



EMBROIDERED DUAL BAND TEXTILE ANTENNA FOR ISM BAND APPLICATION ON BENDING PERFORMANCE

R. Vejasegaran¹, M. Jusoh¹, M. R. Kamarudin², H. A. Rahim³, F. Malek³, T. Sabapathy¹ and M. S. Shakhirul¹

¹Radio Engineering Research Group, School of Computer and Communication Engineering, Universiti Malaysia Perlis, Kampus Pauh Putra, Arau, Perlis, Malaysia

²Wireless Communication Centre - Centre of Excellent, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, UTM Johor Baharu, Johor, Malaysia

³School of Electrical System Engineering, Universiti Malaysia Perlis, Kampus Pauh Putra, Arau, Perlis, Malaysia
E-Mail: muzammil@unimap.edu.my

ABSTRACT

This research proposes a development of embroidered dual band textile antenna that could integrate wearable telecommunication device with a garment. The proposed antenna could operate at 2.4 GHz and 5.8 GHz of WLAN applications. Two versions of the presented antennas are developed from the conventional rectangular patch. Two types of slot structures are loaded on each antenna and the antenna performances are investigated. The research uses silver patted nylon and cotton wearable as conductive and nonconductive materials. Both antennas have successfully achieved reflection coefficient of less than -10dB at the targeted bands. Besides that, the antennas have directional pattern with a gain of more than 2.5dBi. Moreover, antenna performances on bending conditions of 20°, 30°, 40°, 50°, 60°, 70° and 80° have been carried out in simulation in terms of the reflection coefficient. The proposed antenna could be potential for closed point to point communication such as wireless power transfer for pacemaker application.

Keywords: dual band, textile antenna, embroidery and bending performances.

1. INTRODUCTION

The evolution of antenna technology for man-machine interface has taken quantum leaps in utilizing textile materials as antenna substrates, ground or patch. In the future, this will allow complete freedom to design body-worn antenna systems embedded in smart clothes. Smart clothes soon may find their place in our everyday living. They will emerge in various sports outfits, emergency workers outfits, military, medical and space applications [1]. The ability to establish wireless communication is one mandatory requirement for smart clothes.

Moreover, most of the wearable antennas developed in recent research operate on a single frequency band for wireless communications of 2.45 GHz only. Therefore, mobile network connections can be established at the same time by improving the antenna to resonate at dual band. The textile antenna proposed in this project is designed to operate for 2.4 GHz and 5.8 GHz due to significant interest in the Wireless Local Area Network (WLAN) applications for body worn devices. According to Malaysian Communication and Multimedia Commission (MCMC), the low cost of the equipment and the ease in setting up such networks compared to other networks, make it an interesting and hassle-free arrangement in providing short-range wireless communication to the public [2].

Several possible solutions are available in the literature can be implemented to allow a single radiating antenna to resonate on dual frequencies such as slot loading [3-5], slit [6], multilayer patch [7] and frequency reconfigurable through capacitor and shorting pins [8]. This paper focuses on slot loading technique and hence, presents analysis of different type of slot in the patches in terms of antenna performance. Algorithms are also

presented in section 4. Finally, our work of this paper is summarized in the last section.

The nature of wearable wireless technologies requires the integration of flexible, light weight, compact, and low profile antennas. At the same time, these antennas should be physically robust, efficient with a reasonably wide bandwidth for desirable radiation characteristics and achieve user comfort. Therefore, microstrip patch antenna is the most valuable candidate as it can be well integrated onto clothing. The proposed antenna in this project is fully made of fabrics. Textile antenna is different as compared to the typical micro strip antenna. In wearable application, the textile antennas are bendable and have a planar structure so that it does affect wearing comfort for the user.

Parametric studies on various slot structure have been carried that shows H- and L-slot have a better performance as compared to the other shape. The proposed H- and L-slot wearable textile antenna consists of a rectangular shaped patch with a 50 Ω transmission feed line. Analysis of the presence and absence of slot is executed in simulation in terms of reflection coefficient, S_{11} under targeted reflection coefficient, S_{11} of below -10 dB between the desired WLAN 2.4 GHz and WLAN 5.8 GHz for both antennas respectively. Further analysis is also carried out on bending angles of 20°, 30°, 40°, 50°, 60°, 70° and 80°. The slot antennas are design, simulated and optimized using CST Microwave Studio. Design and configuration of textile antenna with and without slot are described.

2. ANTENNA DESIGN AND CONFIGURATION

The proposed patch antenna is designed using silver plated nylon thread with thickness of 0.105 mm. The conductive thread is embroidered on cotton which has a



thickness of 0.5 mm [9]. The thread is sewn at the edges of the substrate that penetrate at the back of the substrate in embroidery method. Therefore, additional three layers of cotton are inserted between the conductive silver plated nylon thread and the ground layer, Nora Dell with thickness and conductivity of 0.17 mm and 1.538×10^6 S/m. The dielectric constant, ϵ_r of the cotton is 2.44 which has been measured using E8362B portable network analyzer (PNA) operates from 10 MHz to 20 GHz.

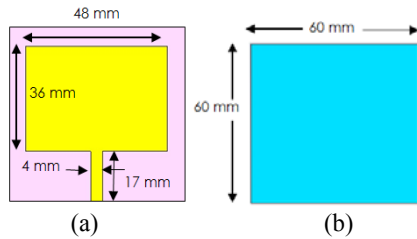


Figure-1. Initial single band antenna design without slot.
(a) Front view (b) Back view

A rectangular shaped antenna is designed using Transmission Line Model equation. The width and length of the rectangular patch is computed at 2.4 GHz using basic equations [10]. The patch with dimension of 48 mm x 36 mm is embroidered on 60 mm x 60 mm substrate which is compact and suitable for wearable applications. The ground size is tuned to get good impedance matching. Figure-1 and Figure-2 display the textile antenna with and without slot. Initially, antenna without slot is proposed. However, the reflection coefficient value is poor and does not achieve target of dual frequencies. Therefore, L-slot and H-slot is proposed on the middle of rectangular patch with feed line of 17 mm x 4 mm.

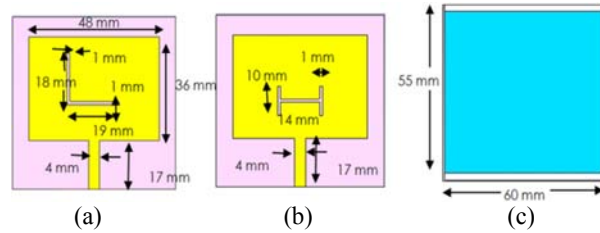


Figure-2. Dual band textile antenna. (a) L-slot (b) H-slot
(c) Back View.

3. RESULT AND DISCUSSIONS

Initially, two types of textile antennas with and without slot are studied inclusive of reflection coefficient, gain, efficiency and surface current. Moreover, further investigations have been made on the flat and eight bending conditions.

3.1 Analysis of embroidered dual band antenna with and without slot

Under tolerable S_{11} of less than $<- 10$ dB, the simulated antenna design using silver plated nylon conducting thread without slot has achieved a single band at 2.6 GHz, which does not meet the design specifications of dual band applications. Therefore, several slot of different shapes has been implemented at particular position of the wearable antenna which eventually resulted to good reflection coefficient $S_{11} <- 10$ dB at desired dual band frequency of 2.4 GHz and 5.8 GHz. A comparison of textile antenna with different types of slot with and without slot textile antenna has been summarized in Table-1.

Table-1. Comparison of simulated various types of slot antennas.

Type of antenna	Original	L-SLOT	H-SLOT
fr (GHz)	2.6158	2.3044 5.8706	2.3246 5.7566
S_{11} (dB)	-23.625	-21.162 -29.897	-16.809 -39.82
BW (MHz)	524.2	338 2401	389.1 2136.8
VSWR	1.141	1.192 1.066	1.3376 1.022
Gain	2.485	2.821 2.762	2.738 2.674
Directivity	6.962	5.290 5.163	5.118 4.979
Efficiency (%)	35.69	53.33 53.5	53.5 53.71

It is observed that textile antenna with slot has a low gain compared to the wearable antenna without slot of 4.215 dB at 2.4 GHz. Since more silver nylon conducting cut is removed, the value of gain has degraded with reduction of the effective aperture size of the antenna with slot as shown in Equation. (1)

$$G = \frac{4\pi A_e}{\lambda^2} \quad [1]$$



G is the antenna gain, A_e is the effective aperture size of the antenna and λ is the antenna wavelength. Originally, both H- and L-slot antenna have been designed for low frequency. By introducing a slot on the radiating patch has enables the antenna to resonate at dual frequencies as shown in Figure-3 and Figure-4. The pink line shows the reflection coefficient, S_{11} in dB without slot while the green line displays S_{11} value when a slot is created.

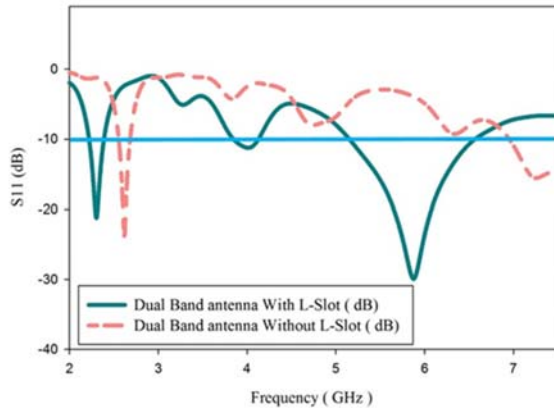


Figure-3. Simulated S_{11} of textile antenna with and without L-slot.

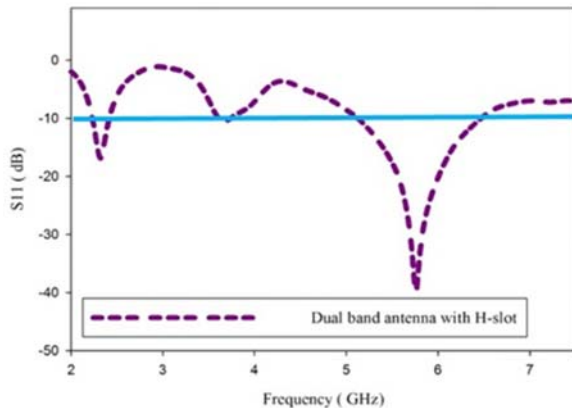


Figure-4. Simulated S_{11} of textile antenna with H-slot.

3.2 Surface current distribution

Figure-5 and Figure-6 represents the current flow at different frequency. It is observed in Figure-5 (a) and Figure-6 (a) that a good strength of current is radiating along the transmission line and distributed almost all over the patch at lower resonant frequency, 2.4 GHz for both L-slot and H-slot antenna.

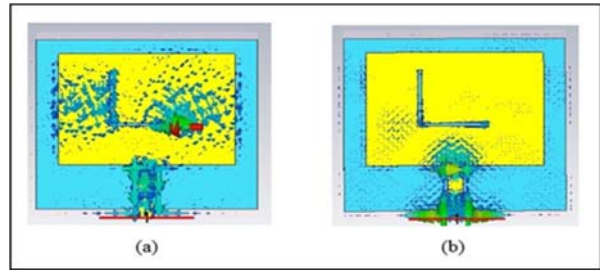


Figure-5. Current distribution for L-slot antenna (a) 2.4 GHz (b) 5.8 GHz.

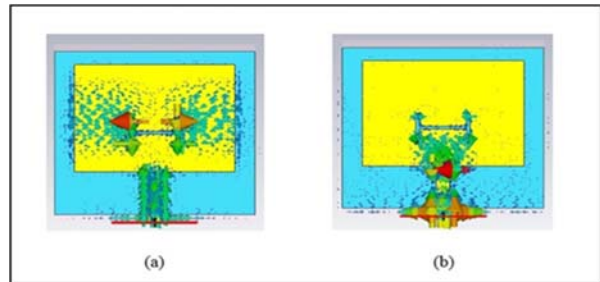


Figure-6. Current distribution for H-slot antenna (a) 2.4 GHz (b) 5.8 GHz.

At higher resonant frequency, 5.8 GHz, the surface current follows the path of slot as shown in Figure-5(b) and Figure-6(b). This is because slot loading allows a strong modification of the resonant mode of the rectangular patch, particularly when the slots are oriented to cut current lines of the unperturbed mode. Hence, slot loading is one of the most popular techniques for achieving dual-frequency behaviour to a single patch. The slot introduces a further resonant length that is responsible for the second operating frequency.

3.3 Radiation pattern

Figure-7 shows the radiation pattern (RP) of the proposed antenna. RP is defined as a graphical representation of the radiation properties of the antenna as a function of space coordinate. Usually, RP is determined in the far field region. There are a few of radiation properties such as power flux density, radiation density, and directivity phase. The radiation patterns can be represented in 2D and 3D version. Three dimensional RP are measured on a spherical coordinate system indicating relative strength of radiation power in the far field sphere surrounding the antenna.

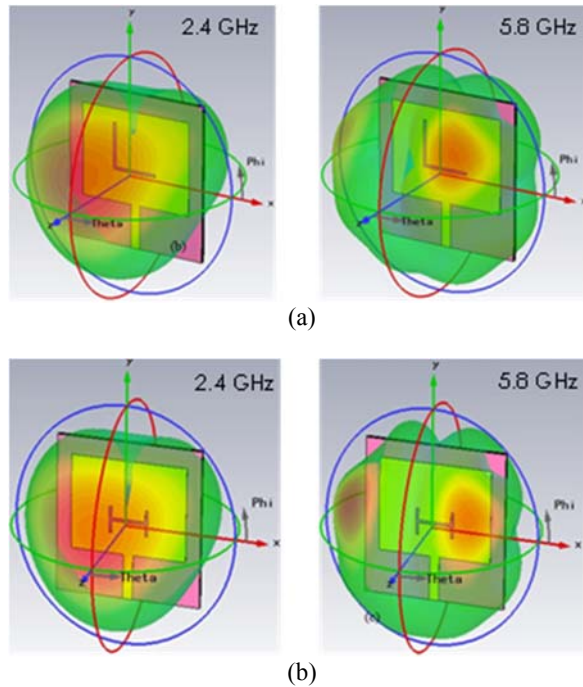


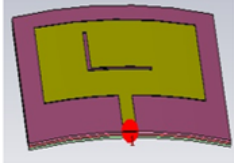
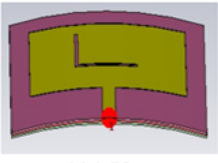
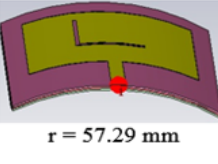
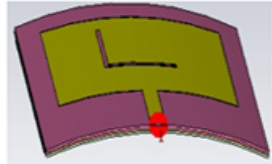
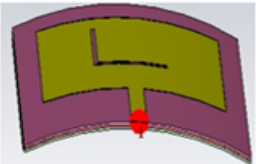
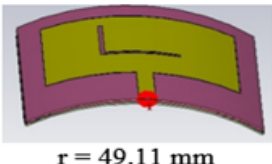
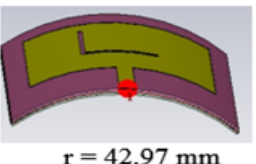
Figure-7. Radiation pattern of the proposed antenna. (a) L-slot and (b) H-slot.

At 2.4 GHz, the presented L-slot antenna has a 3 dBi gain while at 5.8 GHz of H-slot antenna, the gain is achieved as 2.7 dBi. Figure-7 (b) shows a 2.8 dBi gain at 2.4 GHz and has a 2.6 dBi gain at 5.8 GHz of the H-slot antenna. Both antennas achieved a radiated beam at z-axis at low frequency and indicate diversity beam at high frequency. Moreover, the gain of the antenna at high frequency is low as compared to the low frequency which has proven the equation [1].

3.4 Bending analysis of embroidered dual band antenna

The performance of the embroidered dual band antenna is also examined under the bend conditions since a textile antenna should be mobile when the user moves while maintaining its practicality. Besides that, resonant frequency and reflection coefficient, S_{11} need to be evaluated under bending conditions since the values have tendency to decrease due to impedance mismatch and a change in the effective electrical length of the radiating elements. There are seven focused bending angles of 20° , 30° , 40° , 50° , 60° , 70° and 80° as tabulated in Table-2. The bending is designed based on calculated cylinder radius. A big frequency shift toward lower frequencies can be observed for higher frequency bands as shown in Figure-8(a) and Figure-8(b).

Table-2. Bending conditions of embroidered dual band antenna with L-slot.

20 degree bending	30 degree bending
 $\theta = \frac{20 \times \pi}{180} = 0.349$ (Angle in radian) $r = \frac{S}{\theta} = \frac{60}{0.349} = 171.92 \text{ mm}$ (Radius of cylinder)	 $r = 114.59 \text{ mm}$
	60 degree bending
	 $r = 57.29 \text{ mm}$
40 degree bending	50 degree bending
 $r = 85.94 \text{ mm}$	 $r = 68.75 \text{ mm}$
70 degree bending	80 degree bending
 $r = 49.11 \text{ mm}$	 $r = 42.97 \text{ mm}$

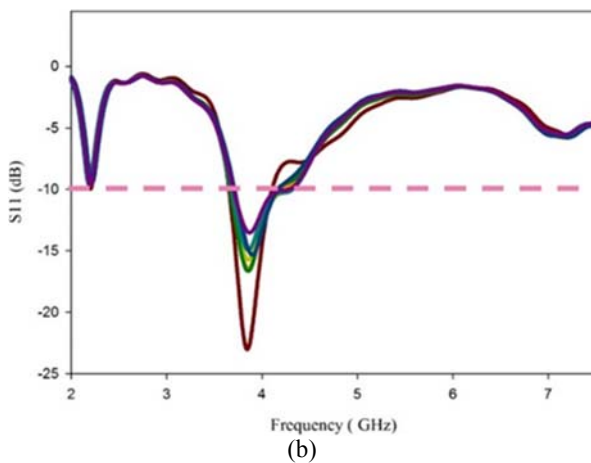
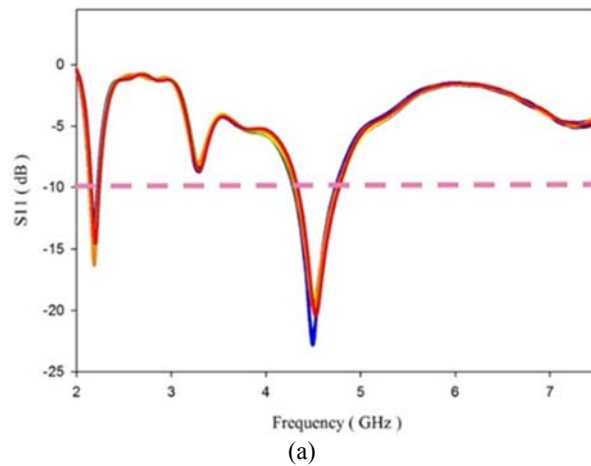


Figure-8. Simulated S_{11} of textile antenna under bend condition (a) L-slot (b) H-slot.

Furthermore, the bandwidth becomes slightly narrower at the lower frequency band and higher frequency band and the impedance matching decreases as shown in Figure-9. Even though, simulation results at all bending angles indicate some variations, the reflection coefficient, S_{11} are still below -10 dB. However, the S_{11} at 2.2 GHz for H-slot antenna are slightly above than -10 dB.

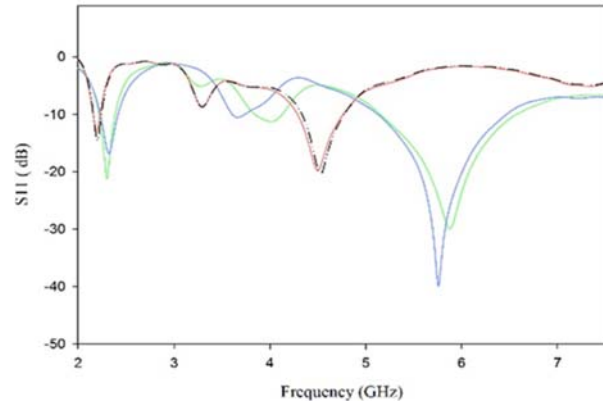


Figure-9. Comparison of bending and non-bending condition.

The effect of lowest and highest bending angle on functionality of the antenna is shown in Figure-10 and Figure-11 below. The more the L-slot antenna is bent, the lesser the reflection coefficient, S_{11} value which depicts better impedance matching. On the other hand, the S_{11} value increases with increase in bending angle for H-slot antenna.

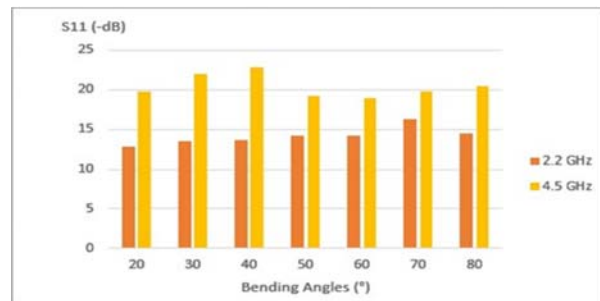


Figure-10. Effect of bending on reflection coefficient, S_{11} of L-slot antenna.

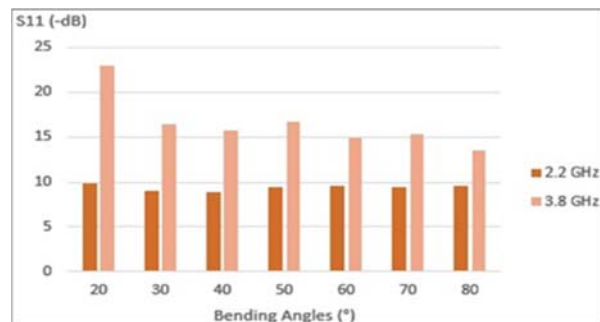


Figure-11. Effect of bending on reflection coefficient, S_{11} of H-slot antenna.

4. CONCLUSIONS

The proposed dual band textile antenna performances on flat and bending condition are investigated. The reflection coefficient, S_{11} falls below -10 dB between the desired dual band frequencies for both H-



slot and L-slot antenna. Besides that, both antennas have low power consumption in terms of gain and efficiency. The bending analysis of both slot antennas also shows that there is shift in resonant frequencies. With all features presented and discussed, the proposed antenna has sufficiently competent for 2.4 GHz and 5.8 GHz WLAN band application.

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