Performance Comparison of Various Textile Composition and Structure through Full-Wave Electromagnetic Simulation and Measurement

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***Abstract*—This paper presents the performance of microstrip patch antenna integrated with textile as a substrate, designed for wearable application. Comparative study between cotton fabric as a substrate with copper tape as radiating element and FR-4 as a substrate with E-textile as a radiating element is performed to evaluate the performance of antennas. The antennas integrated in the proposed structures operate at resonant frequency of 5 GHz. Parameters such as fabric thickness and dielectric permittivity are determined through laboratory measurement prior to simulation to ensure accurate analysis and to take into account non-ideal conditions. Preliminary analysis is performed to observe and investigate the characteristics and electromagnetic performance of the antennas when different types of textile are used as the substrate. Antenna prototypes with two different compositions has been fabricated and tested for validation. The fabricated prototypes give good return loss performance which is -27dB at 4.3 GHz resonant frequency for prototype 1 and -22 dB at 4.7 GHz for prototype 2 (e-textile). However, the frequency for Prototype 2 (E-textile) is slightly shifted about 30% to the left due to non-ideal conditions of the textile materials. The ability of both antennas to radiate good signal is also measured. Based on the measurement data, Prototype 2 (E-textile) shows better performance with higher received power compare to Prototype 1 (copper tape) which is -43 dBm within 1 meter range, while -58 dBm for Prototype 1.**

***Index Terms*— E-Textile; Microstrip Patch Antenna; Return Loss; Textile Antenna; Wearable Application.**

I. INTRODUCTION

In recent years, integration of flexible materials such as fabric or textile with high-frequency devices has good potential due to its conformability and lightweight characteristics[1]. Textile antenna plays a key role in wearable wireless application[2]. Textile material acting as a substrate of the antenna has been an interesting topic due to its significant benefits as it can be carried conveniently around human body specifically for GPS or RFID applications[3]. The use of textile as an antenna requires detailed characterization of their fundamental properties of the textile itself[4][5]. Previous works focused on fabricating copper thread, copper powder or copper tape on fabric materials, which has some limitations when operating under deformed condition. Due to that, preliminary study is performed in this paper based on the performance analysis of various textiles, with or without conductive element and thread composition and structure.

In this paper, the performance of rectangular patch antenna developed on different fabric materials including electro textile are analyzed. Comparison is made between each prototypes to investigate the effects of each fabric and composition to the performance of the antenna. The first prototype uses adhesive copper tape as a radiating patch with cotton as a substrate operating at 5 GHz. The second one uses conductive textile or e-textile as a radiating patch and FR-4 as a substrate.

II. ANTENNA DESIGN

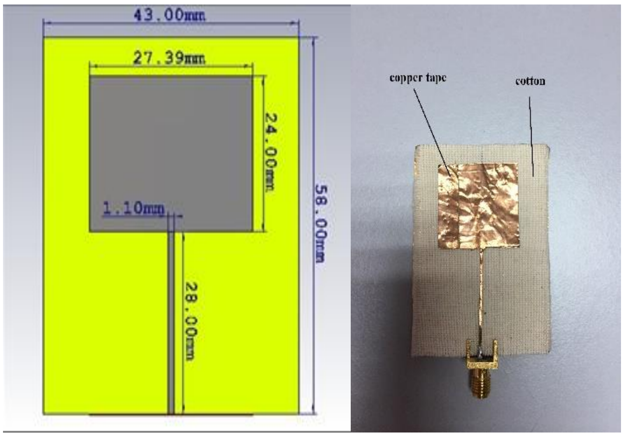
The antenna is designed with radiating patch on one side and a ground plane on the other side of the substrate. For the first proposed antenna design as shown in Figure 1 (prototype 1), the patch is made up of copper tape with cotton as a substrate operating at 5 GHz, whilst in the second design (prototype 2), the patch is made up of conductive textile and FR-4 as a substrate operating at 5 GHz. The conductive textile (electro textile) consists of 50% copper thread and 50% polyester thread. The antenna performance depends on various properties of antenna such as relative permittivity (εr) of the substrate used, the antenna dimension, the height of substrate, and the material of the substrate itself. The choice of dielectric on which the conductor is built affected the antenna's behavior in terms of impedance bandwidth, radiation efficiency and gain. Thickness, dielectric permittivity, loss tangent, resistivity and conductivity of antenna materials are measured for accurate analysis and to take into account non ideal conditions such as thread density and weave pattern.

The parameter shown in Table 1 and Table 2 are considered when designing and fabricating the antenna.

Table 1
Parameter of the design antenna

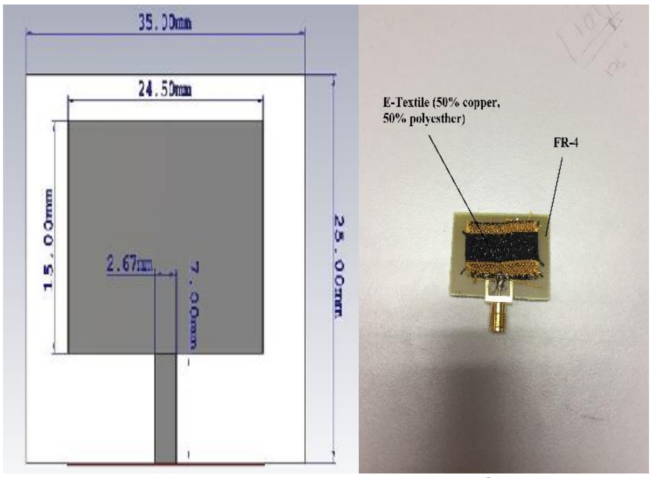
Parameter	Cotton fabric (substrate)
Operating frequency	5GHz
Dielectric constant	1.4
Substrate thicknes	0.3 mm
Patch material	Copper tape
Patch thickness	0.07 mm

The geometry of the second antenna prototype (prototype 2) analyzed in this paper is illustrated in Figure 2. The rectangular patch antenna design is the most widely used because it is very easy to analyze based on transmission-line and cavity model, which is the most precise model for thin microstrip.



(a) (b)

Figure 1: Illustration of prototype 1: (a) Antenna design in CST simulation; (b) Textile antenna on cotton fabric.



(a) (b)

Figure 2: Illustration of prototype 2: (a) Antenna design in CST simulation; (b) Textile antenna on FR-4 board.

Table 2
Parameter of design antenna

Parameter	Fr-4 (substrate)
Operating frequency	5 GHz
Dielectric constant	4.3
Substrate thicknes	1.6 mm
Patch material	E-textile
Patch thickness	0.35 mm

III. MATERIALS AND METHOD

Prior to performing the simulation, the thickness, dielectric permittivity (εr), loss tangent, resistivity and conductivity of antenna materials must be measured to ensure accurate analysis. Figure 3 shows the technique to measure the dielectric permittivity of the textile. Here, the holding jig is developed to ensure constant stiffness throughout the fabric sample. Coaxial probe measurement techniques is applied in this paper to determine the dielectric permittivity of the textile [6]. The dielectric permittivity (εr) is measured by touching it to the flat surface of the textile. The reflected signal (S11) can be measured and related to εr. The measurement is performed by using PNA-L KEYSIGHT N5232A.

Figure 3: Textile Parametric Measurement

Electro-textiles or E-textiles, also known as smart textiles are fabrics that enable digital components and electronics to be embedded in them. It has been developed to provide added value to the wearer. In this paper, the E-textile that consists of conductive thread (copper cover thread) and non-conductive thread (polyester thread) is proposed. Here, conductive textile has been used in the form of filament or thread inside the textile construction. The thickness of conductive copper thread that is used in this paper is 0.35mm and has 4.9e7 S/m conductivity.

Figure 4 shows the electro-textile that is used in this paper as a radiating patch in the second prototype. The composition of the E-textile is 50% copper thread and 50% polyester thread.

Figure 4: Photograph of E-textile that consists of copper thread and polyester thread.

Figure 5 shows the electro-textile that has been magnified under the magnifying glass lamp in the workshop laboratory. Weaving technique has been implied to construct the E-textile. The copper cover threads were used as the weft (horizontal direction), whilst the polyester threads are in the warp direction (vertical).

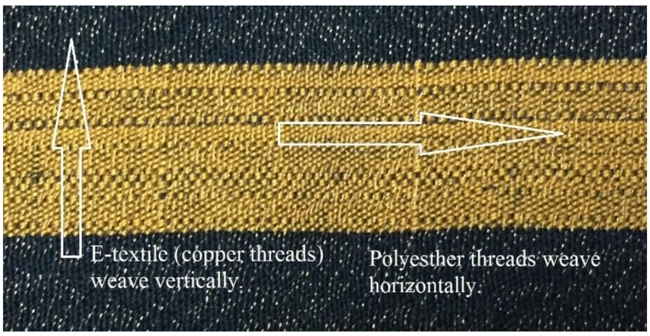


Figure 5: Weaving pattern E-textile under magnifying glass

Full-wave simulations have been performed by modeling the cotton as the substrate and adhesive copper tape as the conductive patch with the following parameters as shown in Table 3.

Table 3
Measured parameters of cotton and copper tape for prototype 1

Materials	Thickness (mm)	Conductivity (S/m)
Cotton	0.3	0.03
Copper tape	0.07	5.8e7

In modeling prototype 2, the parameters shown in Table 4 are used where the E-Textile represents the conductive patch.

Table 4
Measured parameters of FR-4 and E-Textile for prototype 2.

Materials	Thickness (mm)	Conductivity (S/m)
FR-4	1.6	0.025
E-Textile	0.35	4.9e7

IV. Experimental and Numerical Results

Experimental measurement of the reflection coefficient has been performed by using the VNA KEYSIGHT N5234A. The results obtained in Figure 6 shows a comparison between numerical data and experimental data for the resonant frequency and the reflection coefficient (S11) of the first antenna prototype. Numerical data are calculated using CST Microwave Studio.

Based on this graph, it can be seen that a good reflection coefficient, S11 between numerical and measured data has been obtained for the resonant frequency of the prototype antenna, but the frequency has been shifted to the left. This result is probably due to the inaccuracy during the fabrication process. Besides that, the copper thread has enamel coating, which represents a non-ideal case of copper. The resonant frequency, from the measured data and the numerical data of the first prototype has a return loss of -31 dB and -27 dB, respectively.

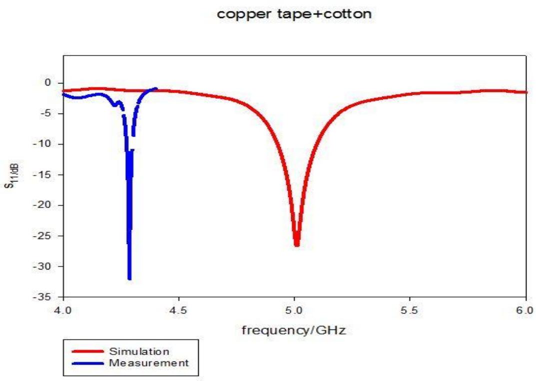


Figure 6: Comparison between numerical and experimental data obtained for the reflection coefficient of the prototype using cotton as a substrate and adhesive copper tape as a patch of the antenna

In order to assess the ability of the antenna prototype to perform and radiate a signal, the performance of the realized antenna when subjected to distance has been evaluated. Experimental measurement of signal strength has been performed by using KEYSIGHT FIELDFOX N9916A. Figure 7 shows the experimental setup adopted for the measurements.

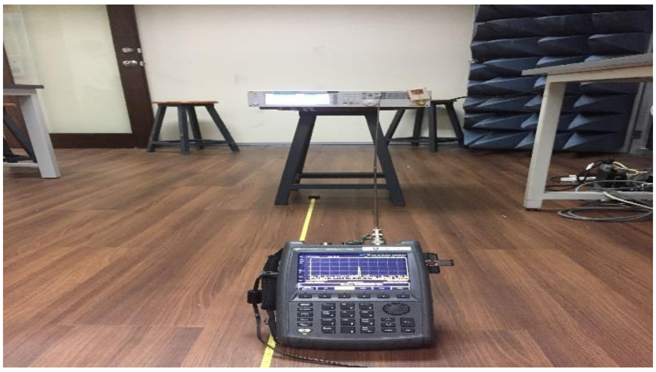


Figure 7: Experimental setup adopted to evaluate the signal strength of the antenna in term of the range distance.

From Figure 8, it can be noticed that the signal strength of the first prototype antenna can be detected within the range of 1 until 5 meter. This shows that the signal strength is decreasing proportionally with the signal against the distant range. Showing the expected correlation between signal strength and free space loss in Radio Frequency (RF) propagation.

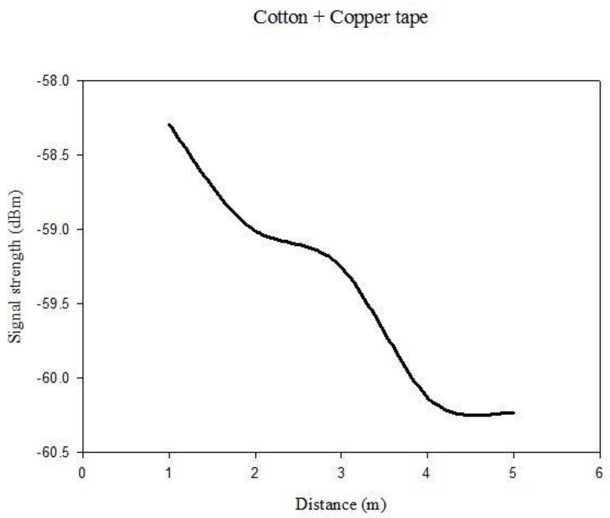


Figure 8: Signal strength measurement of Prototype 1

Results obtained in Table 5 shows a comparison between numerical data and experimental data for frequency and reflection coefficient (S11) for Prototype 2. It can be observed from this preliminary design that the antenna can give good performance at specific frequency. However, the frequency has been shifted to the left, this result is probably due to structure of the copper thread as shown in Figure 4. It can be seen that the density of the conductive copper thread affected the performance of the antenna. The resonance frequency, from measured data and numerical data of the second prototype has a value of -22 dB and -19 dB, respectively. Despite of the structure limitation, this prototype antenna can still perform and radiate well.

Table 5
Parameter of numerical and measurement fo and S11 for Prototype 2

Parametric result	Numerical	Measurement
Operating frequency, fo.	5 GHz	4.7 GHz
Reflection coefficient, S11	-19 dB	-22 dB

From Figure 9, it can be noticed that the signal strength of the second prototype antenna which is using FR-4 as a substrate and e-textile as a radiating patch can be detected within the range 1 until 5 meter. It shows that, with this configuration, better signal strength can be received at the antenna as compared to Prototype 1.

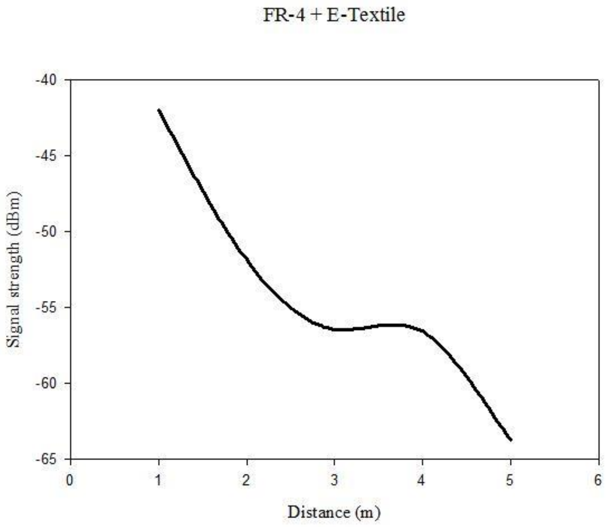


Figure 9: Signal strength measurement of Prototype 2

V. Conclusion

The use of different textile composition and structure for simulation and fabrication of wearable antenna has been investigated in this paper. Experimental data referring to two different prototypes of microstrip patch antenna using textile substrate for the first prototype and FR-4 like a conventional antenna for the second prototype have been observed and compared. The numerical and measured results showed that the proposed antenna gives good return loss performance at the specific frequency and good signal strength during propagation. Despite of the structural limitation, this antenna can perform and radiate well. Prototype 2 gives better performance in term of higher signal strength, this may be due to uniform surface of e-textile compare to copper tape. This study is very useful for further analysis and design on wearable application.

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References

[1] G. Monti, L. Corchia, and L. Tarricone, “Fabrication Techniques for Wearable Antennas,” pp. 1747–1750, 2013.
[2] N. S. M. Yaziz and M. K. A. Rahim, “Wideband Textile Antenna for Wearable Application,” no. Rfm, pp. 14–16, 2015.
[3] P. G. Elliot, E. N. Rosario, B. Rama Rao, R. J. Davis, and N. M. Marcus, “E-textile microstrip patch antennas for GPS,” *Rec. - IEEE PLANS, Position Locat. Navig. Symp.*, no. 3106, pp. 66–73, 2012.
[4] A. Kiourti and J. L. Volakis, “Conductive textiles for wearable electronics,” *2016 URSI Int. Symp. Electromagn. Theory, EMTS 2016*, pp. 518–519, 2016.
[5] I. Gil and R. Fern, “Wearable GPS Patch Antenna on Jeans Fabric,” pp. 8–11, 2016.
[6] A. Note, “Agilent Basics of Measuring the Dielectric Properties of Materials,” *Meas. Tech.*, vol. 2007, p. 32, 2005.