

# Water ageing effect on wearable antenna made of medical-friendly and transdermal material at 2.4 GHz

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**Abstract.** This paper presents the feasibility investigation of a flexible antenna made of medical material as the substrate for medical application. A 2.4 GHz antenna is designed on three different medical-friendly materials: cotton-crepe bandage, artificial cotton patch and semi-transparent silicone patch. Water ageing test is conducted to explore the ability of the proposed flexible substrate materials to cope with the wetness issue. The antenna performance in four conditions (original, fully wet, damp and fully dry) are measured and compared. The water-aged antennas' physical condition are observed and the results show that the flexible antenna made of artificial cotton patch retains its radiation performance. Only a minor shift of approximately 40 MHz of resonant frequency is found for the flexible antenna made of cotton-crepe patch. The work presented here has profound effect on the future development of wearable antenna suitable for health monitoring applications.

**Keywords.** Flexible Antenna, Medical Antenna; Wearable Application; Wetness Test; Medical-friendly Antenna's Substrate; Bowtie Antenna

## 1. Introduction

Flexible antenna for wearable application is aimed at enhancing the quality of human life by providing a comfort during the continuous health monitoring in medical sector. In medical monitoring electroencephalogram (EEG) and electrocardiogram (ECG) are the techniques used for evaluating and recording the bio-signal or electrical activity produced by skeletal muscle, brain and heart. In order to obtain the bio-signal, the measuring devices that consist of sensors are attached to the skin. Conventional measuring devices use rigid electrodes coupled to the skin via electrolyte gels and affixed with adhesive tapes. Thus, to measure the bio-signal for everyday life may be tricky due to inconveniences that cause by bulk wire connection of the electrodes and the reliability of the measurement caused by gel drying. Besides, by using the rigid electrodes, the measurement procedure will be limited only to locate the sensor to the flat region of the body such as forehead or chest. The conventional EEG and ECG electrodes are fabricated on foam material but this material could not be stretched out along with the human skin. In order to overcome the limitation of the traditional measuring devices, a wearable wireless system has currently received great interests among the researchers. In wireless device, an antenna is the main component in the system for transmitting and receiving data. Therefore, an antenna with a high degree of flexibility and stretch-ability is intended, and this paper will provide a platform to achieve the stated characteristics. The current paper focuses on investigating and characterizing several types of flexible dielectric material as the antenna substrate that is suitable for wireless health monitoring purposes. A suitable material for substrate is crucial in order to develop the flexible antenna, and choosing a suitable conducting material is also important to



prevent even a minor crack on the radiating element which may result in performance degradation. The proposed flexible substrate material will be easy to attach to the human skin and does not limit the possible antenna placements. Recent researches have considered various types of material to be used as bendable substrate of the antenna such as different types of textile fabric [1–4], organic paper [5] and also Polydimethylsiloxane (PDMS) [6,7]. These materials however suffer from serious drawbacks such as prone to fluid, and also pattern distortion due to wrinkle and crumpling [2,4]. In addition, the thickness of the substrate material proposed by previous researchers is not suitable to be attached onto the skin for continuous health monitoring purposes. Besides that, most of the papers only focused on the development of flexible antenna, however, limited researches [1,8] are found to address the wetness issue. The performance of the antenna is degraded when immersed in water. Thus, the efficiency of the data transmission will be affected. This paper compares the flexible antenna made of three different medical-friendly materials which are medical bandage (cotton-crepe bandage) and transdermal patch (artificial-cotton patch and semi-transparent film). In addition, the antenna performance is evaluated in four different conditions for water-ageing test.




## 2. Flexible material

The selection of the flexible substrate plays an important role to design a fully flexible antenna especially for medical application. A few characteristics of the flexible materials should be taken into serious consideration such as the material should be robust for a few times of usages and its ability to operate in close proximity to human body. Besides that, a general requirement to achieve a fully flexible and wearable electronic device and antenna are lightweight, widely available, inexpensive material and offer comfortable to wearer. In this paper, three types of flexible materials are used as the antenna's substrate and investigated their ability to replace a dielectric rigid board antenna. Those materials are cotton-crepe bandage, artificial cotton patch and semi-transparent film. To our best knowledge, this is the first attempt using a medical-friendly material as a dielectric substrate for wearable antenna design. The cotton-crepe bandage is a self-adhesive bandage while artificial cotton patch and semi-transparent film are backed with adhesive layer. These features are beneficial when no additional adhesive element is required to paste the antenna onto human body. Besides that, those materials are classified as transdermal patches which commercially and widely available in medical industry. The thickness of the proposed flexible materials is measured using digital micrometre with an accuracy of 0.001 mm. The measured thickness, permittivity,  $\epsilon$  and loss tangent,  $\tan\delta$  of each flexible material are listed in Table 1. Each of the proposed flexible substrate material is chosen considering their ability to be directly attached and offers comfortability to the human body.

## 3. Research Methodology

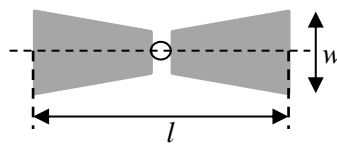
The research presented in this paper starts with the measurement of dielectric properties of each proposed flexible substrate materials. Following that, a conventional bowtie antenna is designed using three types of flexible substrate materials: cotton-crepe bandage, artificial cotton patch and semi-transparent film. The dimension of the bowtie antenna is then optimized based on the measured dielectric properties of those flexible materials. The optimized bowtie antenna is then fabricated and the antenna performance in free space is measured. After that, each of the fabricated flexible bowtie antenna is measured and analysed under wet condition to explore its ability to stand wetness issue.

**Table 1.** Characteristics of the flexible substrate materials.

			
Name	Cotton-crepe bandage	Artificial cotton patch	Semi-transparent film
Thickness	0.338 mm	0.246 mm	0.185 mm
Measured dielectric properties at 2.4 GHz	$\epsilon$ : 1.17 $\tan\delta$ : 0.05	$\epsilon$ : 1.61 $\tan\delta$ : 0.21	$\epsilon$ : 2.23 $\tan\delta$ : 0.14
General description	A self-adhesive bandage with a rough surface	A fluffy cotton surface backed with an adhesive layer	A silicone polymer film with an invisible adhesive layer

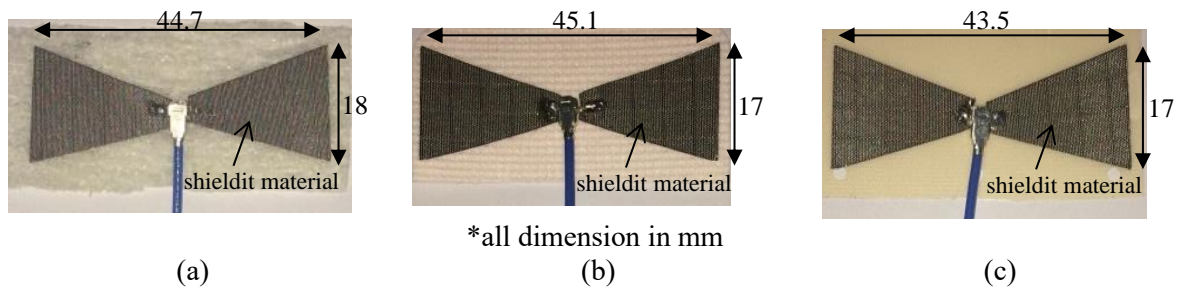
*3.1. Flexible Antenna Design*

In this paper, a conventional bowtie antenna as illustrated in Figure 1 is designed due to its simplicity and offer wider bandwidth compared to the conventional planar dipole. In order to obtain 2.4 GHz bowtie antenna designed on the proposed flexible materials, a few parameters needed to be calculated such as the length,  $l$  and the width,  $w$  of the bowtie antenna. These parameters are calculated based on the equations proposed in [9].



**Figure 1.** Conventional bowtie antenna design.

The bowtie antenna is designed and simulated by means of CST Microwave Studio. Then, the antenna prototypes are fabricated utilizing cotton-crepe bandage, artificial cotton path and semi-transparent film as the dielectric substrates. The fabricated antennas with their optimized dimensions are shown in Figure 2. In this paper, shieldit conducting sheet is used as the conducting materials. Research in [10] compares the antenna performance due to different types of conducting elements. The result shows that fully flexible antenna using shieldit conducting fabric has a strong potential to be used in wearable application. The antenna made of shieldit conducting fabric able to resonate in various tested condition such as when the antenna is immersed inside the water and after completely dried [3]. Shieldit conducting material used in this research is made of nickel on cooper-plates polyester fabric tape backed with a conductive acrylic layer. This conducting material has a thickness of 0.11 mm, electrical resistance of  $0.05 \Omega$  and a conductivity of 20 S/m.



**Figure 2.** Fabricated flexible bowtie antenna using shieldit conduction material placed above three different flexible substrate (a) cotton-crepe bandage, (b) artificial-cotton patch and (c) semi-transparent film.

### 3.2. Water-Ageing Test

The water aging test is performed to investigate the ability of the fabricated antenna using the proposed flexible substrate materials to withstand the wetness issue. The antenna performance and the physical characteristics of each fabricated antenna for four different conditions are measured and monitored in four different conditions as listed in Table 2. This test is considered based on practical situation where the person who wears the antenna is going through medical monitoring for a long period of time. The wearer will need to directly contact with water especially during the bath time.

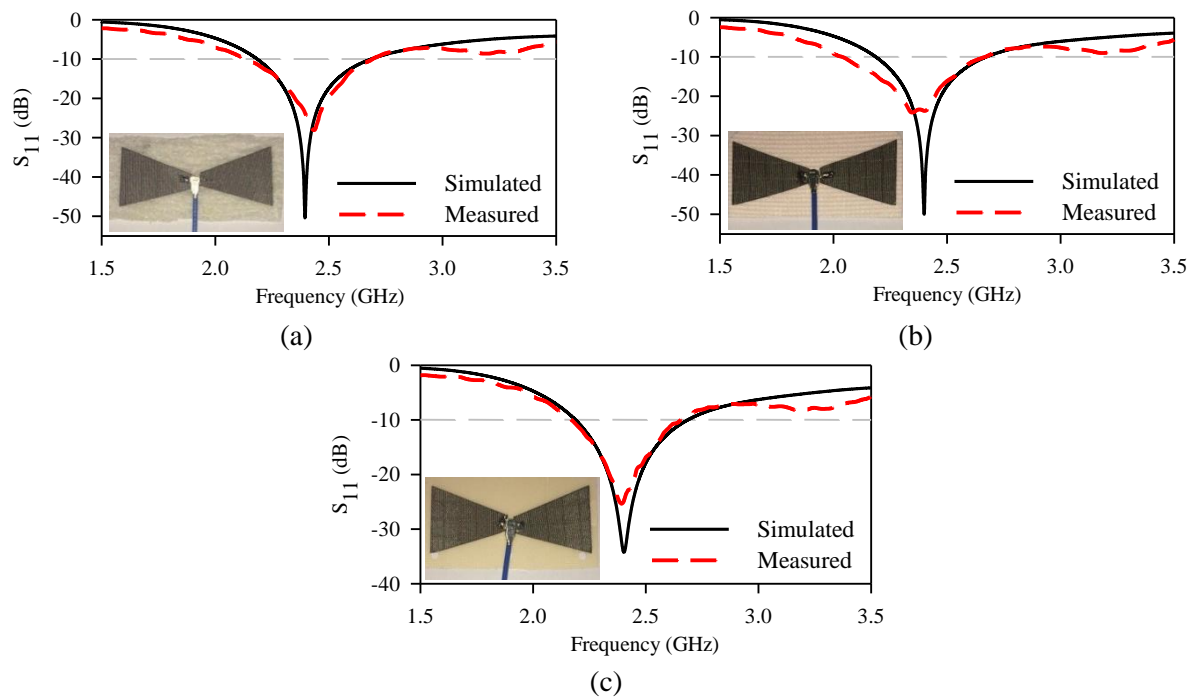
**Table 2.** Antenna's condition measured during the water ageing test

Antenna's condition	Description
Original	The antenna performance is measured before the fabricated antenna is immersed in the water
Wet	The antenna is immersed inside the water for 12 hours. The antenna performance is immediately measured after taken out from the water tank
Damp	The antenna performance is measured after the antenna is left in room temperature for 1 hour after taken out from the water tank
Fully dried	The antenna performance is measured when the antenna is fully dried

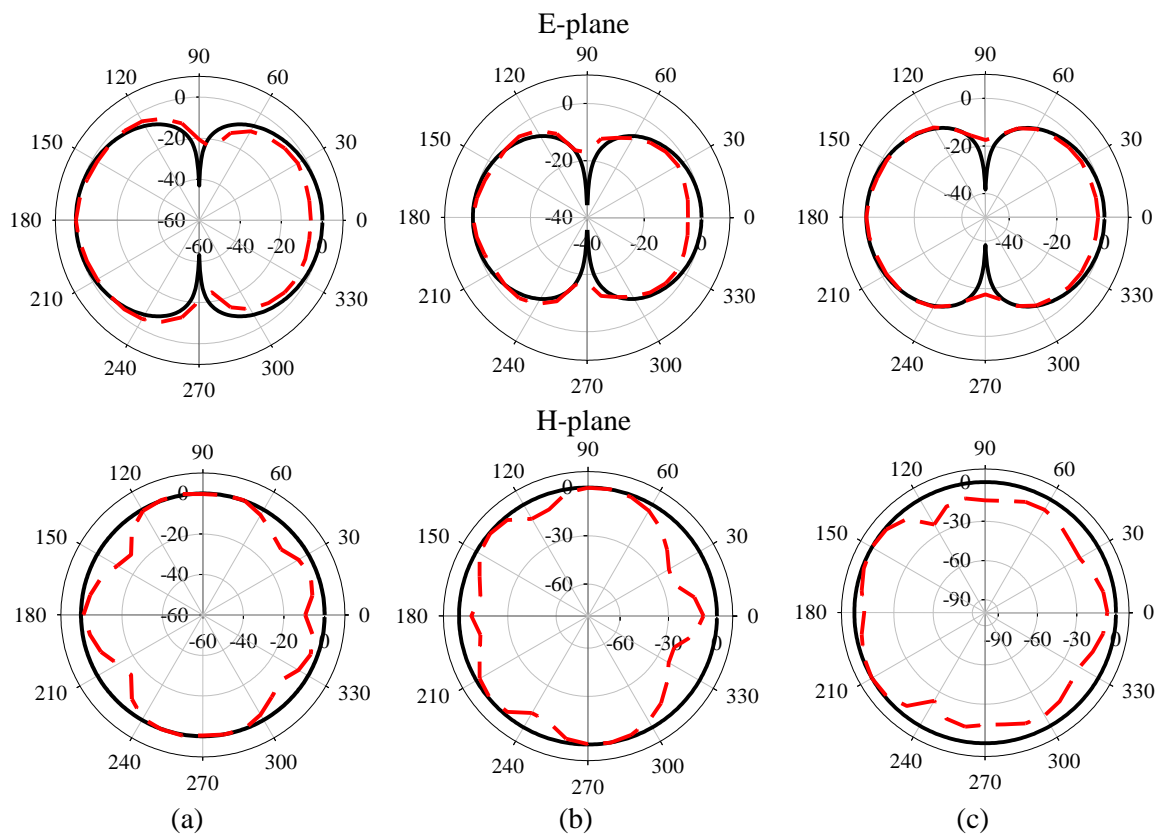
## 4. Results and Discussions

### 4.1. Antenna Performance in Free Space

Figure 3 compares the simulated and measured  $S_{11}$  for the bowtie antenna fabricated using three different substrate materials. The black solid line shows the simulated  $S_{11}$  while the dashed red line represents the measured  $S_{11}$ . Although there are some deviations on the measured  $S_{11}$  for the three types of substrate materials, the fabricated prototypes are able to operate at 2.4 GHz with a return loss below than 10 dB. Besides that, Figure 3 exhibits that simulated and measured  $S_{11}$  for all prototype antennas' are comparable and those flexible materials are suitable to be used as the antenna's substrate.



**Figure 3.** Simulated and measured  $S_{11}$  of bowtie antenna utilizing (a) cotton-crepe bandage, (b) artificial cotton patch and (c) semi-transparent film as the dielectric substrate.



**Figure 4.** Simulated and measured co-polar radiation pattern of bowtie antenna fabricated using (a) cotton-crepe bandage, (b) artificial cotton patch and (c) semi-transparent film in E-plane and H-plane

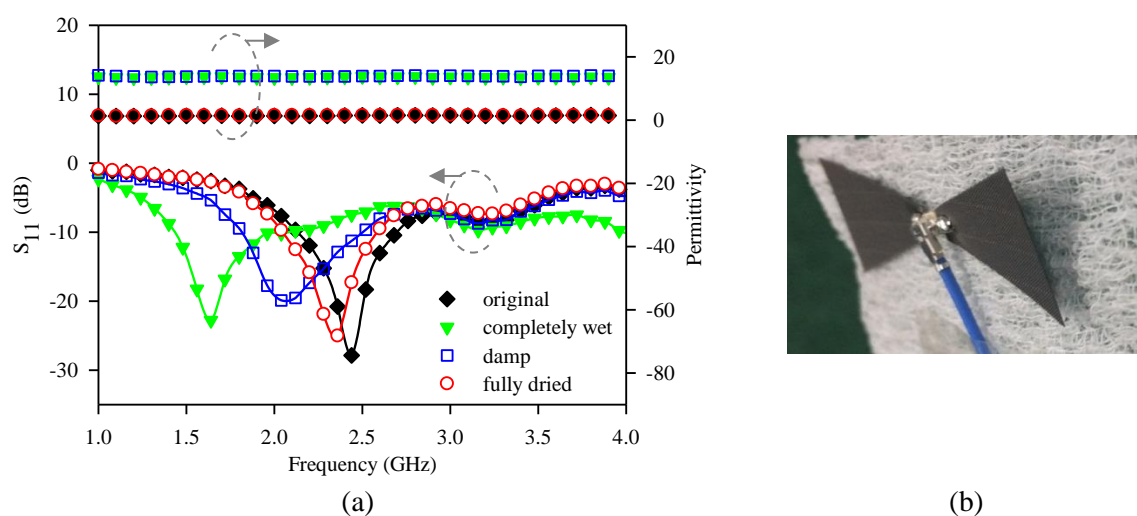
The simulated and measured co-polar radiation pattern both in E-plane and H-plane for antenna's fabricated using three different substrate materials are shown in Figure 4. From Figure 4, it is found that the bowtie antenna has an omni-directional pattern in the H-plane at 2.4 GHz while similar to figure eight shape in E-plane. Good agreement between simulated and measured is obtained for E-plane and H-plane pattern. The difference between the simulated and measured results are expected due to the dissimilarity between the simulation and fabricated prototype. Besides that, the slight difference between the simulated and measured is also expected due to the misalignment during the measurement.

#### 4.2. Water-Aged Antenna

In this section, the effect of water on antenna performance is presented. The  $S_{11}$  is firstly measured in free space before the flexible antenna being soaked in the water. Then, the  $S_{11}$  of bowtie antenna is measured when the antenna is in completely wet condition after being immersed in the water and also when the antenna is damp and after fully dried. Besides that, the permittivity of the cotton-crepe bandage, artificial-cotton patch and semi-transparent film are also measured in those conditions.

##### 4.2.1. Cotton-crepe bandage

Figure 5(a) shows the measured  $S_{11}$  in original (free space), completely wet, damp and fully dry condition. It is observed that the resonant frequency is shifted to the lower when the antenna is in completely wet condition. The wet antenna resonates at 1.62 GHz with return loss depth of -22.85 dB while the damp antenna resonates at 2.06 GHz with a return loss of -21.47 dB. This is expected due to the dielectric properties variation of the flexible substrate material when fully soaked in water. High permittivity of water absorbed by the dielectric substrate contributes to the changes of permittivity. The measured permittivity of wet substrate plotted in Figure 5(a) too. Furthermore, the resonant frequency is shifted back to its original after fully dried. Only a minor variation of resonant frequency is observed between the fully dried antenna and original antenna. The measured permittivity of substrate in fully dried condition is almost similar to original condition. Thus the resonant frequency shifted back to higher frequency which is almost similar to original frequency. Then, the physical condition of bowtie antenna using cotton-crepe bandage after fully dried is observed and shown in Figure 5(b). It is observed that the conducting element is detached from the cotton-crepe bandage substrate. The water-aged bowtie antenna using cotton-crepe bandage is likely to be irrelevant material to be used as the antenna's substrate.

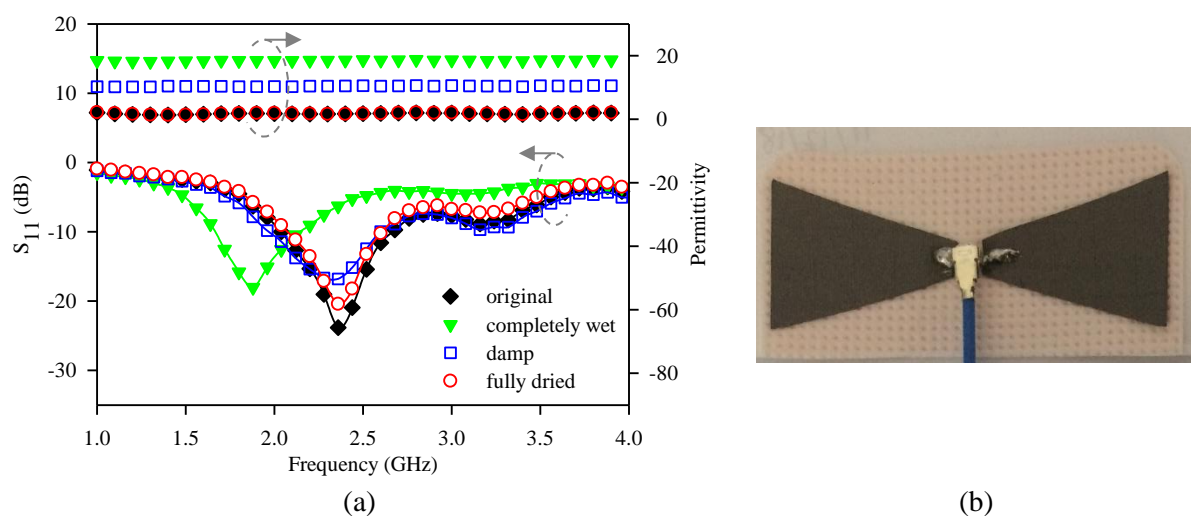


**Figure 5.** (a) Measured  $S_{11}$  and permittivity of bowtie antenna using flexible cotton-crepe bandage as the substrate in original, completely wet, damp and dry condition and (b) post water-aged antenna



#### 4.2.2. Artificial-cotton patch

Figure 6(a) shows the measured return loss for water aging test. Similar to the antenna fabricated using cotton-crepe bandage, the operating frequency of antenna (using artificial-cotton patch) is shifted to the lower frequency due to the high dielectric properties of water that has been absorbed by the flexible substrate. The measured permittivity and loss tangent of artificial cotton patch in original, wet, and fully dried condition is shown in Figure 6(a) too. It can be seen that the permittivity of artificial cotton patch in wet condition is higher than in original condition. The difference in permittivity contributes to the frequency shifts. Following that, the physical condition of bowtie antenna using artificial cotton patch after water aging test is inspected. Figure 6(b) shows the fully dried bowtie antenna using artificial cotton patch after being immersed in the water. It is observed that the post water aged bowtie antenna using artificial cotton patch is still in good condition. The conducting element is strongly adhered to the artificial cotton patch.



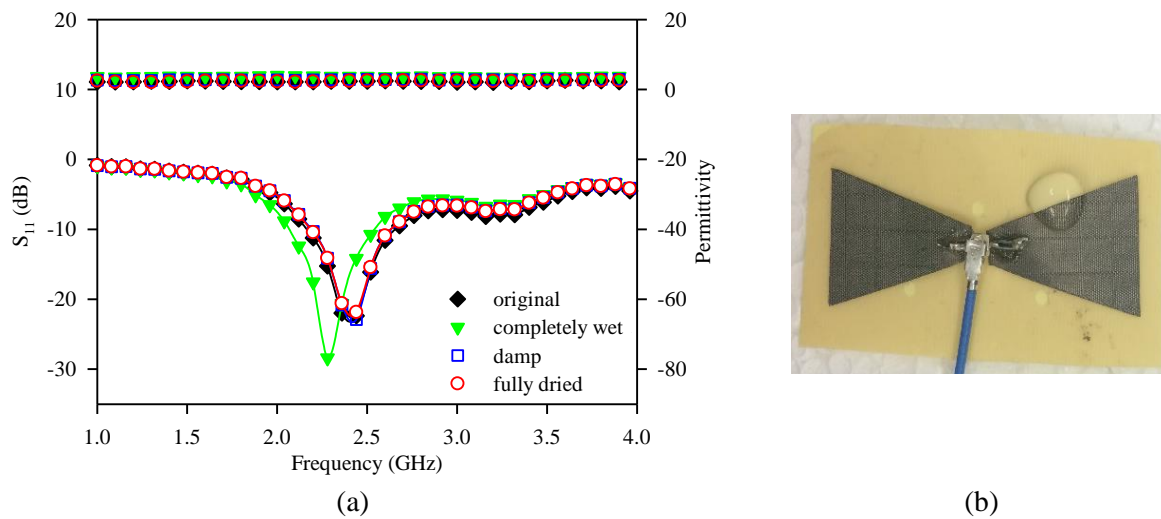
**Figure 6.** (a) Measured  $S_{11}$  and permittivity of bowtie antenna using flexible artificial-cotton patch as the substrate in original, completely wet, damp and dry condition and (b) post water-aged antenna

#### 4.2.3. Semi-transparent film

Figure 7(a) shows the measured  $S_{11}$  of bowtie antenna using semi-transparent film as the substrate. It is observed that, the antenna made of semi-transparent film maintains its performance in all tested conditions. Only a minor shift of approximately 300 MHz in resonant frequency is found when the antenna is measured in completely wet condition and still operating at 2.4 GHz with a return loss below than 10 dB. Besides that, the measured permittivity in original, completely wet, damp and fully dried condition shows a negligible different in all tested conditions. Based on Figure 7(b), it is shown that the semi-transparent film is a waterproof type of material and do not absorb water thus good impedance matching is preserved even in completely wet condition.

### 5. Conclusion

This paper presents the effect of water on antenna performance made of three different medical-friendly materials as the substrate. The results presented in this paper show that medical-friendly flexible material has a strong potential to be used as the antenna's substrate in order to develop a fully flexible antenna especially for medical application. Based on the results presented in this paper, the flexible antenna made of artificial cotton patch and semi-transparent antenna are considered to satisfy the requirement for wearable application which is able to stand the wetness issue while providing a comfort to the wearer. The presented results clearly indicated that artificial-cotton patch and semi-transparent film performed as a good candidate and suitable to replace rigid board antenna substrate. In contrast, cotton-crepe bandage is found to be unsuitable candidate as antenna substrate. However, evaluation of the system performance after repeated usages and long-term behaviour should also be taken into consideration while designing a wearable antenna.



**Figure 7.** (a) Measured  $S_{11}$  and permittivity of bowtie antenna using flexible semi-transparent film as the substrate in original, completely wet, damp and dry condition and (b) post water-aged antenna

## 6. References

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