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Development and design of wearable textile antenna on various fabric substrate for unlicensed ultra-wideband applications

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ABSTRACT

In the area of wearable technology an enhancement of basic microstrip antenna is evolution of wearable textile antenna. A major requirement for wearable textile antenna is its flexible designed materials which incoprates of fabric in the structure. The parameters obtained from the wearable textile antenna are return loss (S-11), directivity, gain, voltage standing wave ratio (VSWR) as well as the specific absorption rate (SAR) value. All these parameters are mostly influenced by the value of substrate dielectric constant and its thickness. In this paper, the design of wearable dual band frequency microstrip antenna is presented for wireless communication services. When the federal communication commission (FSS) has allowed the operation of unlicensed ultra-wideband (UWB) thus it attracted research interest in realizing UWB antennas for wireless applications. The operating frequency of the proposed antenna ranges from 2.85 GHz to 7.3 GHz. For body-worn and wearable applications, the antenna is embedded on selected textiles (i.e. felt, denim, polyester and leather). The prorposed microstrip antenna is designed, simulated and analysed in computer simulation technology (CST) microwave studio.

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1. INTRODUCTION

A wearable antenna normally using the fundamental concept of microstrip antenna. It also known as patch antenna which is flexible and miniature device that can be applied on-body, off-body or in-body for wireless and lightweight. This technology plays a vital role recently in various applications including medical, military, sports and more. Moreover, it can be used to integrate with mobile phone, wristwatches, wearable outfit, and other devices. The rapid grow of wireless communication has led to development and integration more than one communication services in a wireless device [1]–[7].

As for medical example application, these systems functioning to monitor the performance of the body during exercise, monitor the heart rate and blood pressure for medical used by the medical team and for general network connections. Wearable antenna also known as body worn antenna is mostly comfortable and widely been studied on the usage of fabric as substrate [8], [9]. Several types of fabrics are introduced including cotton, denim, leather, felt and more. Wearable antennas are usually develop using different kind of conductive (patch) and dielectric (substrate) materials. In any wireless communication application, the design and selection of the antenna is varies depending on the environment, frequency bands and the strength of transmission [9]. In addition, the performance of the antenna depends on the material used which leads to the properties of it for conductor, substrate and as well as the ground plane and how it's been fabricate. Here the basic configurations that can be used to feed a patch antenna. Figure 1, the structure layers of a patch antenna composition with feeding methods: microstrip patch antenna (MPA) contains of four elements; a conductor patch or radiation patch, a dielectric or substrate plane, a ground plane and a transmission feedline Figure 1.

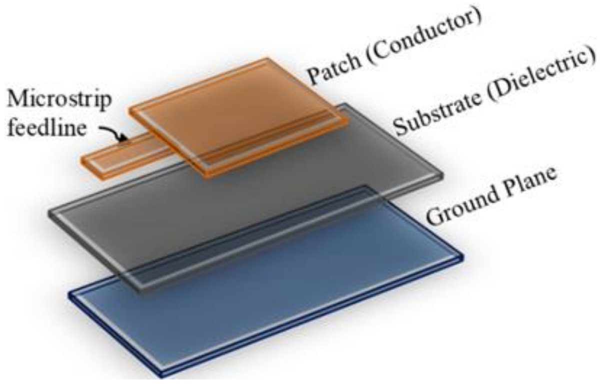

Figure 1. The layes of a patch antenna with microstrip feedline

Wearable antennas are developed by the composition of conductive materials and substrates. The selection of substrate material is chosen based on their dielectric properties (including the dielectric constant, loss tangent and thickness), tolerance to mechanical deformations (wrapping around body and bending), miniature in size, and the endurance in the external circumstance such as weather or other excessive activity like dozens of washing times. To added information, the selection of conductive material is chosen based on their electrical conductivity that may influenced the antenna performance, such as radiation efficiency, directivity, return loss (S-11), voltage standing wave ratio (VSWR) and other performance measurements. Therefore, wearable textile antennas (WTA) are became recent studies for several researcher because of their features that are made up of fully fabric material or partially as compared to conventional rigid and stiff antennas [10]–[23].

The WTAs are developed by using conductive material or some of it that known as e-fabric material used for the conductive patch antenna as well as the ground part [15], [24], [25]. The WTA is a microstrip antenna where the substrate also known as nonconductive is a textile material. This intelligent and smart fabric system means an added values to the conventional function not only for covering the human body from the heat and cold, but it also offers new feature such as detecting, stimulating, and communicating. WTAs are also known as a device that is incorporated into the "smart apparels".

The availability of fabric materials which usually used in daily human being are consider as viable resource to design. In wearable application, MPAs are most popular design, which the ground plane of antenna efficiently protects the body tissues and acceptable for on-body communication applications [26]. Important parameter such as the bandwidth and frequency operating mainly influenced by the permittivity of dielectric constant material and its thickness, the conductivity of the radiating patch also must be the highest possible value since it is a main factor [27]. Therefore, proper selection of a textile for substrate is very important to achieve good performance of antenna.

The main advantages of wearable antennas are its miniature in size, low-cost, less maintenance and flexible. In addition, to design in ultra-wide band (UWB) technologies it just requires a small amount of power to operate and transmit data. This means, it can have longer battery lifespan. It also capable to be wore on the body. Many research activities have been done on analysis of wearable on-body antenna which took look on the performance of that antenna towards human body. An UWB is operated in the range 3.1 GHz to 10.6 GHz that has been approved by federal communication commission (FCC) in 2002 for transmission of UWB-technologies [25], [27]–[29].

2. ANTENNA DESIGN AND PARAMETER

Substrate materials is one of factors that affect the performance of the antenna. The parameters that need to be considered are its thickness, dielectric constant permittivity (ε_r) and loss tangent ($tan\ \delta$) as tabulated in Table 1. It plays a significant role in determining the size and the resonant frequency as well as the bandwidth of an antenna. Textile, in general, have a very low relative permittivity (in comparison to conventional rigid substrate materials for electronic applications such as FR-4) as they are very porous fabrics [30], [31]. By increasing the dielectric constant, it will be decreasing the size of an antenna but lowers the bandwidth and its efficiency of the antenna. While, by decreasing the dielectric constant it will increasing the bandwidth but with an increase in size [32].

As the performance comparison of the proposed antenna, the dimension of the antenna is obtained from the optimized process by taking the sequences of values using the FR-4 material as initial dimension. The values will be simulated by feature of parameter sweep in computer simulation technology (CST) software. The parameters such as feed width, patch length, and radius of slotted antenna dimensions are set as to execute the series of simulations in order to improve the performance of the proposed antenna. The optimized dimension and perspective view of proposed antenna are shown in Table 2 and Figure 2 respectively. To make the comparison between those four selected substrates, all dimensions are being used as in Table 2 except the substrate values that follow as tabulated in Table 1.

Table 1. Dielectric properties of normal fabrics

Nonconductive fabric	ε_r	$tan\ \delta$	h (mm)	Reference
Felt	1.2	0.02	2.0	[33]
Denim	1.6	0.02	0.7	[34]
Leather	1.79	0.042	1.3	[35]
Polyester	1.90	0.04	1.5	[36]

Table 2. Parameter dimension microstrip

Parameter	Notation	Dimension (mm)
Patch width	Wp	51
Patch length	Lp	8
Inset width	Wl	1.7
Inset length	Ll	5.16
Ring 1	R1	6
Ring 2	R2	2.5
Ring 3	R3	3
Ring 4	R4	1.5
Thickness substrate	Ht	According to the material used
Transmission line width	Wt	2.98
Transmission line length	Lt	5.16
Substrate width	Ws	60
Substrate length	Ls	40

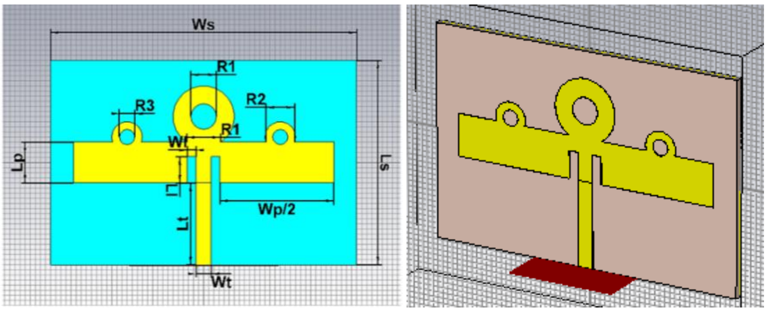

Figure 2. Dimension and perspective views of proposed antenna

3. RESULTS AND DISCUSSION

The CST microwave studio tool was used to simulate the microstrip antenna experiment. Return loss (S-11), VSWR, and a 3D radiation pattern and gain for various substrate textile materials are some of the antenna parameters that have been studied. The S-11 parameter value should be less than -10 dB for proper impedence matching. Figure 3 shows that return loss (S-11) comparison between the conventional non-textile FR-4 and four selected textile substrates. The S-11 parameter is the simplest way to explain the signal sources input and output, or the fact that not all of the generated power is transferred to the load. The peak parameter S-11 results of the simulated design is -46.38 dB at 5.89 GHz resonant frequency. This indicate that polyester has a higher return loss as shown in Table 3. This is expected due to a higher dielectric constant value of the textile that allows for more current flow. As for non-textile FR-4 substrate could give quad-band frequencies, however, to fabricate the wearable antenna which is suitable and comfortable to be worn, textiles substrate is proposed for this study. According to Table 3, all textiles produced dual-band frequencies as respectively.

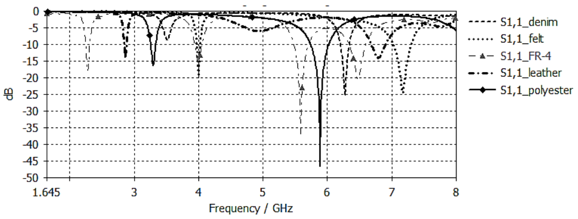

Figure 3. Return loss (S-11) parameter plot comparison for all substrates

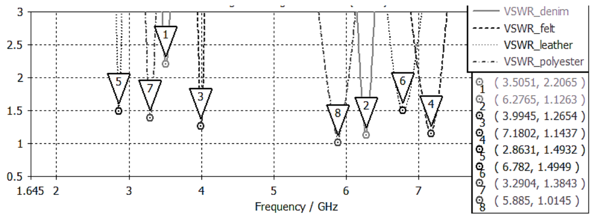

Figure 4. VSWR parameter plot for different substrate fabric materials

Table 3. The results of comparison between substrate and resonance frequencies as well as its S-11 values

No.	Substrate (ε_r, $tan\ \delta$, h (mm))	Resonance frequencies (GHz)	S-11 (dB)
1	FR-4 (4.3, 0.025, 1.5)	2.28, 3.99, 5.58, 6.48	-17.71, -15.19, -37.1, -20.38
2	Felt (1.2, 0.02, 2.0)	3.99, 7.18	-19.04, -24.42
3	Denim (1.6, 0.02, 0.7)	3.51, 6.28	-8.63, -25.1
4	Leather (1.79, 0.042, 2.0)	2.86, 6.78	-14.12, -14.06
5	Polyester (1.9, 0.04, 1.5)	3.29, 5.89	-16.37, -46.38

VSWR is a method of calculating impedance mismatch. The VSWR is another significant parameter to consider when evaluating an antenna's performance. A value between 1 and 2 is significant because it ensures that the antenna is matched to the transmission line and that the antenna receives more power. Figure 4 shows the VSWR values for different textile substrate with values 1.49 for leather, 1.38 and 1.02 for polyester, 2.2 and 1.12 for denim, and 1.27 and 1.14 for felt at their respective resonant frequencies.

An antenna radiation pattern is a representation of the antenna angular distribution of radiated power density. It is also a representation of an antenna tendency to radiate electromagnetic energy as a function of direction in the far-field region. This graphical representation of the radiation properties of the antenna as a function of space. It is important to state that an antenna radiates energy in all directions, at least to some extent, so the antenna pattern is in 3D (three-dimensional) composition.

An antenna directivity is defined as the ratio of the radiation intensity in a given direction from the antenna to the average radiation intensity in all directions. The gain is defined as the ratio of the radiated field intensity by the test antenna to the radiated field intensity by the reference antenna. The 3D radiation patterns of the antennas with different substrates are given in Figure 5 to Figure 8 respectively. The value of directivity is more than 4.895 dBi is achieved for different substrate materials at their operating frequencies respectively. The results clearly show the directivity of 10.20 dBi for leather as substrate textile material is higher than other textile materials.

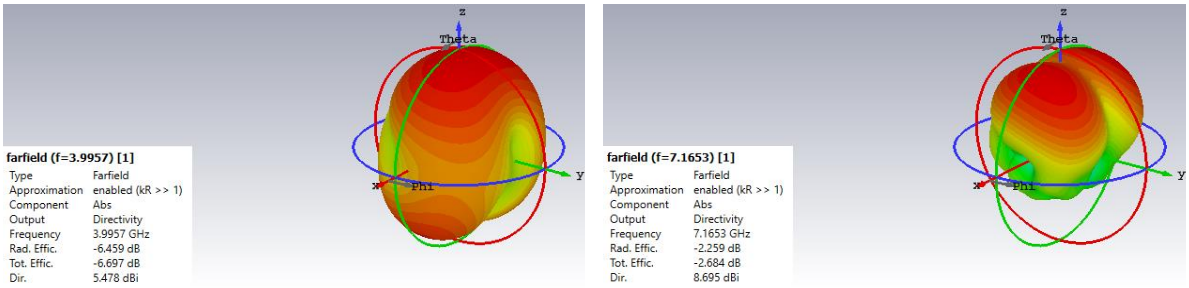

Figure 5. 3D radiation pattern for felt

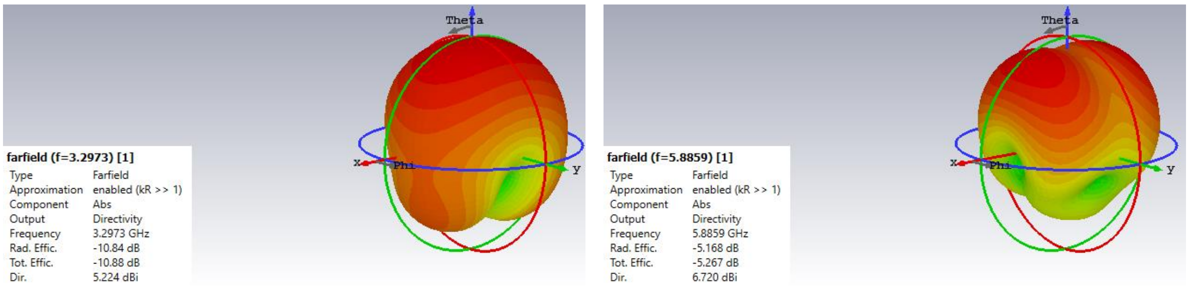

Figure 6. 3D radiation pattern for polyester

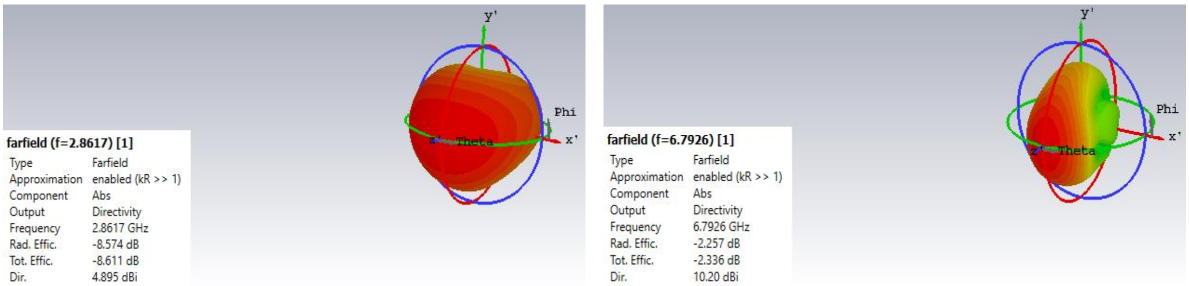

Figure 7. 3D radiation pattern for leather

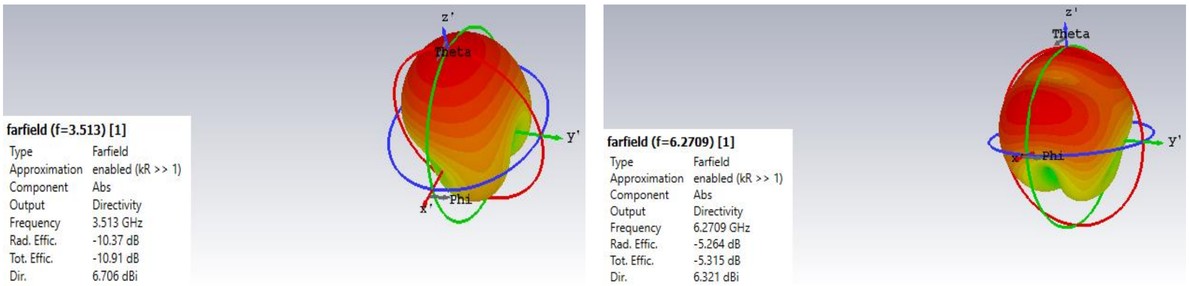

Figure 8. 3D radiation pattern for denim

The maximum gain versus frequency for the proposed four different substrates antenna are plotted in Figure 9. It is shows that the leather substrate has highest value of gain 6.23 dB. As for comparison it can be said that the high frequencies will generate high gain than the lower frequencies. For further comparison Table 4 tabulated the summary of parameters simulation results for four different substrates.

Finally, for the antenna performance in term of specific absorption rate (SAR), it has been considered the impact of the human body on the antenna system on the SAR value. The numerical effect of the antenna and SAR value because of the textiles patch antenna placement on human body. Table 5 tabulated the specifications of human tissue model. For this simulation a four layered body phantom is designed in CST Microwave Studio that consists of bone, muscle, fat and skin as shown in Figure 10 and only polyester textile is chosen to perform this simulation [37]. The simulated SAR value is calculated on 10 g of human tissue at specified frequency which shows 1.06 W/kg is less than the 2 W/kg as shown in Figure 10. A maximum limit of 10 g of any tissue that would be lower than 2 W/kg is specified by the international commission on non-ionizing radiation protection (ICNIRP) [26].

Table 4. The comparison between substrates and resonance frequencies as well as its parameter values

Substrate (ε_r, $tan\ \delta$, h (mm))	Resonance frequencies (GHz)	S-11 (dB)	VSWR	Directivity (dBi)	Gain (dB)
Felt (1.2, 0.02, 2.0)	3.99, 7.18	-19.04, -24.42	1.27, 1.14	5.48, 8.69	0.810, 4.39
Denim (1.6, 0.02, 0.7)	3.51, 6.28	-8.63, -25.1	2.2, 1.12	6.71, 6.32	0.43, 1.27
Leather (1.79, 0.042, 2.0)	2.86, 6.78	-14.12, -14.06	1.49	4.89, 10.20	0.43, 6.23
Polyester (1.9, 0.04, 1.5)	3.29, 5.89	-16.37, -46.38	1.38, 1.02	5.22, 6.72	0.27, 1.43

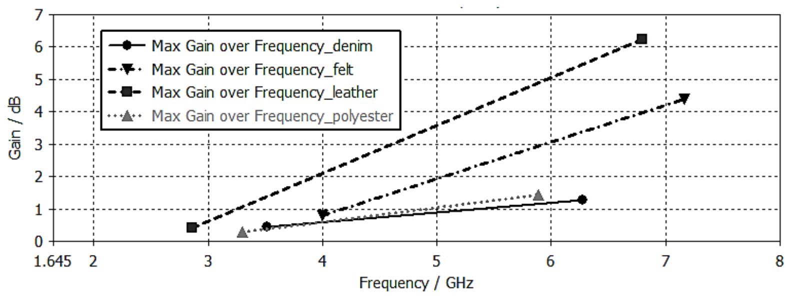

Figure 9. Maximum gain over frequency plot for different substrate fabric materials

Table 5. Properties of human body tissue model

Properties tissue model	Bone	Muscle	Fat	Skin
Permittivity	18.49	52.67	5.27	37.95
Conductivity (S/m)	0.82	1.77	0.11	1.49
Density (kg/m^3)	1008	1006	900	1001
Thickness (mm)	15	15	5	1

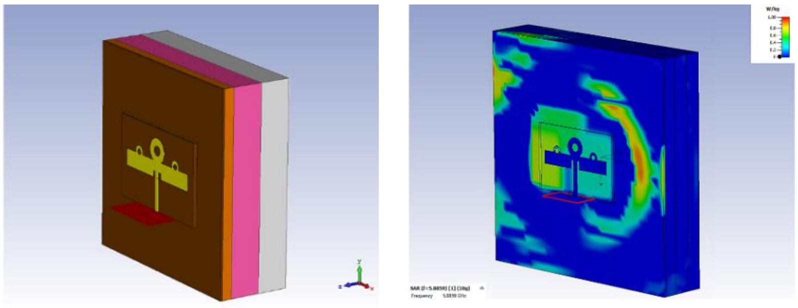

Figure 10. Patch antenna mounted on the flat body phantom of human body and SAR value of the proposed antenna on polyester for 10 g human body at a frequency 5.89 GHz

4. CONCLUSION

In the present work, a novel wearable fabrics dual-band antenna has been designed for UWB applications. The main objective of this research is to use textiles as the flexible substrate. The antenna structure working at 2.85 GHz to 7.3 GHz. According to the results, it is denoted that the designed antenna has the benefits of UWB, conservative size, good directional radiation patterns with acceptable of directivity, gain and importantly the SAR value is acceptable according to the ICNIRP. From the above result, type of substrate will influence the performance and resonant frequency of the antenna. Those designated antennas were designed with the same size and dimension onto the different types of textile substrate.

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