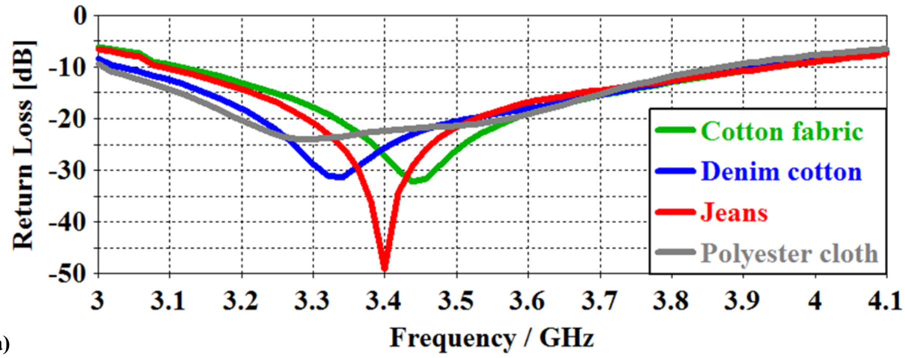
Fig. 1. Layout of the designed antennas (a) UWB (b) Wi-MAX & (c) 5G lower band

Table 1. Different substrate/cloth specifications [11]

Parameters	Values (cotton fabric)	Values (denim cotton)	Values (polyester cloth)
Thickness, h	0.32 mm	2 mm	2 mm
Relative permittivity, ε_r	1.31	1.7	1.39
loss tangent, δ	0.006	0.024	0.01

Table 2. Resonance and bandwidths obtained by various substrate/cloth textiles [11]

Substrate	Operational Frequency (GHz)			
	Wi-MAX		5G lower band	
	Lower cutoff	Upper cutoff	Lower cutoff	Upper cutoff
Cotton	3.11	3.94	4.25	5.81
Denim cotton	3.03	3.91	4.05	5.51
Jeans	3.09	3.94	4.23	5.67
Polyester	3	3.97	4.27	5.89



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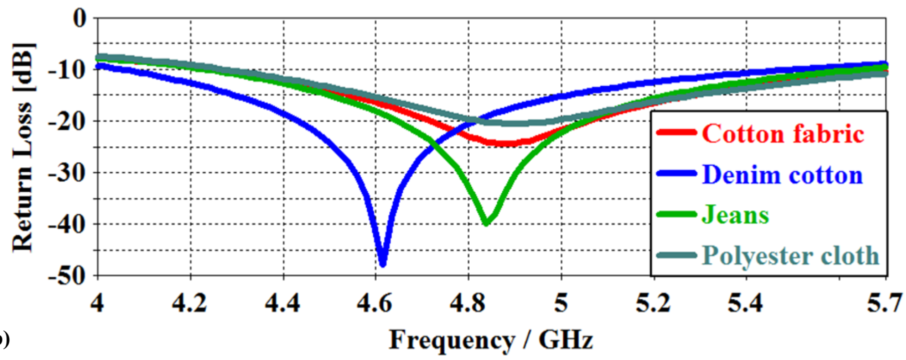


b)

Fig. 2. Comparison of reflection co-efficient (S_{11}) between particular substrate materials (a) for Wi-MAX application and (b) for 5G lower band application [11]

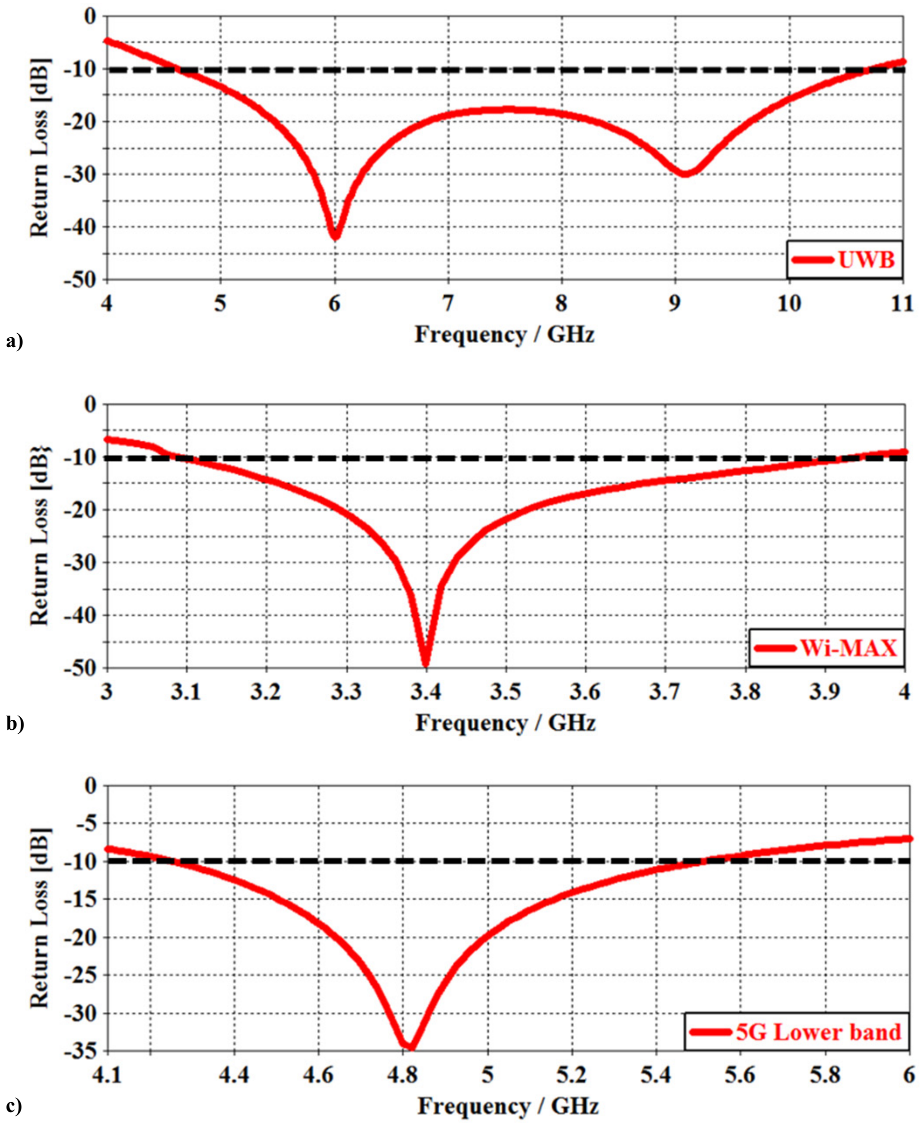


Fig. 3. The S_{11} for (a) UWB, (b) Wi-MAX & (c) 5G

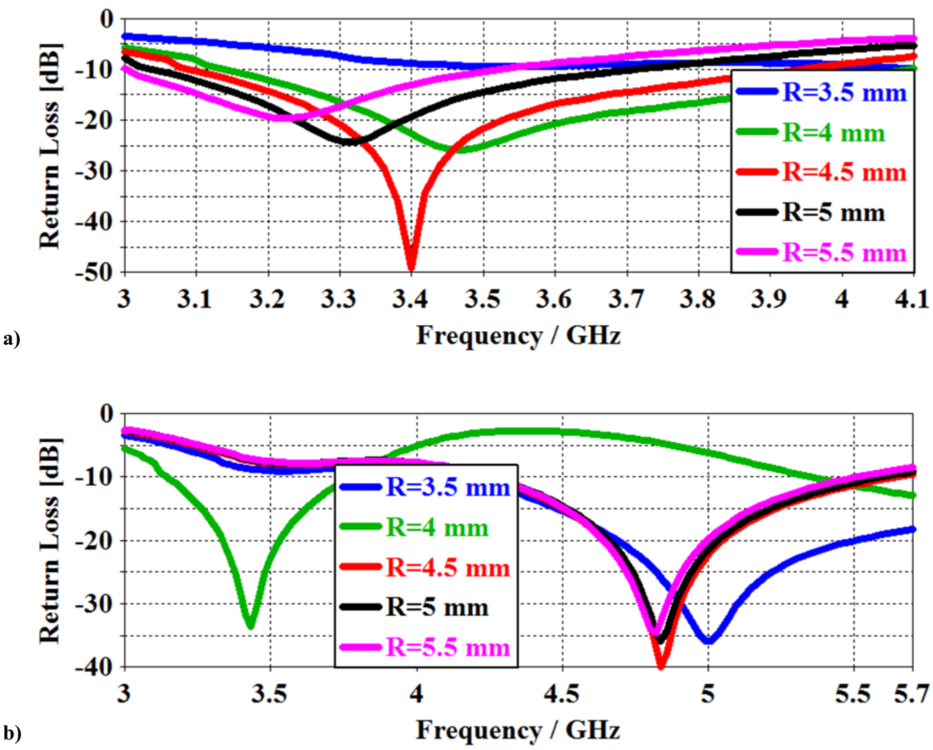


Fig. 4. Comparison study of various values of R (a) Wi-MAX and (b) 5G applications [11]

Fig. 5. Antenna insertion on denim substrate for Wi-MAX application with 3.3–3.8 GHz resonant frequency and 5G band with 4.5–5.5 GHz frequency [11]

3 Result analysis and discussion

In order to determine if antenna enhancements will improve or degrade functioning with UWB, Wi-MAX, BAN, and 5G applications it was important to verify the antenna performance in the simulation before moving forward. To this purpose it is necessary to keep an observation on several simulated results including S_{11} and VSWR as well as 3-D radiation patterns, SAR value, bending analyses and surface current. The VSWR of the entire bandwidth for UWB, Wi-MAX and 5G is less than 2. Figure 6 illustrated the antennas has excellent impedance matching. According to Figure 7 the antenna's operating frequency resonates with the 3-D radiation pattern with directivities such as 3.4 and 4.8 GHz. In both situations the 9.36 dBi and 7.83 dBi exhibited a higher directivity. The CSES generated the surface current distribution (shown in Figure 8) to build at 3.4 GHz and 4.8 GHz with the large amount of current being 189.2 A/m and 165.9 A/m accordingly. But the resonant frequency for UWB at 6 GHz the surface current 65.6 A/m accumulated. Figure 9 shows the banding effect in θ = 0º, 30º, 60º and 75º every case the proposed antennas performed more or less. It is notable that from Figure 9 (b, c) the angle 30º, 60º and 75º has almost same performance on the entire bandwidth.

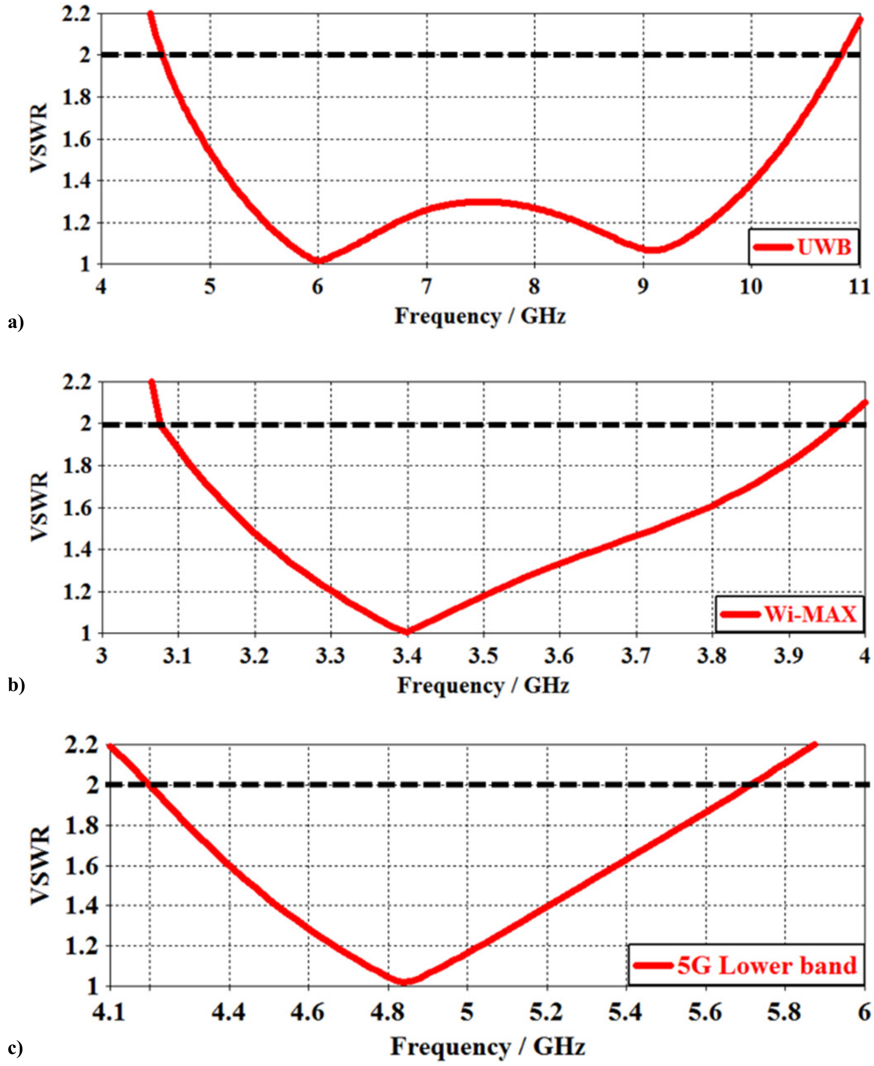
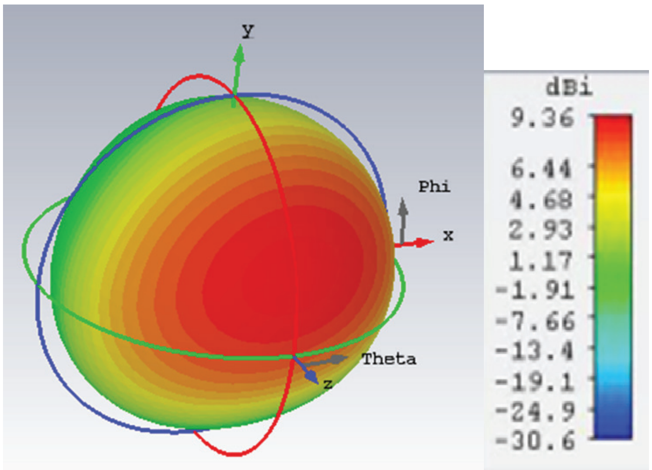


Fig. 6. The graphical view of the VSWR



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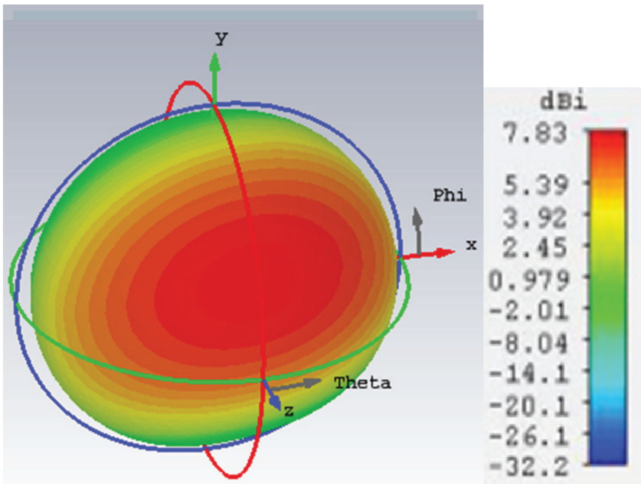
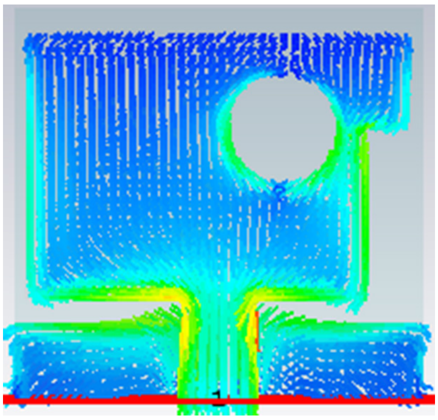


b)

Fig. 7. The simulated directivity of proposed antenna (3D Radiation pattern) (a) for 3.4 GHz and (b) for 4.8 GHz [11]



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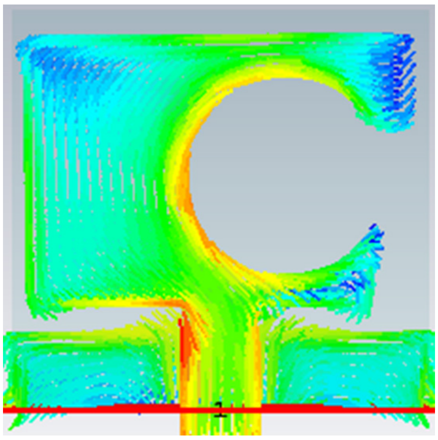

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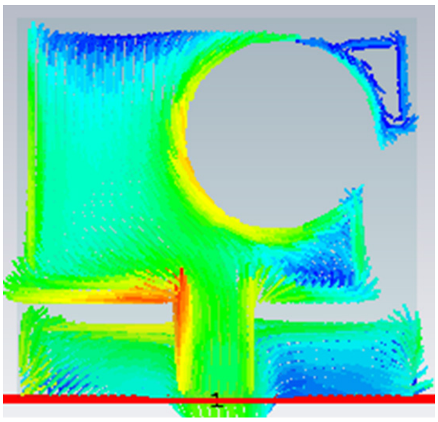


c)

Fig. 8. Surface current distrubatyion of the proposed antenna (a) 6 GHz, (b) 3.4 GHz and (c) 4.8 GHz [11]

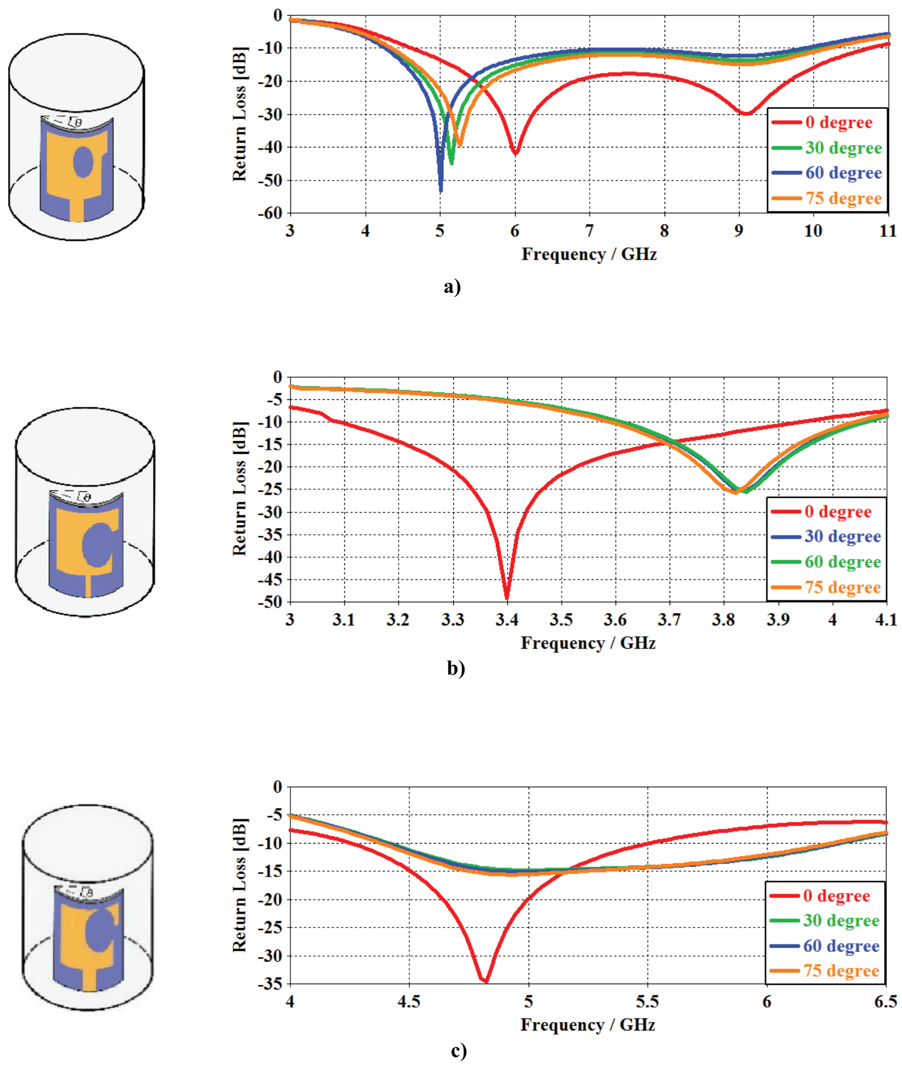


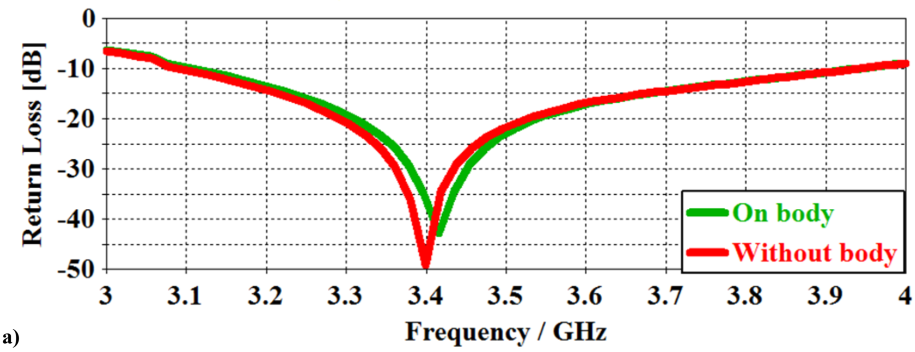
Fig. 9. Bending effect on different angle (a) UWB, (b) Wi-MAX & (c) 5G

4 SAR calculation

In this section, the antenna's output system has an impact on the body, especially the SAR. Figure 10 depicts the compression of reflection coefficient (S_{11}) between on body and off body condition. This figure illustrates 3.4 GHz, 4.8 GHz as the resonance frequency for the compression. The modification of the resonance frequency is mostly caused by two significant factors: large permittivity and movement on the body phantom. The figure shows the antenna bandwidth of without-body conditions for Wi-MAX and 5G applications. However, the overall bandwidth of the Wi-MAX at body phantom is 0.64 GHz while the total bandwidth of the 5G application at body phantom is 1.5 GHz. On the human body an antenna output and SAR value analysis is being carried out on the textile patch.The computed radiofrequency energy emitted by 10 gm of human tissue was 0.353 W/kg, which was less than the 2 W/kg shown in Figure 10 [12]. There is a limit of 10 gm set by the International Commission on Nuclear and Radiological Protection (ICNIRP) to any tissue with radioactivity below 2 W/kg. The specifications of the human tissue model are shown in Table 3. In comparison to other recent research efforts, this one's antenna size, exceptional operating bandwidth, directivity, bending effect, and SAR values [1, 2, 3, 4, 5, 6, 7, 8, 13, 14, 15] set it apart.

Table 3. The physical characteristics of the human body tissue model [13]

	Bone	Muscle	Fat	Skin
Thickness (mm)	13	20	5	2
Density (Kg/m^3)	1008	1006	900	1001
Conductivity σ (S/m)	0.82	1.77	0.11	1.49
ε_r	18.49	52.67	5.27	37.95



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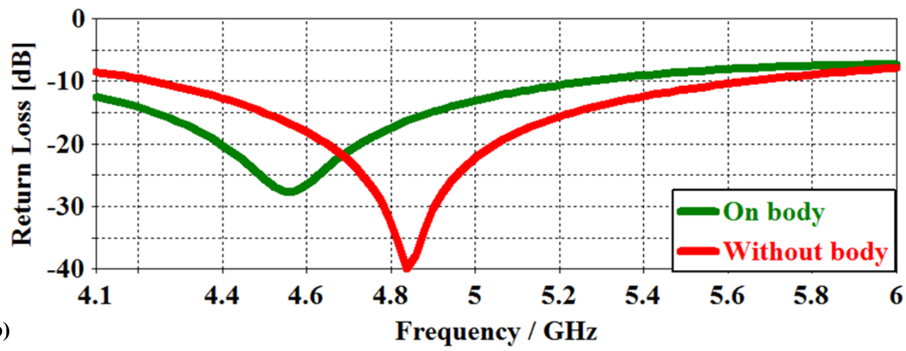

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Fig. 10. The compression of return loss (S_{11}) between with and without body model (a) for Wi-MAX application, and (b) for 5G application [11]

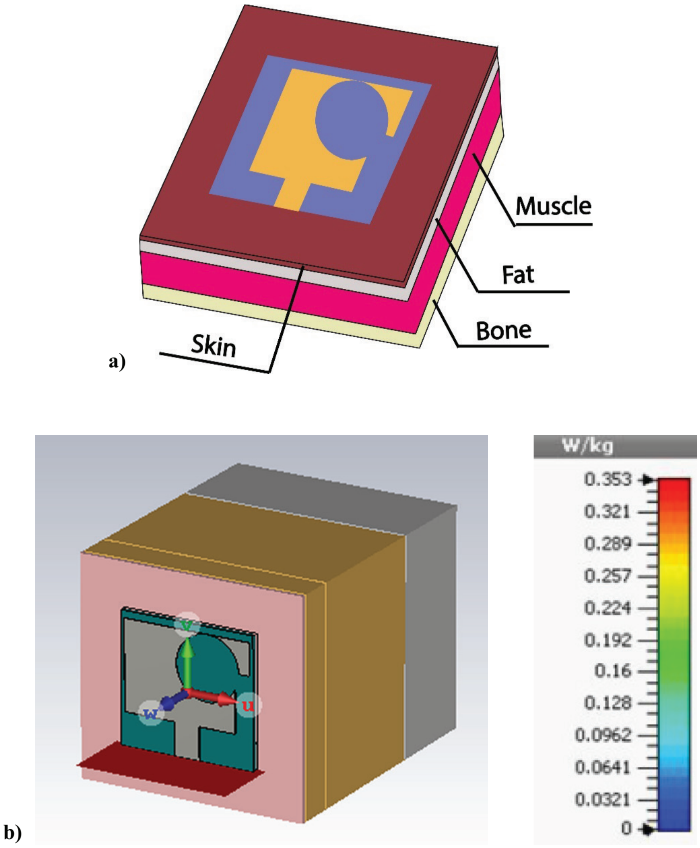

Fig. 11. Proposed antenna with body environment (a) antenna layout with body environment and (b) simulated view with expected output [11]

5 Conclusions

A unique method of C-shape etching slot (CSES) is used to design a textile wearable patch antenna. Wearable antennas for UWB, Wi-MAX and 5G wireless applications are designed using the CSES method on four textile material substrates including Jeans, Cotton, Denim cotton, and Polyester. Designed patch antenna with Jeans substrate is investigated up to 75 degree for bending effects and the specific absorption rate (SAR) for radiation effects on human tissue. The proposed antennas are found to conform with the safety guiding principles and other characteristics of textile antennas. Furthermore, the antenna has been designed for UWB, 5G and Wi-MAX application of wireless communications systems.

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