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Investigate Bending Effect of Wearable GPS Patch Antenna with Denim and Polyester Fabric Substrate

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Abstract—**In high technologies today, wearable devices have become popular. Wearable technology is a body sensing system that supports application of health observance and tracking through a wearable Global Positioning System (GPS). The design of the patch antennas is highly significant for the brilliance of the wearable patch antennas. This paper focuses on analyzing the bending effect on return loss and frequency between three types of GPS patch antenna. Types of GPS patch antennas that have been designed in this project are with different substrates and different designs. The wearable patch antenna has been designed and analyse using CST software. As a result, able to analysis the reflection coefficient (S11), radiation patterns, and analytical approach for patch antenna bending effect were obtained.**

Keywords—**denim and polyester fabric substrates; textile antenna; global positioning systems (GPS)**

I. Introduction

A WIRELESS body sensing system is now capable of supporting numerous Internet of Things (IoT) applications, including tracking, high-speed communication links, and health monitoring system via a wearable GPS and radio-frequency identification (RFID) via wearable technology [1], [2]. Wearable antennas such as GPS are in significant demand to support a wide range of wearable devices because of their flexibleness, lightweight, and easiness of integration with clothes [1]. The wearable antenna aims for communication applications to be part of clothes, including navigation tracking, mobile computing, health monitoring systems, as shown in Figure 1.

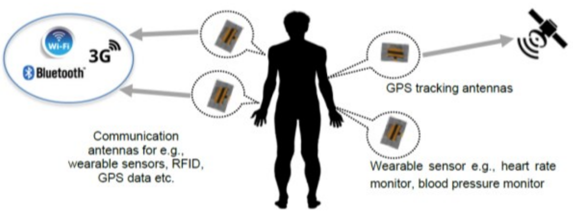

Fig. 1. Example of the wearable antenna of clothing for communication purposes [1]

Recently, GPS for various scientific purposes are widely used these days [3]. In addition, GPS is a global system used everywhere globally. Radio time arrangement systems have completely separate frequencies and are located on national borders with differing transmissions from one place to another [3]. On the other hand, GPS signals are comparable all around the globe.

Wearable systems are frequently part of our everyday body items such as shoes, watches, or caps, and the antenna substrate can also be our fabric material such as cotton or jeans. However, designing a wearable antenna for a wearable substrate could be a critical issue [4]. Wearable antennas are made from a variety of suitable insulators and semi-conductive materials. Therefore, these materials have been precisely selected to offer a low-cost quantity of mechanical deformations such as bending, twisting, and wrapping with the least amount of influence under various environmental circumstances such as rain, snow, or ice with proper Electromagnetic (EM) radiation shielding [5]. Previously, several types of fabric or non-fabric materials were utilised for wearable antennas, where the correct characterization of those textiles is crucial in the case of materials used [5].

The substrate utilized in the wearable antenna is paramount in terms of wearability, fabrication, or operation. Low primitiveness and loss tangent for most versatile substrates are employed [5]. Jeans, polyester, and silk are types of textile fabrics [5]. A previous study investigated the observed dielectric values of several textile fabrics [5]. Alternative research also conferred an entire inkjet-printed localization track and trace system on various substrates for the wearable antenna application [5].

Thus, the use of the different substrates will result in differences in the performance of the wearable antenna [5]. Some articles target a chosen antenna type for a particular purpose, hence modelling or measuring mounted bending conditions and analysing antenna effects [6], [7]. Two bending radii with two primary planes utilise the resonant frequency, bandwidth, and graphical output for three different patch antennas: conventional patch, magnetic attraction bandgap, and

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U-slot antennas [6]. Previous research examined the bending effects under three bending radii and three crumping situations of a textile, inverse F-antenna. Resonant frequencies and radiation patterns were examined, and the numerical and experimental methods [6].

This paper presents our research on types of wearable GPS patch antennas. The main purposes of this paper are to analyse the bending effect on return loss and frequency between types of GPS patch antennas. Then, also to compares the design of types of GPS patch antenna in terms of various designs and substrates. In addition, other purposes are to achieve the 1.575 GHz GPS band for the various designs of the patch antenna by using CST software.

II. SUBSTRATE MATERIALS

The substrate materials of the wearable GPS patch antenna used copper for conductive radiating elements, and non-conductivity (non-radiating) elements used Polyester fabric and Denim textile [8]. For the conductive radiating element such as copper, the conductivity plays a significant role in the antenna performance. Besides, the properties of the non-conductivity such as permittivity and loss tangent is important parameter for antenna design [8]. For this research paper, design three types of patch antenna design which tested on two different substrates for evaluation of the performance of the antenna design on different textile materials.

TABLE I
MATERIALS SPECIFICATION AT 1 GHZ TO 3 GHZ

Material type	Properties	Values
Copper	Thickness	0.5 mm
	Conductivity [9]	5.96e+007 S/m
Polyester Fabric	Thickness	2 mm
	Permittivity [10]	1.9
	Loss tangent [10]	0.0045
Denim textile	Thickness	2 mm
	Permittivity [11]	1.6
	Loss tangent [12]	0.01

III. FORMULA FOR PATCH ANTENNA

The width, length, and coax impedance (Zo) of wearable GPS patch antenna design can be calculated using the Equation (1) to (6) [13] [14].

$$W = \frac{c}{2fo\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\left(\frac{h}{W}\right)^{-\frac{1}{2}}] \quad (2)$$

$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon_{eff}}} \quad (3)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \quad (4)$$

$$L = L_{eff} - 2\Delta L \quad (5)$$

$$Zo = \frac{138 * \log(\frac{D}{d})}{\sqrt{\varepsilon_r}} \quad (6)$$

The calculated patch width and length were 83.53 mm and 73.83 mm, respectively. Therefore, the value of width and length is used as a starting point in designing GPS patch antenna at CST software.

IV. ANTENNA DESIGN

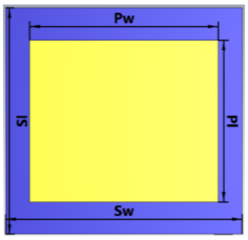
Three different antenna designs are designed and simulated using CST software. A square patch antenna represents design A. Next, a rectangular cross shape patch antenna represents design B, and an oval-shaped side with a rectangular cross shape patch antenna represents design C. The specification of the operating frequency for the GPS patch antenna is 1.575 GHz. The three designs of the GPS patch antenna are simulated and measured using two different substrates: polyester fabric and denim textile. Tables II, Table IV, and Table VI represent the design as shown in Figure. 2, Figure. 4 and Figure. 6 parameters, using denim textile as substrate. Tables III, Table V, and Table VII represent the parameter for the design as shown in Figure. 3, Figure. 5 and Figure. 7 using polyester as substrate.

TABLE II
PARAMETER OF THE DESIGN A WITH DENIM TEXTILE

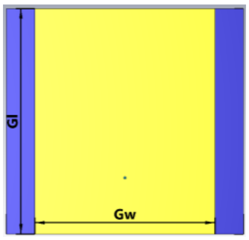
Parameter	Value (mm)
Pw	83.53
Pl	71.5
Sw	105
Sl	100
Gw	80
Gl	100

TABLE III
PARAMETER OF THE DESIGN A WITH POLYESTER FABRIC

Parameter	Value (mm)
Pw	83.53
Pl	66
Sw	105
Sl	100
Gw	80
Gl	100

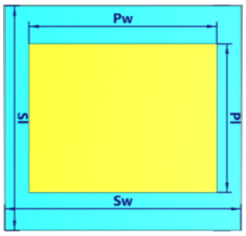


(a) Front view

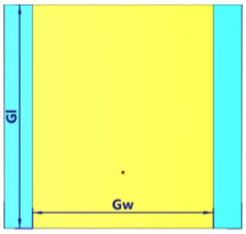


(b) Back view

Fig. 2. Design A (square patch antenna) with Denim Textile as Substrate



(a) Front view



(b) Back view

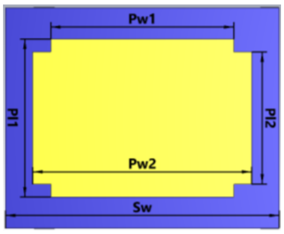
Fig. 3. Design A (square patch antenna) with Polyester Fabric as Substrate

TABLE IV
PARAMETER OF THE DESIGN B WITH DENIM TEXTILE

Parameter	Value (mm)
Pw1	83.53
Pl1	71.5
Pw2	100
Pl2	60
Sw	125
Sl	100
Gw	80
Gl	100

TABLE V
PARAMETER OF THE DESIGN B WITH POLYESTER FABRIC

Parameter	Value (mm)
Pw1	83.53
Pl1	66
Pw2	100
Pl2	60
Sw	125
Sl	100
Gw	80
Gl	100



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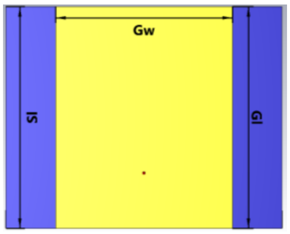
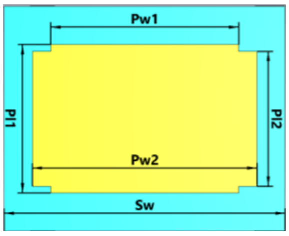
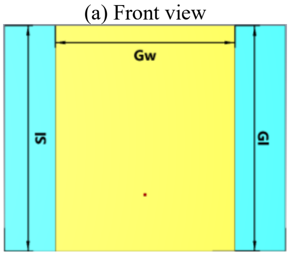


(b) Back view

Fig. 4. Design B (rectangular cross shape patch antenna) with Denim Textile as Substrate



(a) Front view



(b) Back view

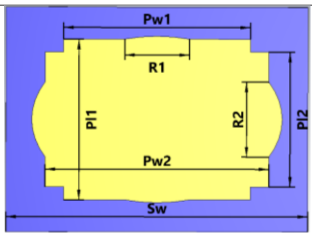
Fig. 5. Design B (rectangular cross shape patch antenna) with Polyester Fabric as Substrate

TABLE VI
PARAMETER OF THE DESIGN C WITH DENIM TEXTILE

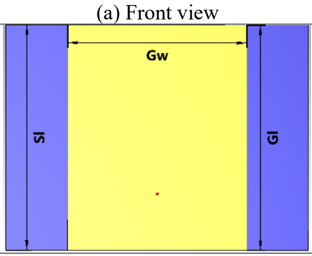
Parameter	Value (mm)
Pw1	83.53
Pl1	71.5
Pw2	100
Pl2	60
R1	28.87
R2	33.33
Sw	135
Sl	100
Gw	80
Gl	100

TABLE VII
PARAMETER OF THE DESIGN C WITH POLYESTER FABRIC

Parameter	Value (mm)
Pw1	102
Pl1	60
R1	60.71
R2	29.49
Sw	135
Sl	100
Gw	80
Gl	100

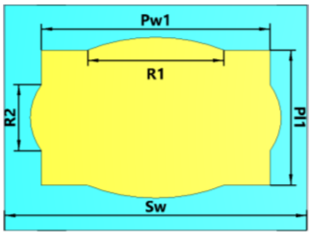


(a) Front view

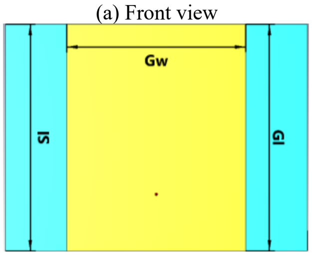


(b) Back view

Fig. 6. Design C (oval shaped side with rectangular cross shape patch antenna) with Denim Textile as Substrate



(a) Front view



(b) Back view

Fig. 7. Design C (oval shaped side with rectangular cross shape patch antenna) with Polyester Fabric as Substrate

V. Results and Discussion

A. Return Loss

The simulated return loss is carried out to see how the three types of designs and the two different substrates show resemblance in the 1.575 GHz resonance frequency. As the below graph shows, all of the designs radiate at the required frequency of 1.575 GHz and are able to attain a minimum of the -10 dB curve dip at the frequency effectivity. As shown in Figure. 8, the S11 of the design A substrate of denim textile and the polyester fabric achieved resonance frequency of 1.575 GHz, but tuning in design parameter needed; refer to Table 2 and Table 3 for the design parameter. The difference between the denim textile and the polyester fabric is the dip curve at 1.575 GHz, is -12.07 dB and -11.58 dB, receptively.

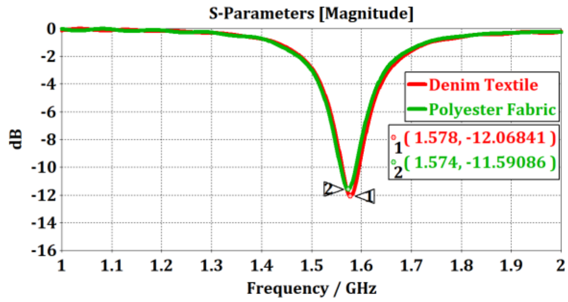


Fig. 8. S_{11} of Design A – Denim Textile and Polyester Fabric

In Figure. 9, the S_{11} of the design B substrate of denim textile and the polyester fabric achieved resonance frequency of 1.575 GHz, but tuning in design parameter needed; refer to Table 4 and Table 5 for the design parameter. The difference between the denim textile and the polyester fabric is the dip curve at 1.575 GHz, is -17.60 dB and -16.91 dB, receptively. In Figure. 10, the S_{11} of the design C substrate of denim textile and the polyester fabric achieved resonance frequency of 1.575 GHz, but tuning in design parameter needed; refer to Table 6 and Table 7 for the design parameter. The difference between the denim textile and the polyester fabric is the dip curve at 1.575 GHz, is -19.92 dB and -15.51 dB, receptively.

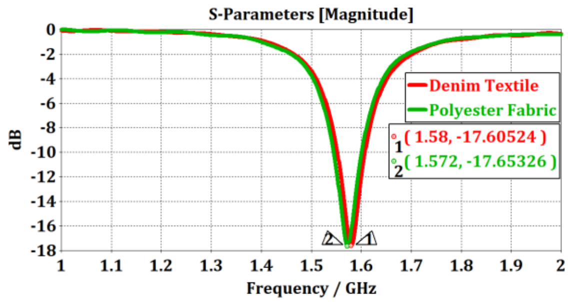


Fig. 9. S_{11} of Design B – Denim Textile and Polyester Fabric

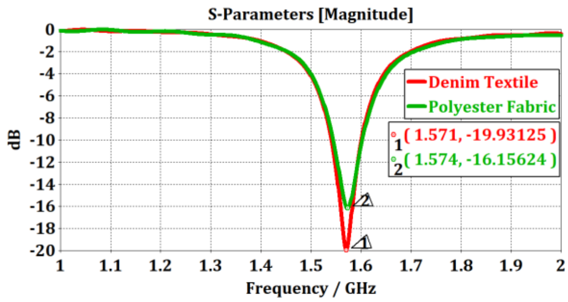
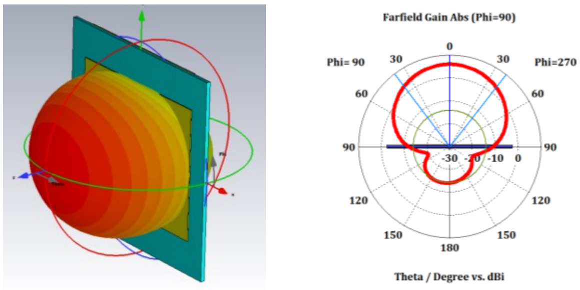


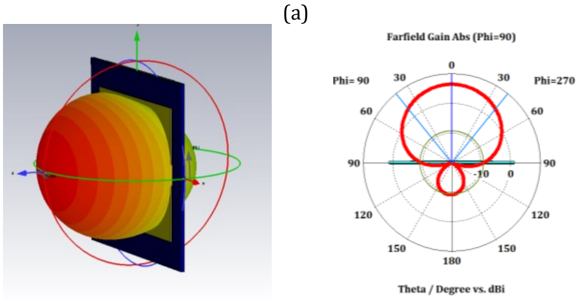
Fig. 10. S_{11} of Design C – Denim Textile and Polyester Fabric

B. Radiation Patterns

An antenna's radiation pattern refers to the angular distribution of the antenna radiated power density. The radiation model can be understood simply as representing an antenna's tendency to radiate electromagnetic energy in a far-reaching region. The antenna gain describes how much power is transferred to one of an isotropic source and expressed in dBi in the direction of peak radiation. In Figure. 11, the radiation pattern is in gain, which (a) is 5.99 dBi and (b) is 6.41 dBi. The difference in gain between (a) and (b) is noticeable due to the permittivity of the substrate used. The radiation pattern of design is shown in Figure 12, its gain for denim textile is 6.25 dBi and 6.51 dBi for polyester Fabric. Figure 13 shows the radiation pattern in gain, which (a) is 6.29 dBi and (b) is 6.55 dBi. The different in gain between Figure. 12 and Figure. 13 is similar due to the shape of design and permittivity of the substrate used. The three design gains are from 5.99 dBi up to 6.55 dB, and the gain is slightly higher for design C than design A and design B.

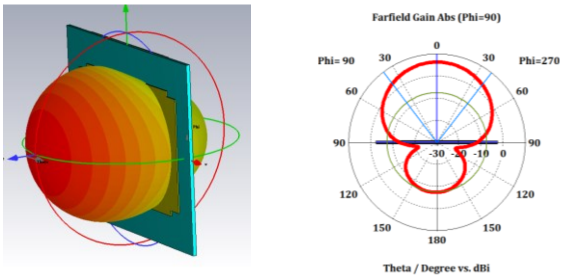


(a)

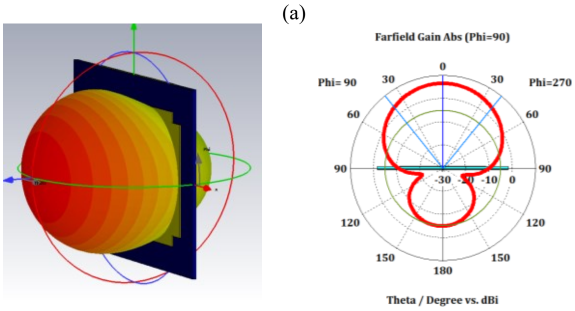


(b)

Fig. 11. Farfield radiation pattern of (a) Design A – Denim Textile and (b) Design A – Polyester Fabric

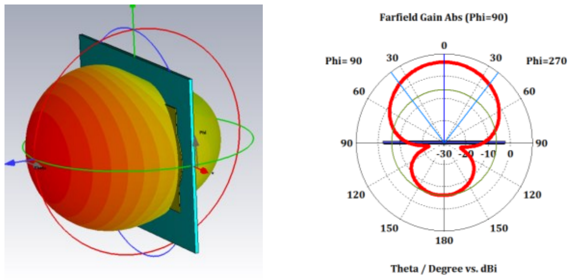


(a)

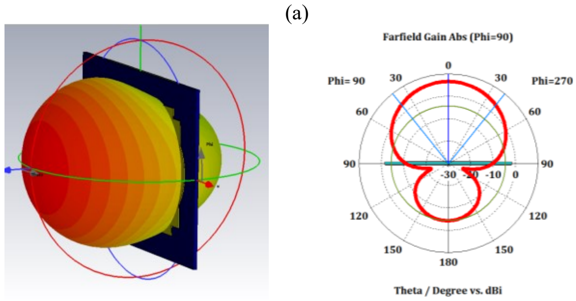


(b)

Fig. 12. Farfield radiation pattern of (a) Design B – Denim Textile and (b) Design B – Polyester Fabric



(a)



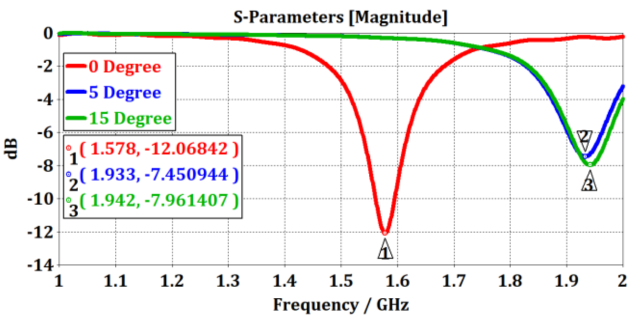
(b)

Fig. 13. Farfield radiation pattern of (a) Design C – Denim Textile and (b) Design C – Polyester Fabric

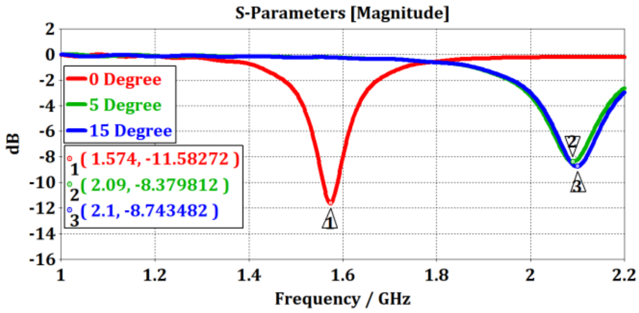
C. *Analytical Approach for Patch Antenna Bending Effect*

Fig. 14. The Bottom View of Design A bended to 5 Degree.

As shown in Figure 15, the performance of S11 for design A - denim textile before bending is 1.578 GHz. While for bending, the design A at 5 degrees, as shown in Figures 14 and 15, is 1.93 GHz and 1.94 GHz, respectively. Besides that, the return loss is also affected by bending the design; it significantly reduces from -12.07 dB to -7.45 dB and -7.96 dB. Next, the bending of Design A – polyester fabric, S11 in 0 degree is 1.574 GHz, while for 5 degree is 2.09 GHz, and 15 degree is 2.1 GHz. The return loss is also affected by bending the design and significantly reduced from -11.58 dB to -8.37 dB and -8.74 dB.



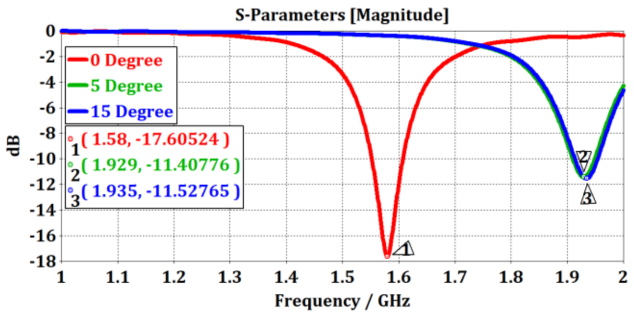
(a)



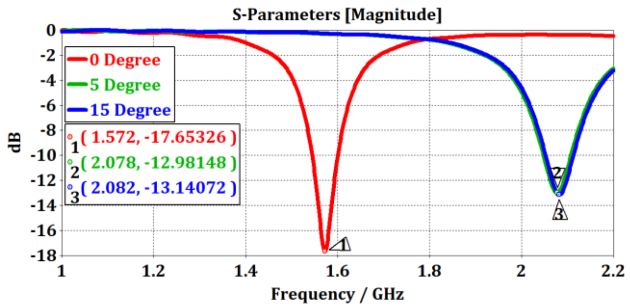
(b)

Fig. 15. (a) Design A - Denim Textile (b) Design A – Polyester Fabric

The result of S11, as shown in Figure. 16 of the design B – denim textile, is 1.579 GHz, bending at 0 degree, while for 5 degree is 1.93 GHz and in 15 degree is 1.94 GHz. The return loss is also affected by bending the design, reduce from -17.6 dB to -11.41 dB and -11.53 dB. The result for the design B - polyester fabric in S11 for bending at 0 degree is 1.572 GHz. After the bending effect, the result S11 for polyester for 5 degree is 2.08 GHz, and for 15 degree is 2.078 GHz. Besides that, the return loss for the design B - polyester, also reduce from -17.65 dB to -13.141 dB and -12.981 dB.



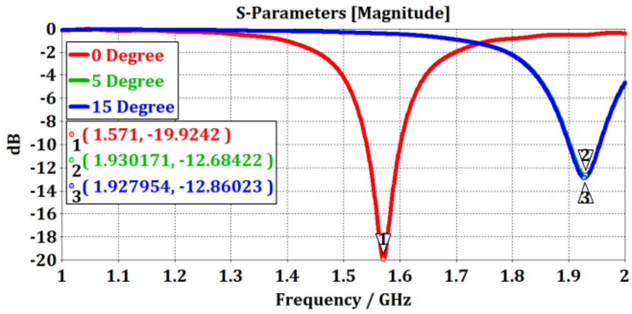
(a)



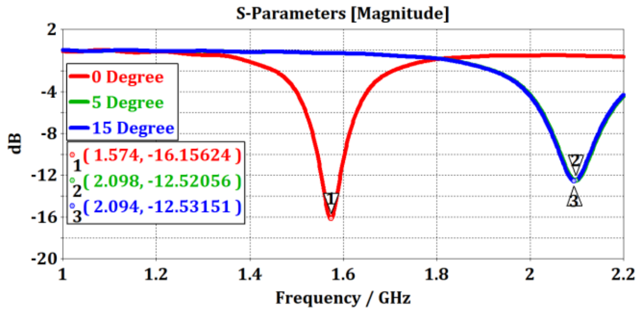
(b)

Fig. 16. (a) Design B - Denim Textile (b) Design B - Polyester Fabric

From Figure 17, the result S_{11} for design C – denim textile bending at 0 degree is 1.571 GHz, while the result for 5 degree is 1.93 GHz, and in 15 degree is 1.928 GHz also. The return loss is also affected by bending the design, reduced from -19.92 dB to -12.68 dB and -12.86 dB. The result of the design C - polyester fabric for 0 degree is 1.574 GHz, while for 5 degree is 2.098 GHz and for the 15 degree is 2.094 GHz. Besides that, the return loss for the design C - polyester, also reduce from -16.16 dB to -12.521 dB and -12.532 dB.



(a)



(b)

Fig. 17. (a) Design C - Denim Textile (b) Design C – Polyester Fabric

CONCLUSION

The conclusion that can be made based on this research on the types of wearable GPS patch antenna design and different substrates for analysing the bending effect on return loss and frequency shifting in S11 achieve the objectives through this research. First, analysis on different shapes of antenna design is done by creating three types of design: a simple square patch antenna (design A) a rectangular cross shape patch antenna (design B), and an oval-shaped side with rectangular cross shape patch antenna (design C). All the different shape of the antenna design has achieved a resonant frequency of 1.575 GHz but shown the different value of return loss due to the shape of the patch design. Then, testing is carried out to analyse the effect of the different use of the substrate, denim textile and polyester fabric, on the three types of GPS patch antenna design. Throughout the analysis, the return loss is almost similar between the types of patch antenna design using denim textile shows a much lower dip curve than polyester fabric material for substrate. After that, analysis in term of radiate pattern mainly focus on the gain which Design B has a gain of 6.51 dBi, the rest of the design is relatively the same but minor differences. Lastly, the bending effect on frequency shifting occurs even with a little of 5 degree of bend to the patch antenna design, similar to how the curvature of a human arm influences its performance by creating a resonance frequency shift. Besides that, bending also affects the performance of the return loss.

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