Wearable Textile Antenna: The Investigation of Flannel Fabric Layers

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1. Introduction

The extensive worldwide research has been carried out on new wearable devices. Wearable Computers can be considered as ancestors to smart clothes. In addition, the evolution of antenna technology for man- machine interface has taken quantum leaps in utilizing textile materials as antenna substrate. This incorporation of the antenna into the uniform has added the benefit of eliminating clumsy devices that can tangle in.

In any wireless communication set up, the antenna requires a careful design. For a wearable system, additional parameters must be considered such as comfort, non-invasive, simple to use, safety of electromagnetic field, and has a low health risk. It also needs to be cost-effective and widely available, allow easy interpretation, and provide consistent results. In the advent of textile antennas, there have emerged a vast number of potential applications and other supporting systems benefiting flexible antennas. Body worn antennas may be made from textiles [1-4] and attached on body or into clothing, or may be worn as a button antenna [5]. More recently, antennas incorporating single frequency electromagnetic band gap materials (EBGs) integrated into the designs have been reported [6, 7].

This paper presents antennas manufactured from flexible materials that are made from clothing. A rectangular microstrip patch antenna design was made using textile materials as antenna substrate. Our study focuses on using the flannel fabric which is suitable for wearable applications. To our best knowledge, this is the first time using the flannel fabric as substrate materials. A comparison was made for one layer and three layers of the substrate textile material. The word textile is typically used for antenna class and fabric to describe particular material. However, in many cases these words are interchangeable. Simulations have been carried out using CST Microwave Studio software and measurements were carried out to verify the results.

2. Materials and Methods

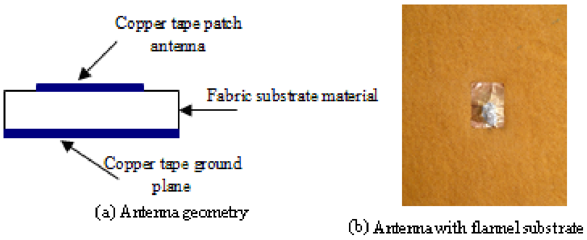
For flexible antenna, textile materials form interesting substrates, because fabric antennas can be easily integrated into clothes [8, 9]. Textile materials generally have a very low dielectric constant, which reduces the surface wave losses and improves the impedance bandwidth of the antenna [10, 11]. In comparison with high dielectric substrates, textile antennas are physically larger.

In this investigation, a rectangular microstrip patch antennas was designed using flannel substrate textile materials as antenna substrate material. In order to characterize the effect of textile materials accurately, the fabric chosen for the comparison are made from a 100% cotton materials. One-layer and multi-layers are made to provide a better investigation on the suitability of using thicker fabrics by adding more fabric layers. Flannel fabric has a kind of a smooth and firm surface with an additional feature of being fluffy surface material. Using such kind of fluffy surface feature is beneficial in reducing the air gap between fabric layers when multi layers from substrate fabrics were required. Conductive parts are made out of copper tape with a thickness of 0.035 mm. These mentioned features together made the antenna flexible in nature. A coaxial SMA connector was provided for antenna feed, which was soldered on the copper tape. In order to model the fabrics it is important to know the relative permittivity of the fabric. The measured relative permittivity at 8 GHz for flannel fabric was 1.7. Table 1 illustrates the fabric thickness and the measured relative permittivity of flannel substrate textile material.

3. Antenna Geometry

The geometry and dimensions in millimeters of the rectangular microstrip patch antennas prototype mounted on the surface of one layer made from flannel substrate textile materials is shown in Figure.1. The conductive surface and the ground plane are made out of copper tape with a thickness of 0.03 mm.

The simulations were carried out using CST Microwave Studio software and the fabric antenna characteristics were studied. According to simulation, the ground plane size is 80 mm x 80 mm. The patch length, width and the feed location from the patch edge are all illustrated in Table 1. The feeding position was determined according to [12]. The distance between the radiating patch and the ground plane should remain constant in order to maintain antenna's electrical characteristics. In this study, the conductive sheets were made out of copper tape in order to characterize the effect of textile materials accurately. In addition, the fabrics should have as a smooth and firm surface as possible and the conductive sheet have to be fastened evenly and stoutly on the fabric surface. If the copper tape detaches merely from one corner and the space between the metal layers varies, the resonant frequency of the antenna changes. In this paper, the copper tape was tightly attached to the surface of flannel fabric, and it did not detach, which has proven the suitability of using this kind of fabric as antenna substrate materials.



(a) Antenna geometry

(b) Antenna with flannel substrate

Figure 1: The geometry of the rectangular microstrip patch antennas with flannel substrate textile material

4. Results and Discussions

The thickness of the fabric has a great influence on antennas bandwidth and generally determines the bandwidth. The simulation showed that it is possible to design well-matched input impedance for one layer of flannel fabric substrate material. As it can be seen from Figure. 2, the simulated bandwidth at 8 GHz is 3.6 %. The bandwidth of the antennas remains too narrow because of fabrics thickness. Simulation results showed that thickness affect the bandwidth as predicted.

In order to characterize the antennas a network analyzer was used to measure the input return loss of the antennas as a function of frequency. The measured bandwidth at 8 GHz for flannel fabric with one layer was 3.7%. A comparison of the simulated and measured return loss results as well as bandwidth results of flannel substrate material are shown in Figure 2 and illustrated in Table 2. The measured results of flannel showed that it does agree very well with simulations and the target frequency 8 GHz is reasonably well met. The reason behind this that the copper tape was tightly attached to the surface of the fabric, and it did not detach. These results indicated the importance of proper fabric selection. Therefore, the desired requirements for particular application need to be properly considered, and a suitable fabric need to be selected to meet these requirements.

The simulated current flow and radiation characteristics of the fabric antennas with one layer of substrate made from flannel fabric were studied. Figure.3 shows the simulated current flow and the simulated radiation pattern. The antenna gain was affected by conductive materials, in the same way as the bandwidth are affected. The simulated gain is approximately 6.7 dB. These results are all illustrated in Table 2 which indicates the importance of proper fabric selection.

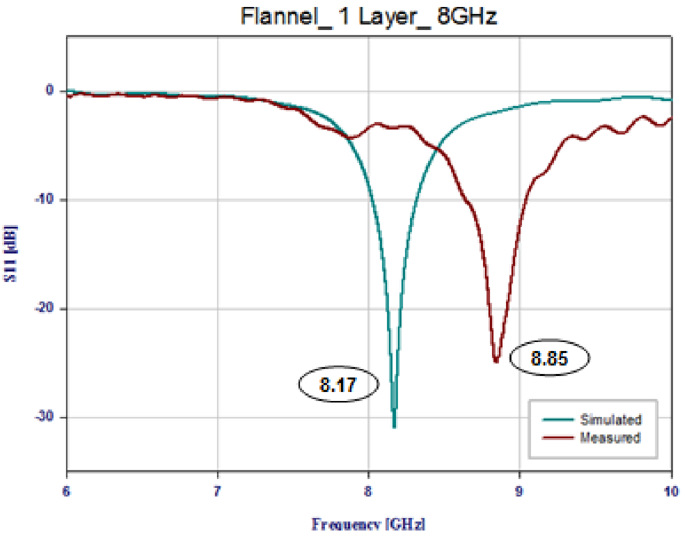


Figure 2: The simulated and measured return loss and bandwidth results of one-layer of fabric antenna

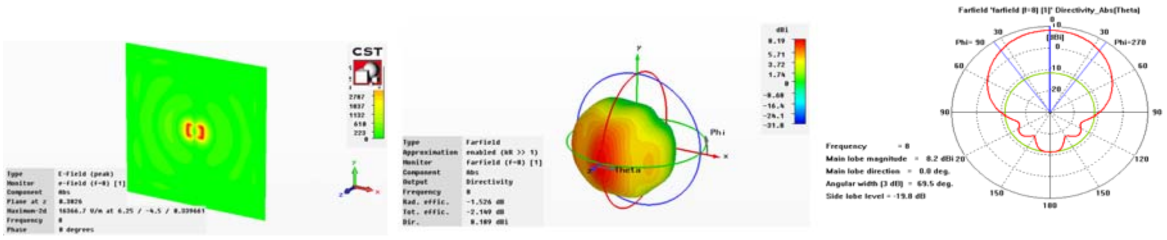


Figure.3: The simulated current flow and radiation characteristics of one layer of fabric antenna

On the other hand, the effect of substrate materials thickness on antenna performance besides antenna bandwidth was studied. Multi-layers of flannel textile material were made to provide a better investigation on the suitability of using fabric layers. Adding three layers of flannel fabric substrate material has resulted in a thicker substrate material compared to one layer of fabric. According to simulation, the changes in antenna’s resonant length detune frequency band and the thickness of the fabric has a great influence on the antenna bandwidth. The ground plane size is 80 mm x 80 mm. The patch length, width and the feed location from the patch edge were also determined according to changes in substrate material thickness. All these results are illustrated in Table 1.

Simulation results showed that it is possible to design well-matched input impedance for flannel fabric substrates after adding more layers to the substrate textile materials. Beside that, by adding more layers the thickness of the fabric increased which resulted in a wider bandwidth compared to the substrate fabric of one layer thickness. The antenna with three layers of flannel substrate fabric had a wider bandwidth than the antenna with one layer of the same fabric. As it can be seen from Figure 4, the simulated bandwidth at 8 GHz is 11.6% for the flannel fabric with three layers. These results are all illustrated in Table 2. Simulation results showed that enlarging the substrate thickness by adding more layers of fabrics affects the bandwidth as predicted.

In addition, a network analyzer was used to measure the input return loss of the antennas with three layers of fabric as a function of frequency. The measured bandwidth at 8 GHz for three layers of flannel fabric was 11.68 %. A comparison of the simulated and measured return loss results as well as bandwidth results of flannel substrate material are shown in Figure 4 and illustrated in Table 2. The measured results of flannel showed that it does agree very well with simulations and the target frequency 8 GHz is reasonably well met

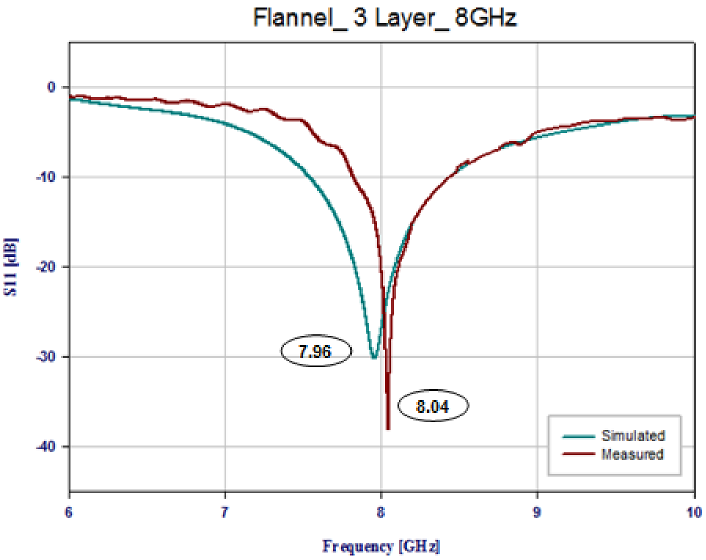
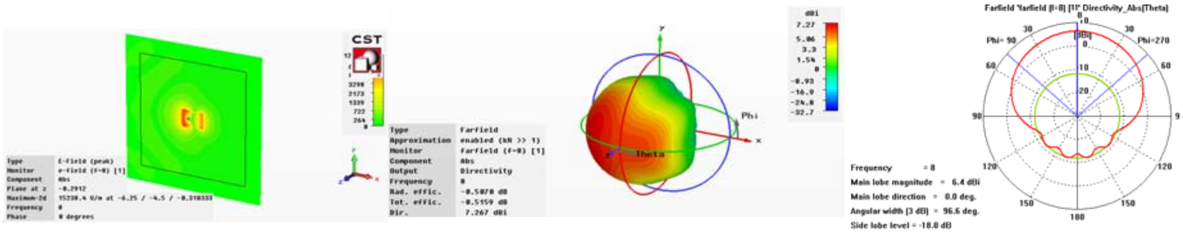


Figure 4: The simulated and measured return loss and bandwidth results of three-layers of fabric antenna

Table 1: Fabric thickness, measured relative permittivity, besides the patch length, patch width and the feed location from the patch edge of flannel substrate textile material.

Flannel Substrate material	**Thickness [mm]**	**Measured Relative permittivity at 8 GHz**	**Patch Length [mm]**	**Patch Width *[mm]***	**Feed location from the patch edge [mm]**
One layer of fabric	0.95	1.7	15.5	13	3.5
Three layers of fabric	2.85	1.7	15	11	3

The simulated current flow and radiation characteristics of the fabric antennas with three layers of substrate made from flannel fabric were also studied. Figure 5 shows the simulated current flow and the simulated radiation pattern. The antenna gain was affected by conductive materials, in the same way as the bandwidth is affected. The simulated gain is approximately 6.8 dB. These results are all illustrated in Table 2.



Type E-Field (peak)
Monitor e-field (f=8) [1]
Component Abs
Plane at z -0.2912
Maximum-2d 15238.4 V/m at -6.25 / -4.5 / -0.318333
Frequency 8
Phase 0 degrees

Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=8) [1]
Component Abs
Output Directivity
Frequency 8
Rad. effic. -0.5070 dB
Tot. effic. -0.5159 dB
Dir. 7.267 dBi

Frequency = 8
Main lobe magnitude = 6.4 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 96.6 deg.
Side lobe level = -18.0 dB

Figure 5: The simulated current flow and radiation characteristics of three layers of fabric antenna

Table 2: Simulated and measured results of one layer and three-layers of fabric antenna

Flannel Substrate material	**Simulated Results**				**Measured Results**		
	f_r [GHz]	**S_{11}** [dB]	**Bandwidth** [%]	**Gain** [dB]	**f_r** [GHz]	**S_{11}** [dB]	**Bandwidth** [%]
One-Layer	8.17	-31	3.6	6.7	8.85	-25	3.7
Three-Layers	7.96	-30	11.6	6.8	8.04	-37	11.68

5. Conclusions

This paper presents the development, manufacture, and measurement of antennas that integrated into clothing. The investigation focused on substrate fabrics thickness and substrate fabrics layers and the results indicate that designs are suitable for wearable antennas application. The antenna with three layers of flannel substrate fabric had a wider bandwidth than the antenna with one layer of the same fabric. In this investigation, it has been shown that enlarging the substrate thickness by adding more layers to jeans and flannel fabrics substrate materials affects the bandwidth. In addition, all these results indicate the importance of proper fabric selection. Therefore, the desired requirements for particular application need to be properly considered, and a suitable fabric need to be selected to meet these requirements.

6. Acknowledgment

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