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A wearable antenna based on fabric materials with circular polarization for body-centric wireless communications

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ABSTRACT

A compact and simple structure antenna for wearable application at 2.4 GHz is presented and studied. The felt fabric material is used in this paper due to its suitable thickness and dielectric constant. This material provides high flexibility which can be easily worn on a body and incorporated into our daily clothes. In view of the fact that the design will work on a moving person, therefore a circularly polarized antenna is desired to optimize the off-body communication link. The Cicular Polarization (CP) is achieved by introducing truncated corners on the patch. The antenna size is 60 × 60 × 2 mm3. The Axial Ratio (AR), the Front to Back Ratio (FRB) and the realized gain are 0.96 dB, 10.5 dB, and 4.62 dB, respectively indicating a good performance of the antenna at the desired frequency. Furthermore, the antenna was investigated when operating near the body. The obtained result shows that the design has performance similar to the case of free space. This is due to the present of the full ground plane that acts as a shielding between the antenna and body. Finally, the Specific Absorption Rate (SAR) is carried out and showed that the antenna has a level less than the limits fixed by the FCC standard. Therefore, the antenna could be useful for wearable applications.

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1. INTRODUCTION

The development of portable wireless communication systems prompted researchers to focus on the design of small-sized antennas. The most valuable among the small-sized antenna selections is the microstrip patch antenna. These antennas are characterized by important features such as compact, low cost, lightweight polarization diversity, and low profile. The wearable antennas, which are part of our daily clothes, are utilized for communication purposes such as health monitoring, sports, tracking, military, public safety, firefighters and mobile computing. Besides that, a wearable antenna considers one of the most vital parts of wearable electronic devices [1-9].

Wearable antennas are employed as transmitter and receiver nodes in Wireless Body Area Network (WBAN) devices for the purpose of sending and receiving the information or data. These antennas are maintained flexible therefore they don't prevent the movement of the body. To ensure the flexibility of these antennas, various flexible materials are utilized as essential parts for the design of wearable antennas [10-15].

Due to the continuous movement of human body, it is relatively difficult to obtain the appropriate polarization alignment to maintain an acceptable power received by the transceiver [15, 16]. Therefore, a circular polarization (CP) is introduced to overcome the misalignment by aligning two nodes continuously to receive maximum power. In that case, a wearable antenna with circular polarization (CP) has the advantages in terms of mobility and ease of movement while performing an activity; and also no limitation in the transmitter to receiver orientation. In addition, the previous documented work on wearable antennas in the literature are mostly linear polarized [17, 18], large in size [19], non-flexible [20] and using thick substrate [21], which limit their employment in wearable applications.

In order to make the wearable antenna circularly polarized, modification in the radiating elements is required, such as truncated, feed arrangements, phase shifting, and slotted. On the other hand, some of the techniques that used to obtain CP wearable antenna are complex or can only achieve CP at very limited bandwidth without covering the desired band [1].

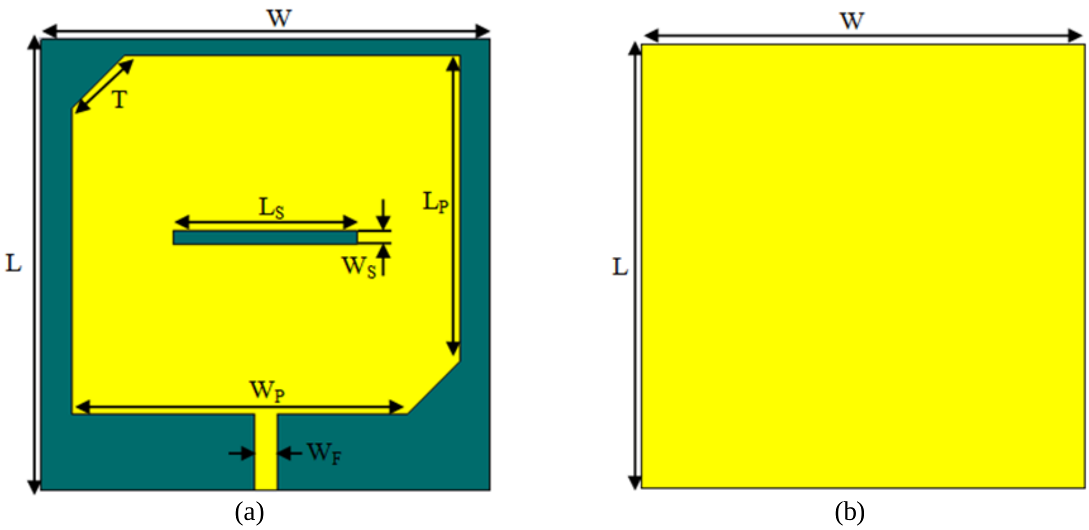
Therefore, in this paper, a fabric antenna designs by introducing the rectangular slot and the truncated edge of the patch in order to reduce the size and obtains CP. The truncated is chosen to avoid the complexity where the complexity is not preferred in fabric design in order to reduce the errors during fabrication. The useful of using wearable CP antenna is to optimize the off-body communication link when the antenna operates on moving person. The circularly polarized fabric antenna is studied and its performance in free space and on the body will be investigated. The proposed antenna covers the 2.4 GHz ISM band. Furthermore, in order to protect the body from the influence of radio waves, the specific absorption rate (SAR) should be kept low enough.

2. ANTENNA DESIGN

The presented antenna is consisting of a dielectric which is sandwiched by a radiating element at the top layer and a full ground layer at the bottom. The full ground is used to act as shielding and reduce the user’s impact on the fabric antenna performance when placed on the human body. The felt materials are used as the supporting materials due to its features that has a firm, inelastic and smooth surface, common fabric material used in daily clothing and has suitable dielectric constant and thickness. For the case of radiating element, Shieldit super with a thickness of 0.17 mm was selected due to a hot melt adhesive on one side that let it stick firmly with the fabric material. In this paper, the felt has a thickness of 2 mm, relative permittivity of 1.3 and tangent loss of 0.02.

3. PERFORMANCE OF THE ANTENNA IN FREE SPACE

Figure 1 illustrates the design of the presented fabric antenna with circular polarization. The initial stage of the design is started based on calculation. Based on the formula in [22], the overall dimension of the antenna is 66× 60×2 mm^3. Then, the design was optimized to resonate at the desired frequency of 2.4 GHz with an overall dimension of 60×60×2 mm^3. The detailed dimensions of the geometry is tabulated in Table 1.



(a) (b)

Figure 1. Circularly polarized fabric antenna (a) front view and (b) back view

Table 1. Parameters of the Presented Fabric Antenna as Labeled in Figure 1

Parameters	Values [mm]
W	60
L	60
WP	44.8
LP	40.8
WS	1.8
Ls	24.6
WF	3
T	7

The presented fabric antenna is analyzed using CST software. Figure 2(a) illustrates the reflection coefficient, S_{11} of the introduced design without slot and truncated corners. It is realized that the resonant frequency resonating at higher band. With the existence of a rectangular slot, the size of the presented wearable antenna is reduced and the resonant frequency is shifted to the lower band as seen in Figure 2(a). This is due to the effect of slots on changing the current path and increases the effective current path length. To achieve CP a truncated corner with equal side length is introduced. The truncation is optimized until the fabric antenna achieves CP. In order to verify the CP of the antenna, the antenna must have an axial ratio (AR) bandwidth of less than 3 dB. Figure 2(b) shows the AR result of the fabric antenna at different truncated values. The results indicate that when the truncated corners are 7 mm, an acceptable AR below 3 dB is obtained, therefore attain circular polarization with 0.96 dB at desired frequency 2.4 GHz.

Figure 3 (a) shows the radiation pattern at E-plane and H- plane. It can see that the backward radiation is low which quite important since the antenna designed for the purpose of wearable. The low backward radiation is due to the full ground that contributes to reducing the radiation towards the body. Furthermore, the presented antenna has achieved a FBR of 10.5 dB and realized a gain of 4.62 dB, respectively as presented in Figure 3 (b).

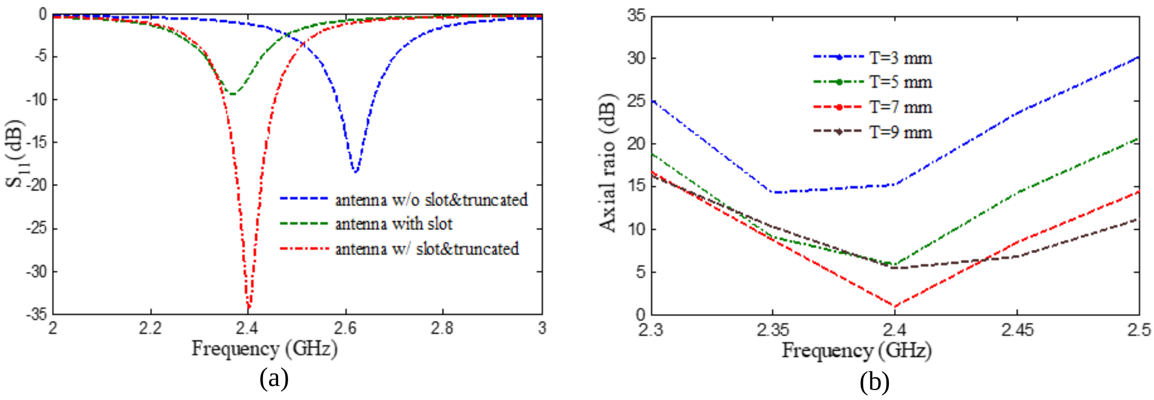


Figure 2. (a) S_{11} of the circularly polarized fabric antenna and (b) Axial radio with different truncated corners

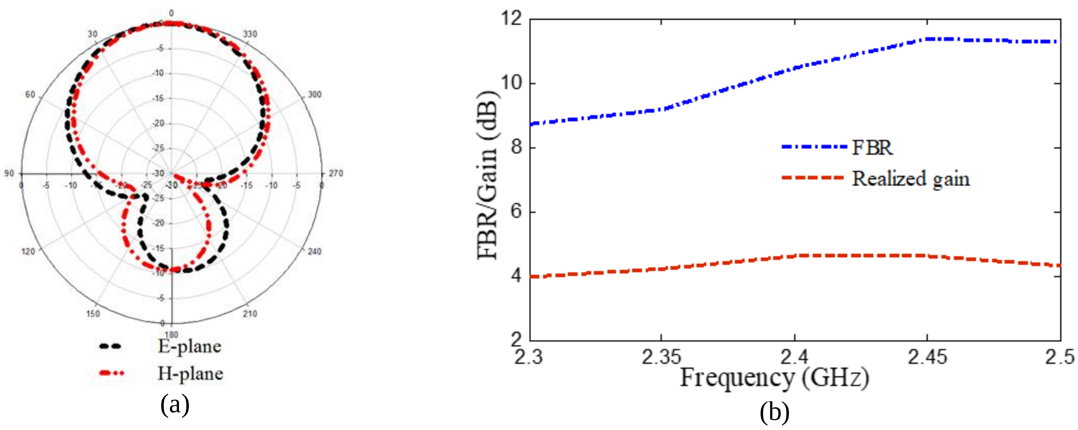


Figure 3. (a) Radiation pattern and (b) Gain and front to back ratio (FBR)

4. PERFORMANCE OF THE ANTENNA ON BODY

Since this antenna is intended for wearable application, the antenna performance should be evaluated when operating in the proximity of the human body. In order to perform the analysis, a phantom model consists of four layers is designed to imitate the human chest. The layers consist of bone, skin, muscle and fat. The area size of the phantom is 150 mm × 150 mm × 40 mm^3 [23-26]. Each layer has a its own thickness, mass density, permittivity and conductivity values as tabulated in Table 2 [24, 25]. The presented antenna was investigated at varies distances to the phantom by 0 mm, 2 mm, 5 mm and 8 mm. The configuration of placement of the antenna on the phantom is illustrated in Figure 4.

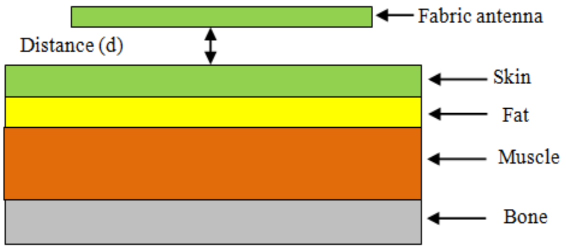


Figure 4. A configuration of the fabric antenna on the phantom model

Table 2. Data of the Phantom [24, 25]

	Skin	Muscle	Fat	Bone
Density (kg/m3)	1001	1006	900	1008
ε	37.95	52.67	5.27	18.49
Thickness (mm)	2	20	5	13
σ (S/m)	1.49	1.77	0.11	0.82

Based on Figure 5(a), the S_{11} of the design is stable even when the antenna placed directly on the phantom. This is due to the presence of the full ground plane which reduced the impacts between the antenna and the human body. The <-10-dB return loss bandwidth is nearly the same as in free space. Figure 5(b) depicts the AR of the antenna with different distances between the antenna and the phantom. It also can be seen that the AR maintains stable as in the case of free space with a value of less than 3 dB. The AR is range from 0.43 dB to 0.92 dB. Based on AR results, the problem of restricted movements of the users while wearing the wearable device on their clothes is solved due to its independence of orientation.

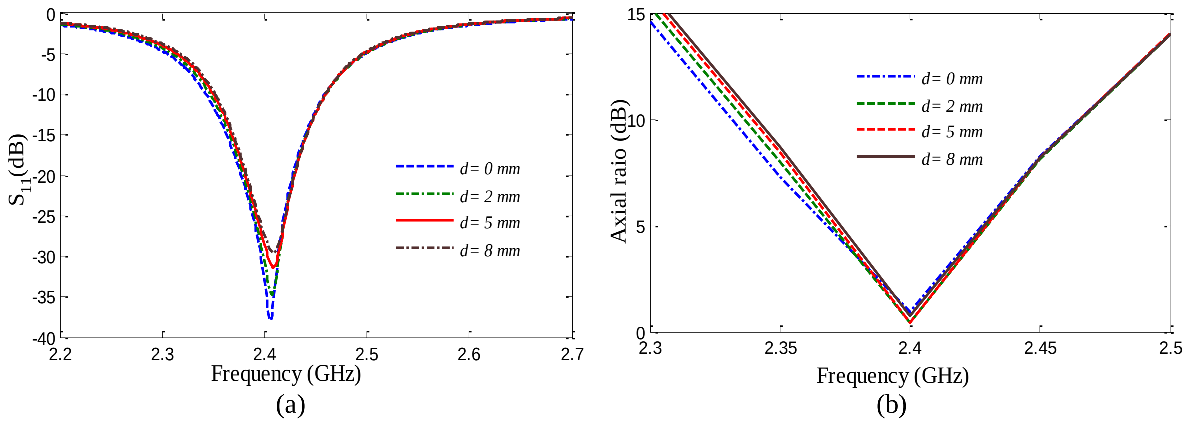


Figure 5. Antenna performances (a) with different distances between the phantom and the fabric antenna and (b) Axial with different distances between the phantom and the fabric antenna

Figure 6 shows the investigation of the radiation patterns with the same distances as studied in S_{11} and AR. In overall, radiation patterns with human proximity maintain close to that in free space. The front to back ratio is slightly increased which result in increasing the directivity. As a result, the increment of directivity also results in an increment on the gain range from 4.53 dB to 4.82 dB compared to free space as depicted in Figure 7. This is due to the human body which can behave as an extension of the ground plane [20].

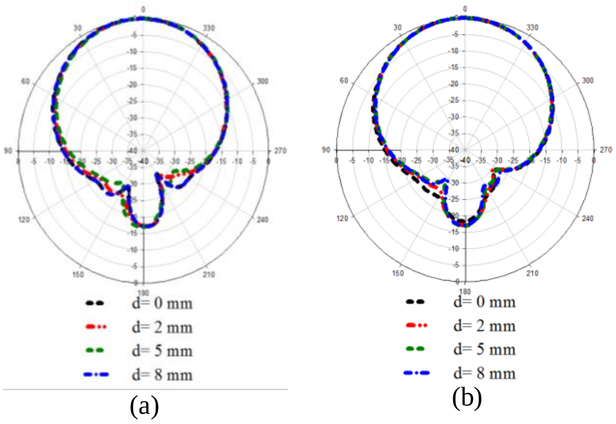


Figure 6. Radiation pattern with different distances between the phantom and the fabric antenna (a) E-plane and (b) H-Plane

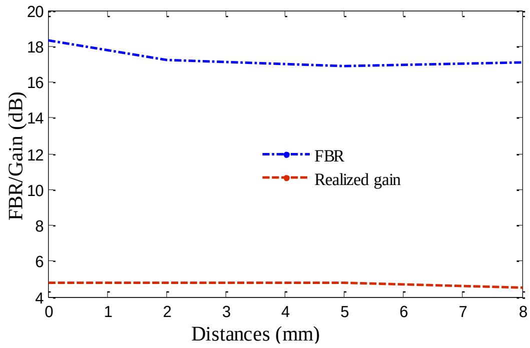


Figure 7. Realized gain and FBR with respect distances between the phantom and the fabric antenna

5. SPECIFIC ABSORPTION RATE

SAR is an essential feature of a fabric antenna in order to find the impacts of the electromagnetic waves on the human tissues. The safety limits of the SAR based on FCC is 1.6 W/Kg over 1 g tissue. The same phantom model used to investigate the S_{11} and AR is used for SAR analysis with the same distances. The input power set at 100 mW [24-27] and the evaluation of the values are according to IEEE C95.1 standard that obtainable in the CST MWS software. The results are depicted in Figure 8 and summarize in Table 3. It is realized that the antenna has values less than the safety level even when it places immediately on the phantom model.

Table 3. Saummary of SAR Values at Varies Distances

Spacing between the antenna and the phantom (mm)	SAR over 1 g (w/kg)
0	1.11
2	0.23
5	0.166
8	0.12

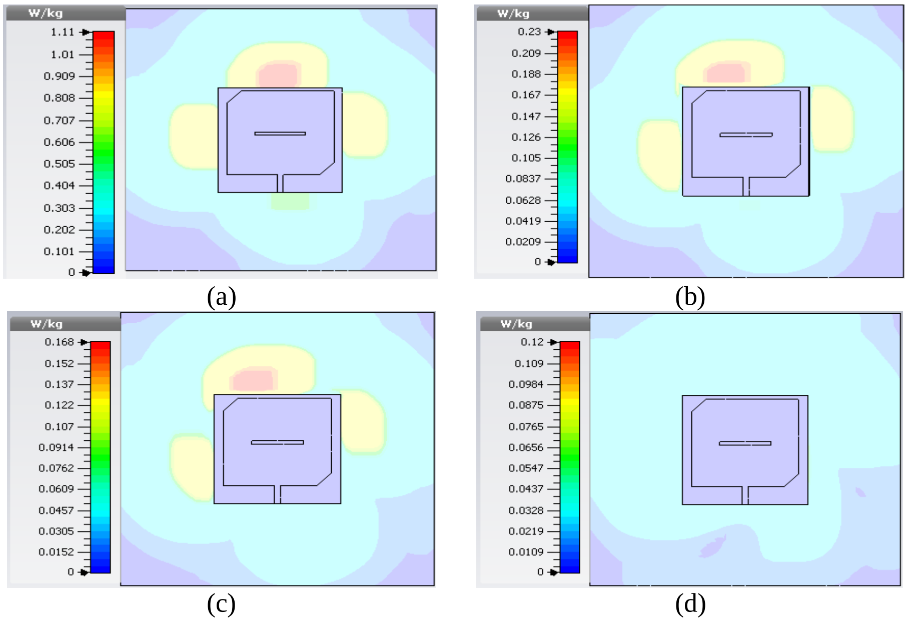


Figure 8. SAR investigation based on 1 g averaged with different distances from the phantom (a) at 0 mm, (b) at 2 mm, (c) at 5 mm and (d) at 8 mm

6. CONCLUSION

This paper presented a compact and simple structure that operates at 2.4 GHz. The introduced slots and truncated corners in the design contribute to reduce the size and achieve the circular polarization. The fabric material is used to maintain flexibility and make it easily worn on the human body. The AR, FBR and realized the gain of the antenna in free space are 0.96 dB, 10.5 dB, and 4.62 dB, respectively. The presented antenna has been investigated when operating close to the human body with different distances in term of S_{11}, AR, FBR and realized the gain. The results showed that the design achieved good performance when operating near the body. Furthermore, SAR was studied and shows that the level complied with the basic restrictions for the general public. The results illustrated that the presented fabric antenna has suitable performance, even when it placed directly on the body. Therefore, we conclude that this presented fabric antenna is appropriate for wearable applications.

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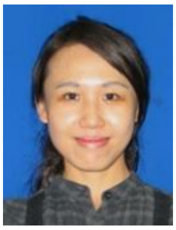

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