Jurnal
Teknologi

Full Paper

TEXTILE DIPOLE ANTENNA FOR WEARABLE APPLICATION

Article history
Received
1 June 2014
Received in revised form
20 April 2015
Accepted
1 October 2015

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Graphical abstract

Abstract

The idea of wearable electronic system has triggered a vast research on the capability of implementing the system on daily garment. As a wearable system, the human body friction should be taken into account. Antenna is one of the main structure in wearable communication system. This paper presents a study on a textile dipole antenna with two different conducting materials. The conducting materials are Shieldit fabric and copper fabric while the substrate is denim. The denim has a dielectric constant of 1.67 with 0.85 mm thickness and loss tangent of 0.019. The antenna resonates at Industrial, Scientific, and Medical (ISM) band which is at 2.45 GHz. Antenna performances are observed in terms of reflection coefficient, bandwidth, and radiation pattern. Three different investigations are analysed: antenna measurement with two different bending sizes, under wet conditions and on-body conditions. The bending and wetness effect of the textile antenna are also investigated. No significant changes to the antenna performance under the bending condition. The antenna cannot operate in wet condition at desired frequency. In addition, on-body measurement is done to investigate the antenna properties in wearable system. A suitable placement of the antenna on the human body has been discovered between the front and back of the body and the arm.

Keywords: Textile dipole antenna, ISM band, bending effect, bandwidth, radiation pattern, on-body measurement

Abstrak

Idea sistem elektronik yang boleh dipakai telah mencetuskan penyelidikan yang luas kepada keupayaan melaksanakan sistem pada kain. Sebagai sistem boleh dipakai, geseran badan manusia perlu diambil kira. Antena adalah salah satu daripada struktur utama dalam sistem komunikasi boleh dipakai. Kertas kerja ini membentangkan kajian mengenai antena tekstil dwikutub dengan dua bahan penjalanan berbeza. Bahan-bahan yang menjalankan adalah kain Shieldit dan kain tembaga manakala substrat adalah denim. Denim yang mempunyai pemalar dielektrik 1.67 dengan ketebalan 0.85 mm dan kehilangan tangen 0,019. Antena bergema di industri, saintifik dan perubatan (ISM) band iaitu pada 2.45 GHz. Prestasi antena duji dari segi pekali pantulan, jalur lebar, dan corak radiasi. Tiga siasatan yang berbeza dianalisis: ukuran antena dengan dua saiz lenturan yang berbeza, dalam keadaan basah dan atas badan. Lenturan dan kebasahan kesan antena tekstil juga disiasat. Tiada perubahan yang ketara kepada prestasi antena di bawah keadaan lenturan. Antena tidak boleh beroperasi dalam keadaan basah pada frekuensi yang dikehendaki. Di samping itu, pengukuran atas badan dilakukan untuk mengkaji ciri-ciri antena dalam sistem boleh dipakai. Penempatan sesuai antena pada tubuh manusia telah ditemui antara depan, belakang badan dan lengan.

Kata kunci: Antena dwikutub, ISM band, corak radiasi, jalur lebar, pemalar dieletrik

1.0 INTRODUCTION

In recent years, the invention of textile antenna for wearable application has attracted a lot of researchers. The rapid development of wireless communication standard, including wireless local area network (WLAN), ultra-wideband (UWB) and ZigBee in recent years has contributed to the convergence of wireless and wired network [1]. The other short range communications used in wearable application includes WiFi and Bluetooth system. In wearable communication system, antenna acts as a transmitter and also as a receiver. The best characteristics in designing wearable antenna are flexible, light-weight, robustness and comfortable to wear [2]. Therefore, the antenna made of a textile or fabric is the best choice for wearable applications. The integration between electronics with textile material indicates a new era for the attire industry. The on-body communication requires the development of suitable antennas that combine flexibility with robustness and reliability [3].

Wearable wireless communication systems have become well-known topic in the past few years. Numerous papers have been published and discussed about the design, fabrication and the applications [4]. A dual band wearable antenna has been discussed in details in [5-7]. Meanwhile, the investigation of using substrate fabric materials for antenna design is studied in [8-10]. Furthermore, electro-textile microstrip patch antenna were designed and reported in [11]. The effect of antenna bending on the performance characteristic of wearable antennas is investigated in [12-14].

Three main parameters are considered in determining the antenna's substrate. They are electromagnetic properties, permittivity and loss tangent. Various textile materials such as flannel, felt, and cotton have been used in designing the antenna [5-8]. Those materials have low permittivity in between 1.05 and 1.9 while the loss tangent is between 0.0001 and 0.025 [5]. Besides, the material with high conductivity, flexible and homogenous sheet resistances are essential as the conducting element for the wearable antenna. A few materials have been used as the conducting elements such as copper foil tape, Zelt fabric, Pure Copper Taffeta fabric and Shield It fabric [5-8].

Fabric is a flexible material. The properties of fabric material such as bendable, crumpling and washable have to be taken into consideration to ensure the good performance of the antenna. Under on-body environment, it is difficult to keep the fabric material in a flat condition [8]. From the previous researches, the performance of the antenna in terms of return loss, efficiency, resonant frequency and bandwidth had degraded when the antenna is placed on the human body. The resonant frequency of the antenna had changed drastically when the antenna is in hyper bending condition [12]. The wet antenna that has been produced shifted the resonant frequency theoretically due to high dielectric constant of water. However, low moisturizes material is able to minimize the wet condition effect[15]. Therefore, since the antenna is purely made of fabric, this research is to investigate the antenna's performance under bending, wetness condition and on-body movement.

In this paper, two fully textile dipole antennas at ISM band are presented. The antennas feature an average of 10 dB bandwidth (330MHz) in both flat and bending conditions. For flexible antennas, textile materials are used as substrates because of it can be integrated with clothes. Comprehensive analyses of the antenna performance with different bending, wetness condition and on-body environment are investigated and presented in this paper.

2.0 ANTENNA DESIGN

The antennas are design on a denim substrate with a thickness of 0.85 mm, permittivity of 1.67 and tangential loss of 0.019 [4]. Figure 1 shows the geometry of the prototype antennas. The conducting material in Figure 1(a) is Shield It Super fabric while the conducting material in Figure 1(b) is pure copper fabric. Table 1 summarizes the characteristic of two conducting material which are Shield It Super and purely copper fabric. These two materials are characterized in terms of surface resistivity, thickness and adhesive as reported in datasheet.

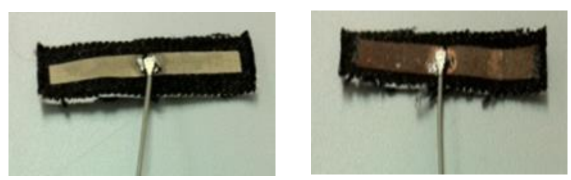

Figure 1 Snapshot of the Proposed Antenna (a) Shieldit antenna (b) Purely copper fabric antenna

Theoretically, dipole antenna consists of two quarter-wavelength arm conductors. The total length is given by L = λ/2 [17]. The length, *l* and width, *w* of dipole antenna is 26.5mm and 6.5mm respectively. In this work, no balun is considered because the feed is matched to 50 ohm. The balun is only needed to prevent radiation from the third arm which is the inner conductor of the coaxial. Ultra small surface mount coaxial connector is used to replace the SMA port. This is to ensure the flexibility of the antenna. The connector has two parts which is shown in Figure 2. This connector area is 7.7mm^2 with maximum 2.5 mm height. It is light weight with the plugs terminated with ultra-fine coaxial cable.

Table 1 Comparison between Shield It Super fabric and purely copper fabric

Properties	Shield It Super	Purely Copper Fabric
Materials	Conductive nickel and copper plated	Copper
Surface resistivity(Ohm/sq)	<0.5	<0.05
Thickness(mm)	230	0.08
Weight (g/m^2)	0.17	80
Adhesive	Yes	No

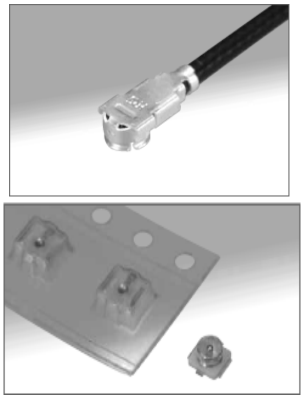

Figure 2 (a) Cable Assembly (plug), (b) receptacle

Firstly, the conducting material is cut using a cutter while the substrate is cut using a pair of scissors. Then, the conducting materials are attached with the denim substrate. The Shieldit fabric has self-adhesive at the back and thus makes it easy to attach with the denim compared to the purely copper fabric. The purely copper fabric need to be glued using special glue which have $\varepsilon_r = 1$. To strengthen the attachment of the fabrics, the prototypes are steamed using a steamer. Finally, ultra-small SMA port is soldered to the prototype.

3.0 RESULTS AND DISCUSSION

3.1 Bending Effect

Two different radius of cylinder foams are used to investigate the bending effect. These cylinder foams ($\varepsilon_r = 1$) are in two different sizes representing the human arm which are small and medium sizes. The small cylinder is set to 3.5cm radius, while the medium size cylinder is set to 7.0 cm in radius. Position of the antennas on the cylindrical foams is shown in Figure 3.

Figure 3 3.5cm and 7.0cm radius of Cylindrical Foams

Figure 4 shows the comparison for bending effect between copper fabric antennas and Shieldit fabric antenna. Antenna performance in terms of reflection coefficient at 2.45GHz and bandwidth are investigated under the different bending sizes, as shown in Figure 4. Both straight and bent antennas are compared to each other in terms of reflection coefficient and bandwidth and the results are shown in Table 2. From the table, it shows that the performance of the antennas is not affected either in bent condition or straight condition. However, when the antenna is bent towards the smaller size, the reflection coefficient of purely copper fabric antenna increases. The percentage differentiation of the bandwidth of the antenna between straight and bent condition is only about 4% for purely cooper fabric antenna and 7.5% for Shieldit fabric antenna.

The measured radiation patterns at different size of bending and conducting material are shown in Figures 5 and 6. Figures 5 and 6 show the radiation patterns for all conditions considered in this study. The characteristic of E-plane and H-plane for both fabrics with and without bending are the same with standard planar dipole antenna. The antennas produce omni-directional radiation pattern at straight and bent condition. The insignificant discrepancy proved that the antennas are less affected by the bending size.

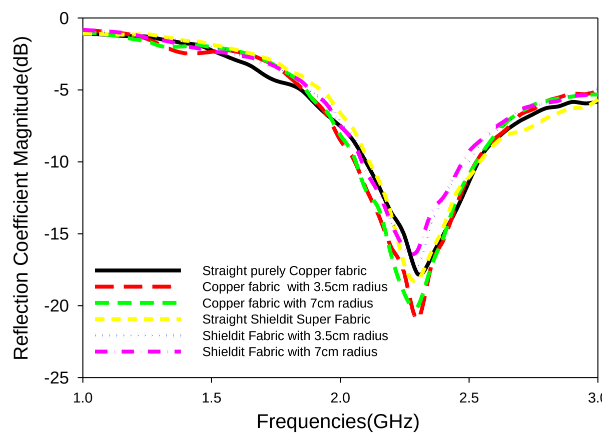

Figure 4 Comparison of Bending Affect for Both Fabrics Measurement

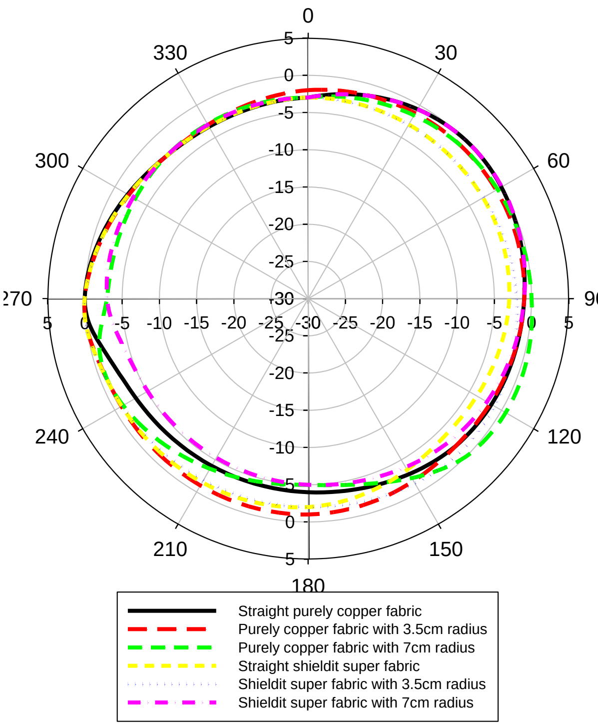

Figure 5 H-Plane

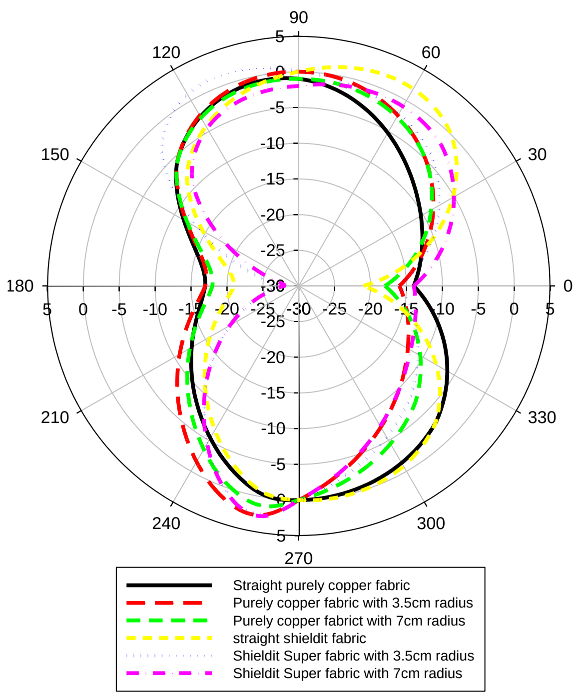

Figure 6 E-Plane

Table 2 Bending effect results for both antennas

Types of Antenna Fabrics	Reflection Coefficient(S_{11})	Bandwidth(MHz)
Straight Copper Sheet	17.90	430
Copper Sheet with 3.5cm radius	21.58	470
Copper Sheet with 7cm radius	20.34	470
Straight Shield It fabric	19.00	430
Shield It fabric with 3.5cm radius	17.10	370
Shield It fabric with 7cm radius	16.30	390

3.2 Wetness Effect

The investigation is continued by measuring five different weight of the antenna to represent the wetness properties. Initially, the return loss of the dry antenna is measured as the reference value of the antenna. Both antennas are measured in the small room with standard room temperature. Then, the antenna is soaked into the water and the weight is recorded using calibrated digital scale as shown in Figure 7. The antenna is dried under the sunlight to have variable weight of the antenna. The return loss of the antenna is collected continuously until the antenna is fully dried (initial weight). These steps are repeated for both antennas

Figure 7 Snapshot of Antenna's Weightiness

Figures 8 and 9 show the reflection coefficient $|S_{11}|$ responses at different percentage of wetness level for copper fabric and Shield it fabric, respectively. Zero percentage of water level means the textile antenna is fully dried while hundred percentages of water levels means the textile antenna is completely in wet condition. Both graphs show that the reflection coefficients in dB of the antennas are proportional to the wetness level percentage. In other words, the reflection coefficient of the antennas are shifted to the left with the increasing volume of water in the antennas. The presence of water changes the properties of the substrate. The water changes the permittivity of the substrate to a higher value and caused the minimum reflection coefficient shifted to the lower frequencies. It can be concluded that both antennas cannot operate well in wet condition

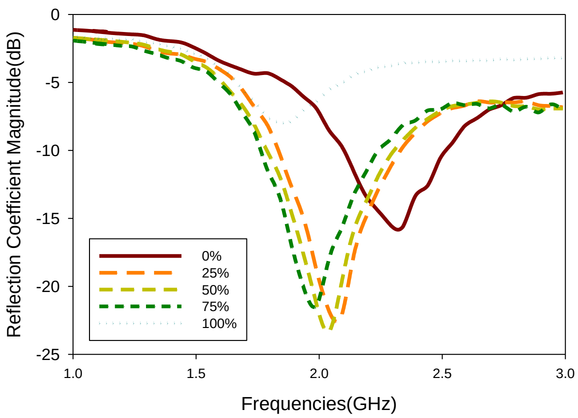

Figure 8 Percentage Water Level of Copper Fabric Antenna Measurement

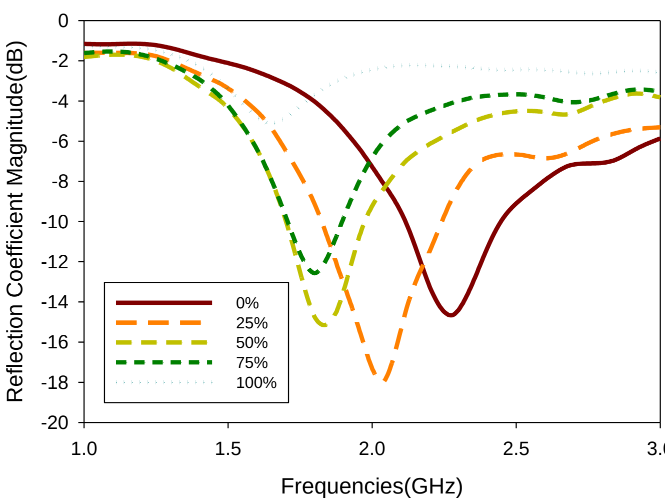

Figure 9 Percentage Water Level of Shield It Antenna Measurement

3.2 On body Measurement

Three different locations on the human body are chosen to investigate the effect of reflection coefficient of the antenna towards the human body. The antenna is placed horizontally and attached on a shirt worn on the body. The appropriate placement of the antenna is investigated to get the location with minimum shifting in terms of return loss. A man with 160cm height and 70kg of weight is used as a model for the experiment. Figure 10 shows the antenna locations for on-body measurement which are at the back of the body, the front of the body and upper arm.

a) body-back b) body-front c) upper

Figure 10 Locations of the Antenna on the human body measurement

Figure 11 and 12 show the reflection coefficient results of on-body measurement for both fabrics. The resonant frequency responses changed at different locations for both fabrics. Table 3 presents the comparison of the bandwidth and resonant frequency for both antennas. Because of on body coupling effect, the reflection coefficient of both antennas at the front body have shifted between -0.05 till -0.11 GHz. However, the resonant frequency of both antennas at the back of body is less shifted between -0.03 till 0.04 GHz. Moreover, the bandwidth of both antennas at back of body achieves wider bandwidth. From Table 3, the back of the body is the most suitable position to put the dipole antenna. The performance of the antenna is greatly influenced by the specific absorption and electromagnetic coupling by the human body [21]. Wider bandwidth and less resonant frequency changes are achieved compared to the other position. When the dipole antennas are put on the human arm, the resonant frequency is shifted to the higher frequency. This is because; each part of human body has different permittivity and conductivity which influences the antennas performance [20-24].

These results follows the previous work in [25] in terms of resonant frequency. The resonant frequency is less shifted when the antenna is put at the back-body compared to the front-body [25]. This comparison is shown in Table 4.

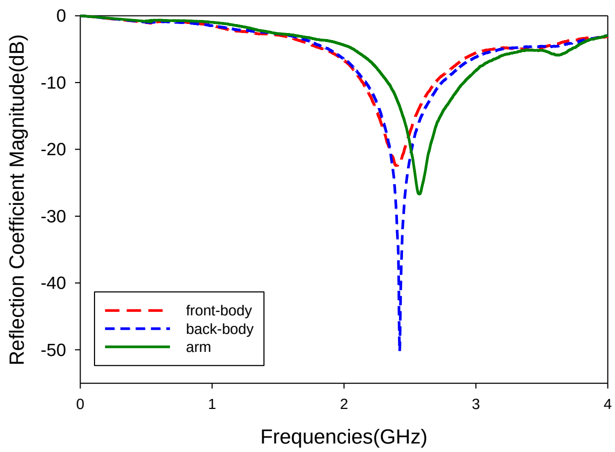

Figure 11 Copper Fabric antenna On-Body Measurement

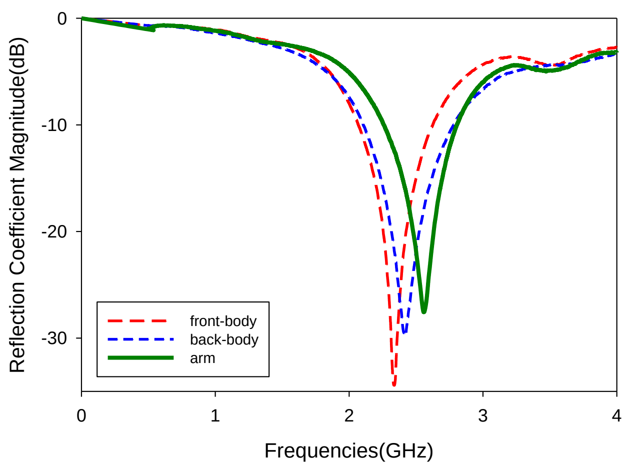

Figure 12 Shield It Fabric antenna On-Body Measurement

Table 3 Comparison of resonant frequency and bandwidth for both fabrics

Location	Antenna	Resonant Frequency (GHz)	Bandwidth (MHz)
Front-body	Copper Fabric	2.4	550
	Shield It Fabric	2.34	550
Back-body	Copper Fabric	2.41	570
	Shield It Fabric	2.42	680
Arm	Copper Fabric	2.56	570
	Shield It Fabric	2.55	540

Table 4 Comparison of resonant frequency with previous work [24]

Location	Antenna	Resonant Frequency (GHz)	Bandwidth (MHz)
Front-body	Copper Fabric	2.4	550
	Shield It Fabric	2.34	550
	Fractal Koch Multiband Antenna	2.56	120
Back-body	Copper Fabric	2.41	570
	Shield It Fabric	2.42	680
	Fractal Koch Multiband Antenna	2.48	110

4.0 CONCLUSION

Two textile dipole antennas have been measured and compared. The robustness of the antenna characteristics with respect to bending is investigated. Both antennas can radiate successfully in straight and bent condition and produce omni-directional pattern. It has been demonstrated that both antennas only radiate in dry condition. The resonance frequency is shifted to the lower frequency which is 1.5 GHz when the antenna is in wet condition The results for both conducting fabric are not much different. The best position of on body antenna placement is at the back of human body because of less resonant frequency shifting. The resonance frequency is shifted between 2.4 and 2.56 for front body and arm.

Acknowledgement

The authors thank the Ministry of Higher Education (MOHE) for supporting the research work, Research Management Centre (RMC), School of Postgraduate (SPS) and Communication Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) for the support of the research under grant no 05J64, 04H38 and R.J130000.7823.4L811

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