The Design and Measurement of Modified Capsules-Shaped Patch Antenna with Textile Material

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Abstract. *This article presents a design technique for a modified capsule-shaped (MCSS) patch antenna for the ISM band centered on 2.45GHz. In the design, a blue denim fabric was used as a layer of the substrate material and covered with a conductive fabric layer on both sides. The main objective of this research is to reduce the total size of the radiating layers of antenna whereas the main properties of the antenna are remained the same. The total size of the antenna while modifying the capsule-shaped (CSS) patch antenna by adding multi-slot on the patch, which made the total radiation patch area 38% smaller than the original size (the size of the radiating layer was reduced from 125mm. x 45 mm. to 90 mm. x 45 mm.). However, the results of the measurements showed that the antenna gain was quite different from the simulation. The simulation results of the designed antenna showed an antenna gain value of 9.18dB, while the measurement result from the prototype antenna was 5.35dB. Finally, the impedance bandwidth from the simulation and measurement results were 2.4123GHz-2.4904GHz and 2.4173GHz-2.5112GHz, respectively.*

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1. Introduction

The 2.45GHz ISM band is one of the frequencies commonly used in wireless networks such as wireless local area network (WLAN) as well as wireless body area network (WBAN). WBAN is a very interesting protocol for healthcare monitoring networks, typically used in the 2.45GHz band [1-4]. WBAN normally consists of sensors attached to the patient's body to measure various medical data and communicate to a wireless network.

The measuring instruments on the sensors are responsible for measuring the various values of the patient monitor the health condition and then transmitting the data through the main network for storage for long-term treatment. Generally, the shape of a human body is cylindrical with a curved surface, so an antenna made of a flexible material which can be bent on a curved surface is more suitable for a WBAN. For this reason, WBAN antennas for small sensor devices are often made of flexible materials [5-12]. The benefits of a flexible antenna include more suitable characteristic for curved surfaces and the efficiency of antenna size which is convenient for using on different body parts. Flexible materials, such as stretchable textiles, are more interesting because they can be better attached to the human body. For on body antennas, it is necessary to be compacted so that it can be easily installed without interrupting the user's daily life. Therefore, when designing an antenna to be applied on the human body, besides considering the gain, a suitable size is also necessary.

The main contribution of this work was to study the ability of modified capsule-shaped (MCSS) patch antenna to reduce the total size of antenna that can optimize the effect on the antenna properties. Otherwise, the study results also showed that antenna modified with multi-slot can be used to reduce the radiating size of antenna but still improve the main characteristics of antenna. The computer model will show the radiation pattern result of the antenna and the other properties such as antenna gain and bandwidth will be discussed.

The paper was divided into five sections as follows. The first section is the introduction of WBAN and the background of this study. The second section is the structural design along with discussion on CSS patch antenna. Then, the effect of multi-slot is shown as a result of simulations. Then, the results of measurement from the prototype antenna are discussed. Finally, the last section is conclusion.

2. Antenna Design

For the normal form, micro-strip patch antennas consist of two parallel conductive components including radiating element and ground plane, separated by a dielectric substrate. The dielectric materials used for the design were made from textile called blue denim. On the other hand, the patch and ground layers of antenna were made from conductive fabric (Pure Copper Polyester Taffeta Fabric - PCPTF).

In the construction of textile antenna, a layer of conductive fabric (PCPTF) is cut off before it is attached to the surface of substrate (blue denim or other textile material) by suture or glue. [10]. The electromagnetic characteristics of the blue denim fabric used in antenna design were measured using coaxial technique with the N1501A Dielectric Probe Kit. The characteristics of the textile material used in the antennas design were reported in [10-12]. The result of dielectric constant (ε_r) at 2.45GHz was 1.95. The thickness of the blue denim substrate was 0.91 mm. The conductive fabric's parameters were provided by the manufacturer [13], the thickness was equal to 0.08 mm. and conductivity (σ) was equal to 2.5×10^5 S/m.

The radiating parts of CSS patch antenna was based on basic rectangular patch antenna with two halves of circular at both ends. So, the rectangular patch antenna was designed to the procedure described in [14-17], using (1) – (4) as follows.

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{2}$$

where

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$

After the basic design of rectangular patch antenna with blue denim and textiles conductor was used in the simulation, centered at 2.45GHz. After that, two halves of circular shape were added at both ends to form a textile CSS patch antenna. Then, a micro-strip feed was used to provide a build suitability that was easier to design and adjust, as well as more convenient than using a coaxial probe as being used in [10]. So, the micro-strip feed and a quarter wavelength transformer were used as connection ports on the bottoms of antenna as shown in Fig.1. The dimension of each parameter was shown in Table 1.

The antenna model was simulated by commercial simulation software [18]. According to the simulation, the designed antenna was expected to operate at the center frequency of 2.45GHz with 2.76% (2.4154-2.4830GHz) fractional bandwidth for 10 dB return loss and the S11 at center frequency (2.45GHz) was -24.818dB as shown in Fig. 2.

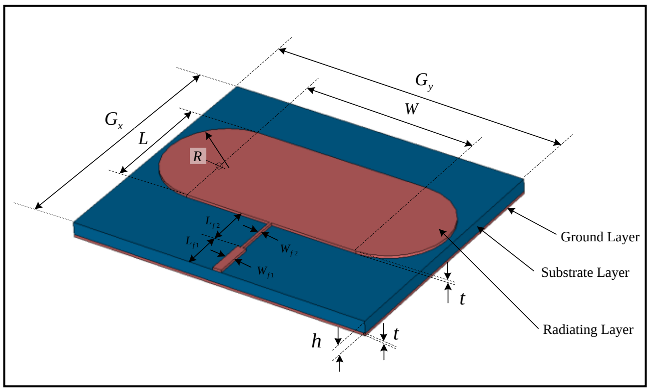


Fig. 1 Basic CSS patch antenna model

Parameter Name	Value (millimeter(s))	Parameter Name	Value (millimeter(s))
G_x	120.00	G_y	130.00
h	0.91	t	0.08
W	80	L	45
L_{f1}	14	L_{f2}	20
W_{f1}	2.8	W_{f2}	0.5
R	$L/2$		

Table 1 Basic CSS patch antenna parameters

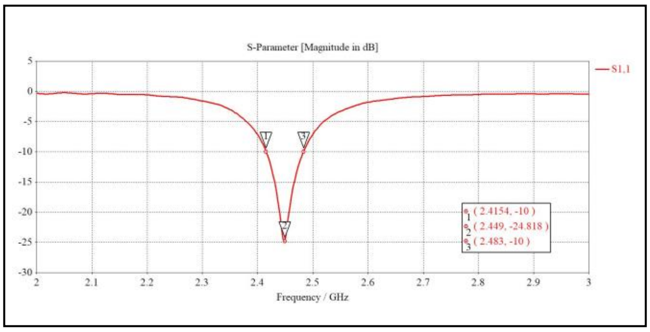
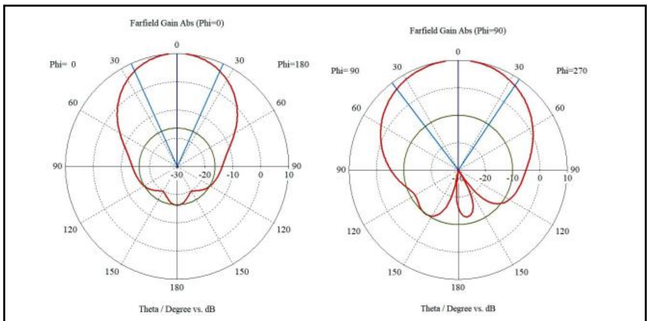


Fig. 2 S11 from simulation result of CSS patch antenna



a) vertical plan b) horizontal plan

Fig. 3 Radiation pattern for CSS patch antenna from simulation

The result shown in Fig. 3 presents the simulated 2D far-field radiating patterns of the CSS patch antenna using textile material and conductive fabric at 2.45 GHz. The antenna's layout was laid on XY-plane. The simulation indicated a maximum antenna gain of 10.10dB. The antenna was a directional antenna consisting half power beam-width (HPBW) equal to 48.4 degree for azimuth plane and 71.2 degree for elevation plane at the main lobe on Z-direction.

3. The Modified Capsule-Shaped Patch Antenna

The size of the CSS patch antenna illustrated in Fig.1 was bigger when being compared to the basic rectangular shape patch antenna and it is necessary to have a suitable size. To optimize the characteristic of antenna and still minimize the size of patch, the multiple-slot technique was used. The dimensions of slot can be designed using the simulation optimize process as the result of the dimension of each parameter was shown in Table 2. The size of radiating patch antenna after being modified with multi-slot was 38% smaller than the original size (the size of the radiating layer was reduced from 125mm. x 45mm. to 90mm. x 45mm.) as shown in Fig.4.

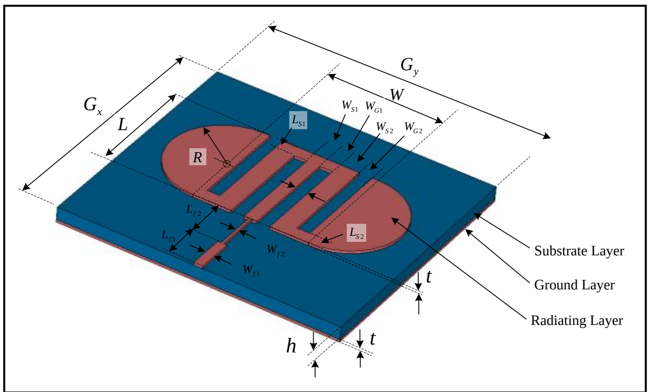


Fig. 4 MCSS patch antenna model

Parameter Name	Value (millimeter(s))	Parameter Name	Value (millimeter(s))
G_x	120.00	G_y	130.00
h	0.91	t	0.008
W	45	L	45
L_{f1}	18	L_{f2}	24
W_{f1}	2.8	W_{f2}	0.5
L_{s1}	40	L_{s2}	40
W_{s1}	5	W_{s2}	7.5
W_{g1}	5	W_{g2}	5
R	$L/2$		

Table 2 MCSS patch antenna parameters

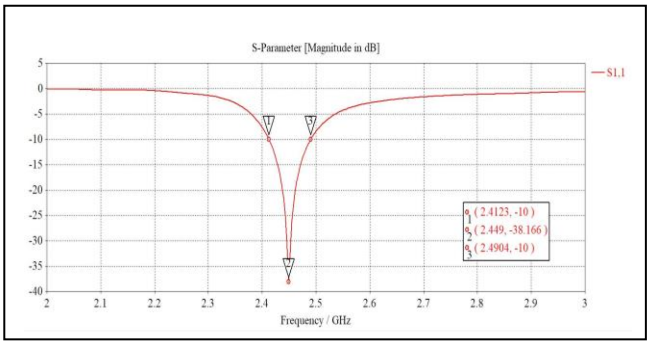
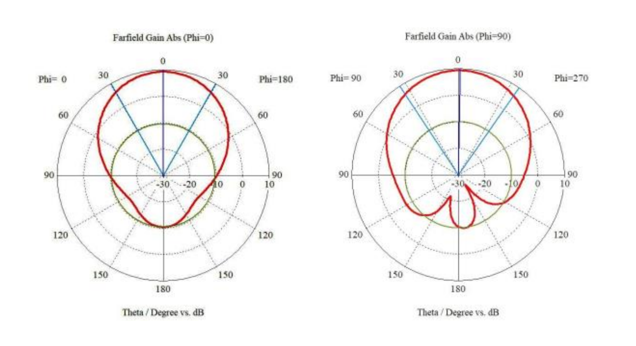


Fig. 5 S11 from simulation result of MCSS patch antenna



a) vertical plan b) horizontal plan

Fig. 6 Radiation pattern for MCSS patch antenna from simulation

It was found that the bandwidth of MCSS patch antenna from the simulation results started from 2.4123GHz to 2.4904GHz (3.18% bandwidth) and the return loss at center frequency (2.45GHz) was -38.166dB.

Fig. 6 presents the results of the simulated far-field radiating patterns of the MCSS patch antenna using blue denim as substrate layer and operating at 2.45 GHz. The simulation results showed that the antenna received a maximum of 9.18dB, which was 0.92dB lower than the original CSS patch antenna. The HPBW was 59.0 degree for azimuth plane and 68.2 degree for elevation plane at the main lobe on Z-direction.

4. Fabrication and Measurement

Firstly, the blue denim was used as the dielectric layer of the antenna; the PCPTF structure was used as the radiating patch; and the ground layer was cut. Then the conductive fabric material (PCPTF) and the blue denim were glued together. After that, the SMA connector was installed at the bottom of the antenna. The completed antenna was illustrated in Fig. 7. The radiation pattern of the antenna was measured by a network analyzer E5063A in an anechoic chamber.

Fig. 8 and Fig. 9 present the return loss values and radiation pattern obtained from the simulated and measurement results of the proposed antenna, respectively.

Fig. 7 MCSS patch antenna prototype

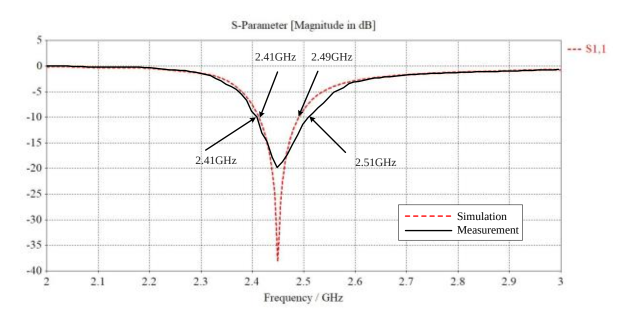
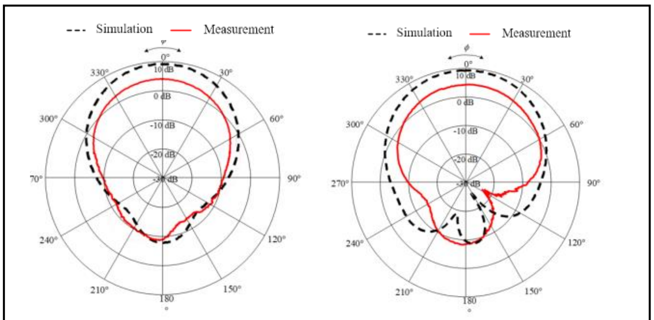


Fig. 8 S11 for MCSS patch antenna from simulation and measurement



a) vertical plan b) horizontal plan

Fig. 9 Radiation pattern for MCSS patch antenna from simulation and measurement

The bandwidth of MCSS patch antenna from the measurement results started at 2.4173GHz to 2.5112GHz (3.83%) but the center frequency band (2.45GHz) was -20.613dB as shown in Fig 8. Then, the radiation pattern from the simulation and measurement of MCSS patch antenna was shown in Fig. 9. From the measurement result, the gain of the prototype antenna was 5.35dB on front direction.

5. Conclusion

A MCSS patch antenna for 2.45GHz ISM band with blue denim material was presented and studied. The performance of the designed antenna was simulated as being considered to reduce the total size of the radiating layers of antenna while maintaining the main properties of the antenna. The result of the simulations revealed that bandwidth of antenna was of 3.18% compared with 3.83% of the results from prototype antenna measurements. However, the results of the measurements showed that the antenna gain was lower than the simulation. According to the simulation results of the proposed antenna, the gain was 9.18dB. Meanwhile, the measurement results of the value of prototype antenna, the value was 5.35dB. The multi-slot technique used in this research reduced the radiation patch area especially the patch width from 125mm. to 90mm. However, a limitations and constraints of the study was the effect of multi-slot technique on the other antenna properties including with gain and radiation pattern. So, the recommendations based on this study show that the textile material can be used as substrate of a flexible antenna and the technique of multi-slot can be used to improve the properties of antenna and also to reduce the radiating size of antenna. The results of the study showed that the MCSS antenna helped make the antenna suitable for using with various kinds of communication application because it caused the total radiation patch area smaller than the original CSS patch antenna size.

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