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## Flexible Co-Planar Waveguide (CPW)-Fed Y-Shaped Patch UWB Antenna for Off-Body Communication

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**Abstract.** This paper intends to design an Ultra-Wideband (UWB) antenna for future Internet of Things (IoT) applications for off-body Wireless Body Area Networks (WBAN) communication. An antenna based on the Y-shaped patch fed using co-planar waveguide (CPW) line, with a full ground plane is designed. It is implemented on two different substrates, namely a 5mm thick Rogers RO4350B and a 5-mm-thick felt textile. Parametric analysis of antenna is performed by changing its critical dimensions and monitoring parameters such as gain, bandwidth, efficiency, radiation pattern when using both substrates. Besides that, the bending effects towards reflection coefficient and radiation patterns are also studied. The final patch size with the Y-shaped slot is  $36 \times 40 \text{ mm}^2$  for both substrates. The antenna is capable of providing coverage for the bands from 8 to 10 GHz. Finally, the antenna designed on RO4350B substrate outperforms the antenna designed on felt by about four times in terms of bandwidth, with 3.3 GHz (7.7–11 GHz).

### 1. Introduction

Future 5G architecture is envisaged as highly-dense, diversified, versatile as well as a unified technology with an extra-ordinary bandwidth availability for almost unlimited upgradation [1]-[2]. Such future technology integrated with IoT-based applications is WBAN that offers endless benefits in the medical monitoring system. It is anticipated that the future wireless access networks also will be combined with radio over fibre (RoF), making it possible to realize high speed data transmission [3]. Through such application, smart wearable devices are created, having capability of sensing data, controlling actuators, communicating with external devices and recharged wirelessly. Integration of electronics into smart textiles has been recognized as key enabler for this future revolutionized technology where one of the key features is wearable textile antenna [4]. The smart textile will be embedded into day-to-day garments and the trend has been increasing rapidly for other applications such as localization [5], and energy harvester [6]. The off-body communication antennas [7] play pivotal role in realizing the future wearable 5G IoT network where it provides seamless established communication between on-body sensors and other external devices, such as base station and wireless fidelity (WiFi) router.



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Antenna design becomes one of the key considerations to deploy 5G front end systems. Several popular topologies for wearable planar antenna have been proposed in the literature, like textile monopole antennas [8]-[11], textile planar inverted-F (PIFA) [12]-[13] and patch antennas [7], [14]-[15]. The microstrip patch antennas (MPAs) have been regarded as the best choice in smart wearable devices for off-body communication in enhancing the front-to-back ratio (FBR) and specific absorption rate (SAR) values. The MPA offers low profile, planar, lightweight, easy to integrate with clothing, robustness against human body and obtrusive body communications, making it one of the prominent designs for WBAN applications. In addition, due to its full rear ground plane, the MPA enables shielding against the effects of the body, reducing power absorption and dielectric coupling, besides influencing its SAR level [7], [11] and [16]. The effect of antenna towards human body and tissue is such of importance since public worries about the negative health effect caused by the radio frequency radiation exposure [17]. Despite its various advantages, such antenna suffers from a very narrow bandwidth. Several techniques were introduced to overcome this limitation by using different substrate and conductive materials with varied thickness, partial ground or non-ground structure in UWB antennas [18] and CPW structures [19]-[20]. Co-planar waveguide (CPW) structures are among the commonly-used technique to excite additional resonances and providing a wideband feature within the antenna structure. For optimum performances of wearable antenna, UWB is used whereas it requires 3.1 to 10.6 GHz according to the Federal Communication Commission (FCC) in 2002 with the minimum bandwidth of 500MHz. UWB is preferred in WBAN or to be specific as medical sensor, i.e. blood pressure, glucose level, or electrocardiogram (ECG) that requires a continuous signal in short range with high data rate transmission where in 5G, high data rate is crucial in combating the interference caused by multipath fading [21].

In addition, due to massive demand in wearable wireless device systems in the market, the focus of research has been centralized to the flexible antennas [7]. In this paper, the antenna topology is designed based on CPW. The appropriate CPW geometry dimension resulted in wider bandwidth coverage when utilized RO4350B as the substrate material in comparison to the felt textile.

## 2. Material and method

The workflow of the antenna design can be summarized as the following sub sections. The scope includes designing an antenna and optimizing the design before proceeding to the fabrication. The details of material used and stage involved in this research work are explained in the subsections below. The technique used in this design including the suitable design and unit cell was also presented.

### A. Substrate Selection

Since it is a wearable device in WBAN system, the selection of the material is crucial in order to ensure high flexibility, wide bandwidth and mechanical robustness. Therefore, RO4350B and Felt textile material were analyzed. Felt substrate with a relative permittivity of  $\epsilon_r = 1.44$ , a loss tangent,  $\tan\delta = 0.044$ , and a thickness,  $t = 5$  mm. The relative permittivity for RO4350B substrate is,  $\epsilon_r = 3.66$  with thickness of material,  $t = 5$  mm. The selection of substrate material heavily depends on the deployment location of the antenna. There are some wearable antennas which are inserted in wireless sensors for sport applications. The whole module is boxed in a container made of plastic and the antenna is not in direct contact with the body. In such applications, every sort of substrate is possible because antenna would be printed in the same substrate with sensor and transceiver.

### B. Antenna Topology

The Y-shaped antenna with CPW was designed with RO4350B as a substrate with a relative permittivity of  $\epsilon_r = 3.66$  and ShieldIt conductive textile as the radiator. ShieldIt Super electrotextile, manufactured by LessEMF Inc., was used to form the conducting parts of the antenna with a thickness,  $H_t$ , of 0.17 mm. The estimated conductivity of ShieldIt Super is  $\sigma = 1.18 \times 10^5$  S/m [7], [11]. The thickness of RO4350B is  $t = 5$  mm. The specification of proposed antenna can be observed in the Table

1. The use of RO4350B help to broaden the bandwidth as it will tune to the desired resonant frequency. Finally, the implemented of full ground plane also will reduce the radiation effect towards human. CST Microwave Studio Simulation software was carefully chosen due to the comparable results as compared to the measurement as well as the user-friendly features. Among the critical parameters considered when designing the antenna are the operating frequency, gain and input return loss or input reflection coefficient,  $S_{11}$ . The most important aspect of this design is the enhancement of bandwidth. The 5G technology uses spectrum above 6 GHz to 100 GHz and the UWB are declared by at least 500 MHz of bandwidth or at least 50% fractional bandwidth [16]. Thus, this antenna will be operating from 8 to 11 GHz with a bandwidth of 3 GHz. This antenna is three layer antenna, consisting of one layer of substrate and two layers of ShieldIt Super textile conductor as the conductive part. Figure 1 show the detail dimension and the isometric view of UWB slotted Y-shaped antenna with integrated CPW. Table 2 shows the dimension of UWB slotted Y-shaped antenna with integrated CPW.

Table.1. Antenna Design Specifications

Specification	Details
Operating frequency (GHz)	8 – 11
Gain (dB)	> 3 dB
Reflection coefficient ( $S_{11}$ )	< - 10 dB
Substrate	RO4350B
Feeding technique	Thin microstrip line
Efficiency	> 50%

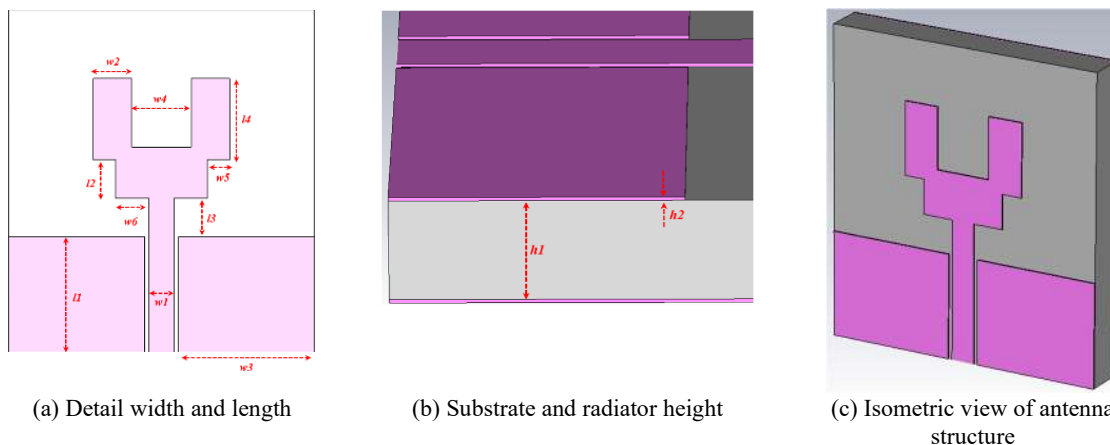


Fig.1. Details Dimension of Y-Shaped Patch antenna design: (a) Detail Width and Length (b) Substrate and Radiator Height (c) Isometric View of Antenna Structure

Table.2. Detail Dimension of Y-Shaped Patch Antenna

$w_1$	$w_2$	$w_3$	$w_4$	$w_5$	$w_6$	$l_1$	$l_2$	$l_3$	$l_4$	$h_1$	$h_2$
3.0mm	4.5mm	16mm	7.0mm	2.6mm	3.9mm	13.5mm	4.5mm	4.5mm	9.5mm	5.0mm	0.17mm

### 3. Results and Discussion

### A. Critical Parameters Assessment

The UWB slotted Y-shaped antenna with integrated CPW antenna was simulated to obtain the desired frequency range. Figure 2 and Table 3 shows the  $S_{11}$  and bandwidth improvement, respectively. The use of RO4350B is to ensure the enhancement of bandwidth, gain and radiation pattern meanwhile the use of felt is to assess the feasibility of textile material in the end applications. Simulation indicates bandwidth of 3.3 GHz for the antenna with RO4350B substrate material as opposed to 0.8 GHz with felt material, which translates to 300 % of bandwidth improvement. As for the  $S_{11}$ , antenna with RO4350B substrate material performs better with more than 10dB of input return loss across the intended frequencies as shown in Figure 2. The same figure also shows that the  $S_{11}$  with both substrate materials achieves the desired range of frequencies which is from 8 GHz to 10 GHz. Since the antenna is the key component of front-end part of WBAN system, thus the important aspect to be considered is the radiation pattern. Therefore, with RO4350B, the performance antenna is expected to be good especially in term of radiation pattern. The wider the bandwidth, more electromagnetics (EM) wave is reflected to the front. This characteristic affects the operating frequencies, gain directive and efficiency of an antenna significantly. The radiation pattern antenna of the antenna at 9 GHz and 10 GHz is presented in Figure 3. Antenna with RO4350B substrate material exhibits good direction compared to antenna with felt substrate material. Table 4 summarize the critical parameters performance for both substrate material. At 8.5 GHz, with increases of 3% from 83 % to nearly 86%. Gain at 8.5 GHz and 10.2 GHz is far superior for RO4350B than felt. Efficiency for antenna with RO4350B substrate material is 30% better than felt substrate material. However, directivity for felt is better at 8.5 GHz as compared to RO4350B.

### B. Bending Evaluations

With the aim to evaluate the antenna operation under bending, the antenna is bent over cylindrical radii of  $r = 40$  mm and  $r = 80$  mm in the x-axis and y-axis, as illustrated in Fig. 4. The simulated  $S_{11}$  for antenna with RO4350B substrate material is shown in Fig. 5. The result shows the resonant frequency shifted to lower frequencies when bent with all radii except for  $r = 80$  mm in x-axis where the resonance point shifted 1 GHz higher, about a maximum of 3.6 % less than the flat condition. As for the bandwidth, bending for all radii in both axes reduces the bandwidth, for example bending with  $r = 80$  mm in x-axis

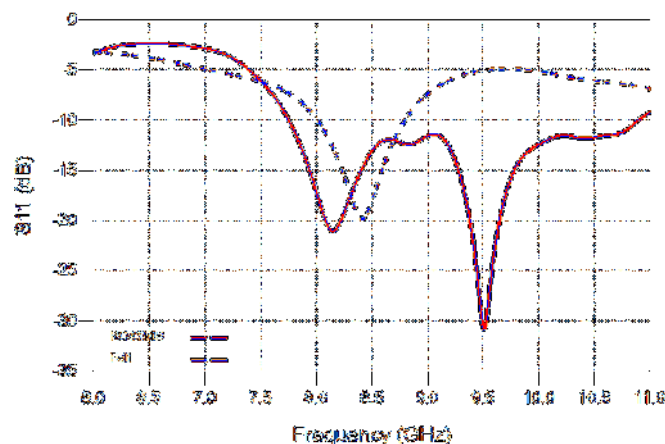


Fig. 2. The  $S_{11}$  of antenna with Rogers 4350B and felt substrate material.

Table.3. Bandwidth for RO4350B and Felt Substrate Material

	RO4350B	Felt
Frequency <-10dB (GHz)	7.7 - 11.0	8.0 – 8.8
Bandwidth (GHz)	3.3	0.8

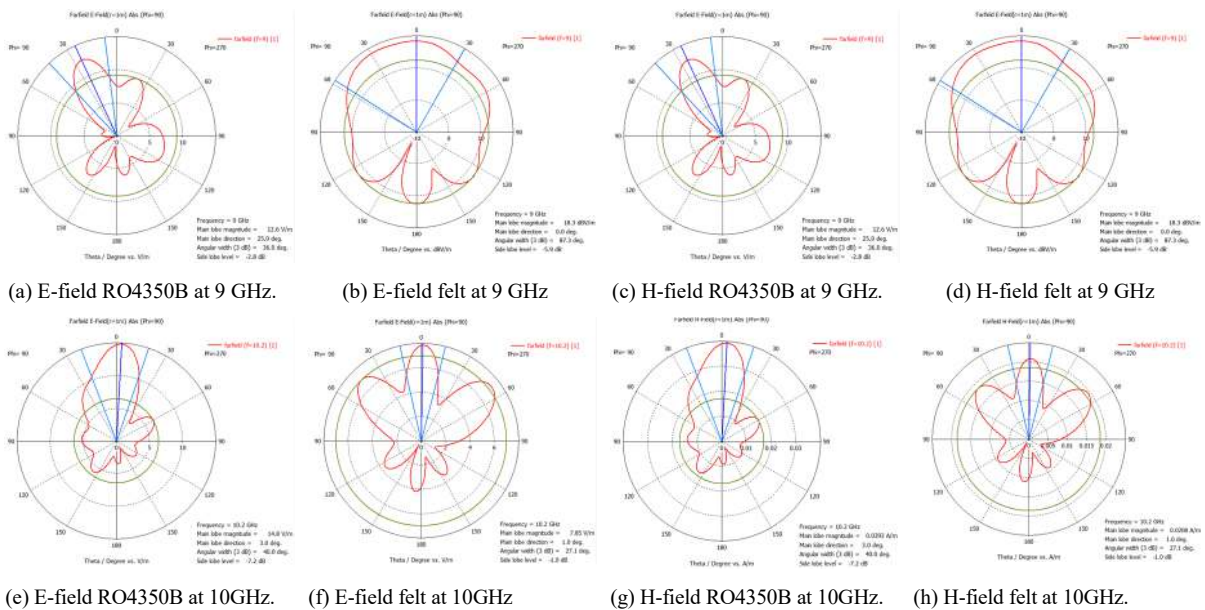


Fig. 3. The far field of antenna with RO4350B and felt substrate material at 9 GHz and 10 GHz.

exhibits 30% smaller bandwidth than the flat condition. As for felt material, bending with  $r = 80$  mm radii shifts the resonance point higher by 1 to 2 GHz, about 16 % less than the flat one. Meanwhile, bending with  $r = 40$  mm radii moves the resonance point lower by 1 GHz, exhibiting a maximum 12% lower resonant frequency in comparison to the flat condition. As for the bandwidth, antenna with felt substrate demonstrated an increased bandwidth under the bending with  $r = 40$  mm radii in  $x$ -axis by widening the bandwidth about 80% but with the expense of poorer  $S_{11}$  and lower resonant frequency.

#### 4. Conclusion

The paper presents the design of a UWB slotted Y-shaped antenna integrated with a CPW feedline. This antenna is designed on two substrate materials, which are RO4350B and felt, and studied in terms of key performance parameters such as range of frequency, gain, directivity, antenna efficiency. The paper has successfully demonstrated that the antenna with RO4350B exhibits four times improved bandwidth and reflection coefficients in comparison to the antenna designed on felt, at the expense of less mechanical flexibility.



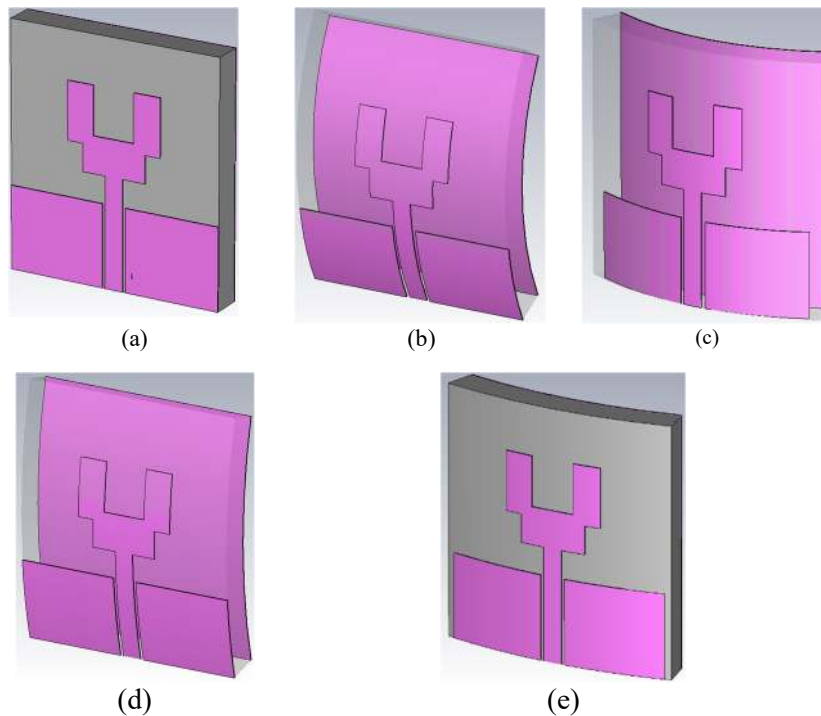


Fig. 4. Bending condition of the proposed antenna: (a) flat (b) at  $x$ -axis with  $r = 40$  mm; (c) at  $y$ -axis with  $r = 40$  mm; (d) at  $x$ -axis with  $r = 80$  mm; (e) at  $y$ -axis with  $r = 80$  mm

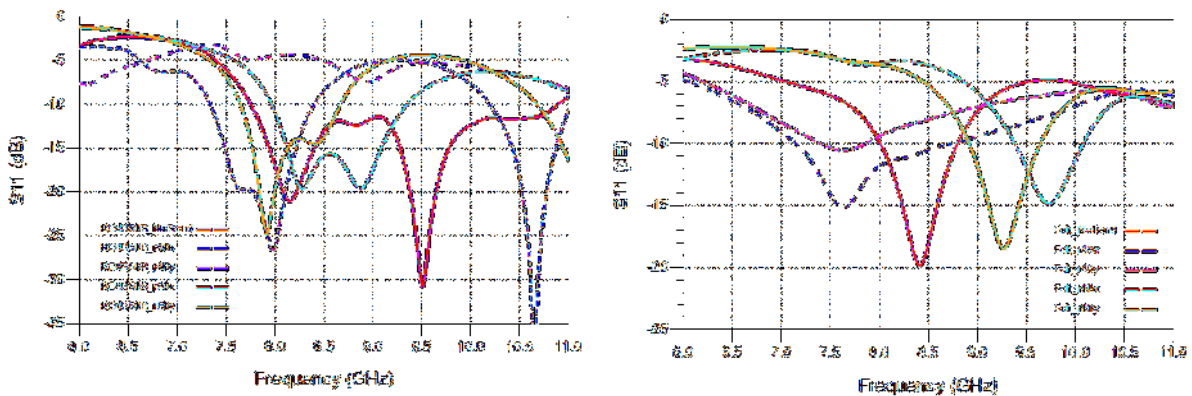


Fig. 5.  $S_{11}$  comparison between flat and bent antenna using (a) RO4350B and (b) felt materials

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