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Conducting Materials Effect on UWB Wearable Textile Antenna

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***Abstract*—The wearable electronic devices are such devices worn by a person as un-obstructively as clothing to provide intelligent assistance. A wearable antenna is meant to be a part of the clothing used for communication purposes such as tracking, navigation, mobile computing and public safety. Ultra-wideband (UWB) is an emerging technology that promises high-speed data transmission at low cost for short-range communications. In this paper, textile wearable antennas working in the dedicated Ultra-Wideband (UWB) frequency range UWB are fabricated and presented. Flannel fabric has been used as the substrate of the designed antennas, while the radiating element and ground plane are made from several types of conducting materials. Simulated and measured results in terms of return loss, bandwidth, radiation pattern, current distribution as well as gain and efficiency are presented to validate the usefulness of the proposed design.**

***Index Terms*—conducting materials; flexible fabric antennas; textile substrate materials; Ultra Wide-Band antennas; wearable devices**

I. Introduction

THE evolution of antenna technology for man-machine interface has taken quantum leaps in utilizing textile materials as antenna substrates. In that sense, textile materials form interesting substrates hence fabric antennas can be easily integrated into clothes. [1-2]. In addition, electrically conducting materials are required for the ground plane as well as for the antenna patches In order to build the communication system. Therefore, by embedding antennas and interconnections in garments, a wearer- friendly standalone suit can be obtained.

On the other hand, The commercial use of frequency bands from 3.1 to 10.6 GHz was approved for ultra-wideband (UWB) systems by the Federal Communications Commission (FCC) in 2002 [3]. By merging the UWB technology with textile technology, UWB antennas using 100% clothing materials and suitable for wearable application are fabricated and presented in this paper. Unlike previous designs of textile antennas, the present antenna design is able to meet the requirements of wearable electronic devices such as being robust, consume a small amount of power, comfortable to wear with flexible materials and compact size antenna prototype. In addition, the current manuscript materials used can guarantees washing of the wearable device and accordingly reuse of it. Measured results of the presented antennas are compared with simulations and good agreement is observed. .

II. System On Textile

Ultra-Wideband (UWB) antennas seem most suitable for integration into clothing. These antennas consist of a metallic patch on top of a dielectric substrate that is mounted onto a conducting ground plane. According to that, these types of antennas when integrated into clothing will have a compact geometry, light weight, low cost, soft and comfortable to the wearer. Moreover, UWB antennas are often used for mobile communication equipment since they can readily be incorporated with other electronic circuits. Additionally, in low or medium data-rate applications, like wearable computing, UWB antenna offers low-power operation and extremely low radiated power, thus being very attractive for body-worn battery-operated devices. However, several wearable antennas aspects contribute in the overall design features of the antennas such as the avoidance of elastic fabrics, taking into account wetness aspects and considering bending conditions of the wearable system. Moreover, designers need to ensure that the wearable telecommunication devices operate properly in the vicinity of human body. Since UWB antennas provide a kind of Omni-directional radiation pattern component, special attention must be paid to the Specific Absorption Rate (SAR) in order to avoid harm to human body.

Since 1997, wearable telecommunication systems have become popular topics in research institutions. Several antennas have been developed for wearable antennas in the form of flexible metal patches on textile substrates [4-7]. Numerous papers have been published about the design, fabrication and applications of wearable antennas and systems [6, 7]. On the other hand, Wideband and Ultra-Wideband antennas using rigid substrate materials were reported with detailed discussions in [8, 9]. In this paper, UWB fully textile wearable antenna has been designed and analyzed. The substrate of the designed antennas was made from flannel fabric. However, most of previous textile antennas research introduced materials that were not

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possible to allow washing and reusing of the wearable suite. Thus, our new antennas are made entirely from textile materials along with new features provided by being easily and directly integrated into clothing, guarantees washing of the wearable device and accordingly reuse of it.

A. Substrate Fabric Materials

In this work, our study focuses on using flannel fabric as substrate material. Flannel fabric is made from 100% cotton materials with a smooth and firm surface and suitable for wearable applications. The thickness of the mentioned fabric is approximately 1 mm. On the other hand, electrical performance evaluations must be performed before the implantation of any kind of substrate material. Therefore, it is important to know the relative permittivity of the fabric in order to characterize the effect of textile materials accurately. The measured relative permittivity of flannel fabrics at several frequencies using the free space method was about 1.7 and the tangent loss about 0.025.

B. Conducting Materials

In order to build the communication system, an electrically conducting material is required for the ground plane as well as for the antenna patches. However, for the purposes of textile antenna designs, a conducting material needs to satisfy several requirements such as having a low and stable electrical resistance (1 ohm/square) in order to minimize losses. The material must be homogeneous over the antenna area, and the variance of the resistance through the material should be small. In addition, the material should be flexible such that the antenna can be deformed when worn. Besides, the material should be inelastic as electrical properties of elastic materials might change in case of stretching or bending [1, 2]. Therefore, the conducting properties of various materials used in antenna fabrication and packaging play an important role in achieving the desired performance of antenna designs.

In this paper and based on the above-mentioned facts, a systematic study was demonstrated using three types of conducting materials. Those conducting materials are: Copper Conducting Sheet/ Tape, Pure Copper Taffeta Conducting Fabric and Shieldit Conducting Fabric. Table I presents a brief description about the selected conducting materials and the specification of each material. The Copper conducting sheet is desired for preliminary investigations of wearable textile antenna design and applications [8, 9]. The other two types of conducting materials seem to be most suitable and convenient for textile wearable antenna applications due to the unfeasible features of Copper Conducting Tape (inflexible, non-washable, and unable to withstand multiple deformations). According to manufacturer specifications, Pure Copper Polyester Taffeta Fabric is a kind of smooth fabric made from pure copper. It is very light in weight, flexible and can be sewn like ordinary fabric. Furthermore, Copper Polyester Taffeta Fabric can be washed as well as its ability to resist temperature up to 150ºC. On the other hand, Shieldit Conducting Fabric is made from strong polyester substrate that is plated with nickel and copper as provided in the manufacturer brochure. The fabric is coated on one side with a non-conductive hot melt adhesive. Therefore, it can be ironed on to fabric very easily. Moreover, Shieldit Conducting Fabric can be washed as well as its ability to resist temperature up to 200ºC.

Generally, copper conducting sheet is used in antenna designs and numerical analysis for the sake of preliminary investigations. Since the study of fully textile antennas are one of the major aims of this paper, replacing the copper conducting sheet by textile conducting materials is essential. However, due to software limitations, numerical design investigations considering one conducting material (copper conducting sheet) will be presented and discussed in the following section. Whereas, the fabrication process of several textile antennas will be discussed considering two types of conducting materials. According to that, comparisons between the performances of ideal copper sheet antenna prototype and related antennas prototypes made from conducting fabrics will be clearly presented and discussed.

TABLE I
DESCRIPTION OF THE SELECTED CONDUCTING MATERIALS AND RELATED SPECIFICATIONS

No.	*Conducting Material*	*Thickness [mm]*	*Surface Resistivity, ρ [Ωm]*	*Conductivity, σ [S/m]*
1	Self-Adhesive Copper Conducting Tape	0.03	5.0×10^{-3}	2.0×10^{2}
2	Pure Copper Polyester Taffeta Fabric	0.08	5.0×10^{-2}	2.0×10^{1}
3	Shieldit Fabric	0.17	1.0×10^{-2}	1.0×10^{2}

C. UWB Antenna Design Considerations

The radius of the radiating element was calculated according to Equation (1) below in order to obtain the UWB antenna design presented in this paper. Where a is the radius of the circular patch antenna in millimetres, f_r is the resonance frequency in GHz and ε_r is the relative permittivity of the textile substrate material.

$$a = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \quad (1)$$

Moreover, the simulation has been carried out using CST microwave office software simulation package. Measured results of the antenna prototype were compared with the simulated results of ideal copper sheet antenna prototype. In addition, a partial ground plane was implemented in simulated and fabricated UWB antenna design. Such types of truncated ground plane play an important role in the broadband and wideband characteristics of the designed antenna [8, 10]. Figure 1 below demonstrates the CST Model along with the geometry and dimensions in millimetres of the wearable textile UWB antenna design presented in this paper showing that the design of this antenna has been conducted in air space. A 50 ohm

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microstrip feed line was provided for the antenna feed; hence the position was determined according to [11, 12]. The size of the substrate is 60 mm x 60 mm with a patch radius of 14 mm. In order to enhance the bandwidth as well as optimizing the design, one slit at the top of the circular patch and two slits at the bottom of the circular patch were implemented in this design along with a square slot at the centre of the circular patch with a size of 6 mm x 6 mm. The ground plane size is 50 mm x 27 mm. Yet, all these dimensions are illustrated in table II and supported by figure 1. According to simulation results, the designed UWB antenna was able to cover the range of frequencies from 3 GHz up to 15 GHz.

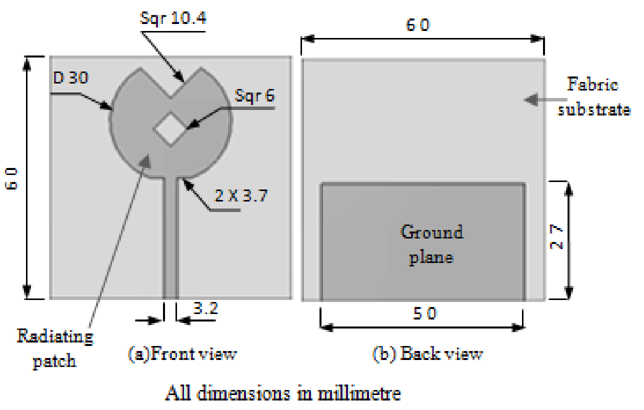

Fig. 1. Dimensions in millimetres of the designed wearable fully textile UWB antenna with both front and back views.

III. Prototyping Of The Antenna

TABLE II
DIMENSIONS OF THE DESIGNED TEXTILE UWB ANTENNA IN MILLIMETRES

	Wearable textile antenna
Overall Substrate Thickness [mm]	1
Substrate dimensions [mm]	60 x 60
Patch radius [mm]	14
Partial ground plane dimensions [mm]	50 x 27
Upper Square slot dimensions [mm]	15 x 15
Centre Square slot dimensions [mm]	6 x 6

The fabrication process was initially conducted for antenna design consisting of a radiating element and a ground plane that are made from self-adhesive copper conducting sheet. Subsequently, two types of conducting materials are accordingly considered for investigation due to the unfeasible usage of copper conducting sheet (not possible to be washed, not attractive to the wearer, unable to withstand multiple deformation processes, etc.). The proposed conducting materials that are so called "Electro-textile materials" seem to be most suitable and convenient for textile wearable antennas applications. Flannel substrate fabric has a kind of smooth and firm surfaces that allow and simplify the process of attaching conducting materials. In addition, direct metal soldering is used to connect the top radiating patch and the ground plane to the SMA coaxial connector as illustrated in Figure 2. The fabricated antenna satisfied the requirements of providing the wearer with such compact size, flexible materials, ease of washing, and very attractive wearable device.

IV. Results And Discussions

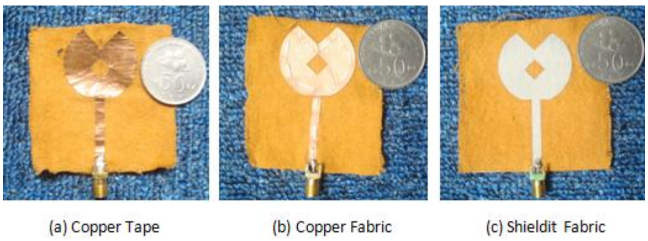

Fig. 2. Snapshots of UWB fabric antenna prototypes along with three types of conducting materials.

Numerical design investigations considering one conducting material (copper conducting sheet) will be presented and discussed. In order to characterize the designed UWB antenna, a network analyzer is used to measure the input return loss, bandwidth and the input impedance locus results of the antenna as a function of frequency. Comparisons of these measured results with simulated results are made to provide better investigation. Moreover, simulated results of radiation pattern, gain, efficiency, and current distribution of the antenna design are also presented in this paper.

The simulated (|S11|) results of fabric UWB antennas using copper tape clearly showed that the achieved BW results expanded from the lower frequency of 2 GHz until the upper frequency of 15 GHz. The obtained BW through numerical analysis is almost 13 GHz. Figure 3 represents snapshots of (|S11|) measurement environment. The comparisons are made between the simulated (|S11|) results of ideal copper tape antenna design and measured (|S11|) results of the related antennas prototypes considering alternative types of conducting materials.

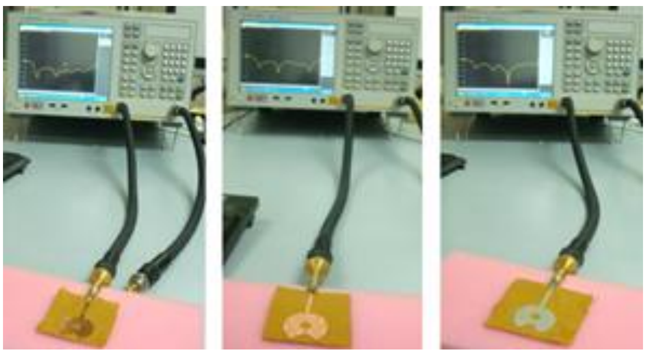

Fig. 3. Snapshots of (|S11|) measurement environment of UWB antennas prototypes using one layer of flannel fabric along with variable types of conducting materials.

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As depicted in Figures 4, results clearly exhibited that (|S11|) results were comparable. From Figure 4 all UWB antennas prototypes satisfactorily achieved BW results of more than 12 GHz within the intended frequency range, where (|S11|) results successfully maintained below the level of -10 dB. The red solid line illustrates the simulated results of copper tape antenna prototype, while the orange dotted line illustrates the measured results of the copper tape antenna prototype. The long dashed line represents the copper fabric antenna prototype and the green dashed dotted line shows the Shieldit antenna prototype.

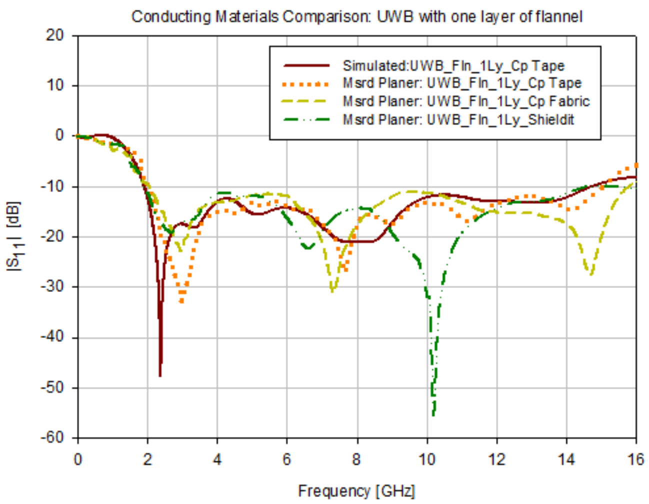

Fig. 4. Comparisons of (|S11|) measured results of UWB antenna design using several types of conducting materials

In addition, Figure 5 demonstrates the simulated and measured input impedance locus results using smith chart, where several loops emerged and appeared completely inside the VSWR circle = 2. These results are achieved due to the perfect match with the feed line of 50 Ω. The achieved bandwidth results give notion that flannel UWB antennas are capable to cover the intended UWB frequency range.

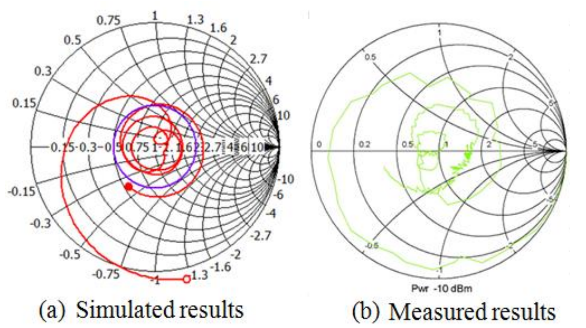

Fig. 5. Simulated and Measured Smith Chart Results of the Wearable Fully Textile UWB Antenna Design

Furthermore, Figure 6 clarifies the behaviour of 3D radiation pattern of the UWB textile antenna design. The textile antenna design resembles omni-directional radiation pattern components over the whole range of frequencies. Six different selected frequency samples are shown in Figure 6. The range of frequencies from 3 GHz up to 5 GHz as shown in Figure 6 (a) and (b), found to have most of the signal intensity at the centre of the antenna. However, the range of frequency samples from 6 GHz up to 15 GHz found to have most of the signal intensity at the centre and the top parts of the designed antenna as demonstrated in Figure 6 (c), (d), (e), and (f).

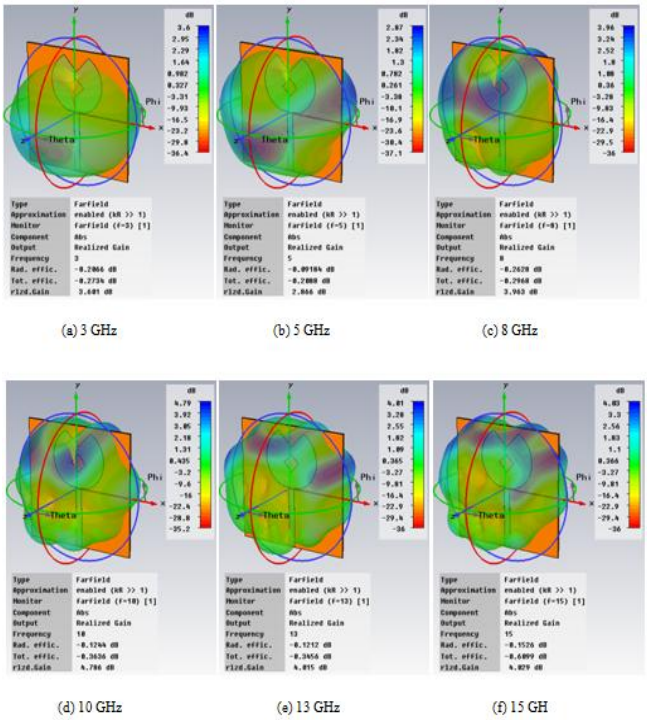

Fig. 6. Simulated 3D radiation pattern results of the fully textile UWB antenna design.

Current distribution results make the idea visible in order to understand how the current flows on the conducting areas of the simulated UWB textile antenna. Figure 7 demonstrates six frequency samples of the simulated current flow at 3 GHz, 5 GHz, 8 GHz, 10 GHz, 13 GHz and 15 GHz for the proposed UWB antenna design using the copper tape as the conducting material. From Figure 7 (a), (b) and (c), high strength of current in the range of frequencies from 3 GHz up to 8 GHz appeared along the conducting parts of the antenna and especially along the transmission line as well as the top and the bottom parts of the radiating patch. However, the rest of frequencies from 9 GHz up to 15 GHz are found to have high strength of current along the transmission line as well as the bottom parts of the circular patch, as illustrated in Figure 7 (d), (e) and (f).

Furthermore, the variations of frequencies versus the gain of the textile UWB antenna designs are demonstrated in Table III. The maximum gain achieved was about 4.8 dB at 10 GHz, while the lowest gain achieved was almost 2.6 dB at 2 GHz. However, the highest percentage of efficiency reached 95% at 6 GHz and 9 GHz, while the lowest efficiency was about 85% at 15 GHz.

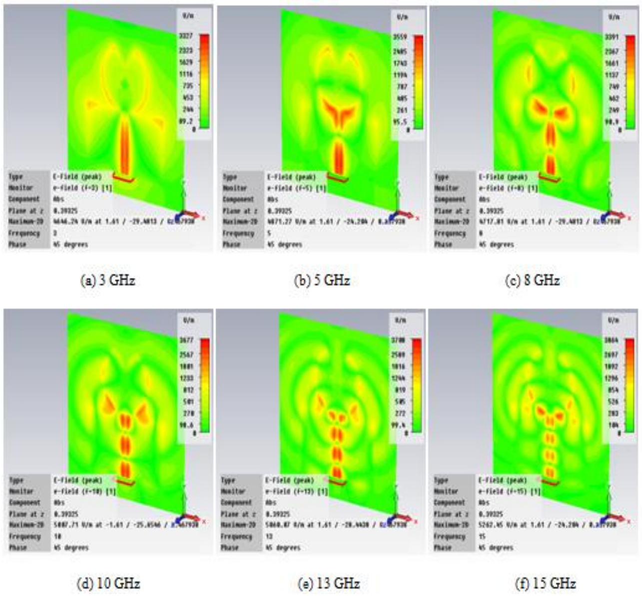

Fig. 7. Simulated current flow results for the fully textile UWB antenna design

TABLE III
THE VARIATION OF FREQUENCY VERSUS GAIN AND EFFICIENCY SIMULATED RESULTS OF THE WEARABLE UWB ANTENNA DESIGN

Frequency [GHz]	*Gain [dB]*	*Efficiency [%]*
3	2.6	85
4	2.1	95
5	2.8	90
6	3.6	94
7	4.7	97
8	4.9	95
9	4.9	96
10	4.7	94
11	4.0	96
12	4.0	70
13	4.2	96
14	4.5	95
15	4.8	92

V. CONCLUSION

This work demonstrated that fully textile UWB antennas have a strong potential to be used as antennas for transmission purposes in garments. Due to the usage of the conducting fabrics, the fabricated antennas has satisfied the requirements of providing the wearer with such compact size, flexible materials, ease of washing, and very attractive wearable device. The proposed antenna design provides 12 GHz bandwidth and showed good measured return loss (|S11|) characteristics, Omni-directional patterns as well as adequate gain and efficiency results. According to these results, future antenna designers need to ensure that the wearable telecommunication devices operate properly in the vicinity of human body.

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