# Analysis on the Performance of Textile Circular Antenna under Bending Conditions

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***Abstract*—Wearable antenna is becoming a popular study in antenna technology. This paper presents a dual band wearable antenna for on body application. Since a wearable antenna is designed to be incorporated on human torso, this paper has been focusing on the performance of a dual band wearable textile antenna under bending conditions at both E-plane and H-plane. The reflection coefficient and radiation pattern of the antenna are investigated at dual WLAN band; 2.4 GHz and 5.2 GHz. In this paper, the bending effect on the microstrip patch antenna design is simulated in CST Microwave Software at the conditions of flat and bended with radius of 50 mm, 150 mm and 300 mm. The bending effect is most likely to be seen at smaller bending radius of E-plane propagation where the resonant frequency of the antenna shifted downwards. The radiation pattern of the antenna shows almost similar performance with the flat patch antenna condition especially at large bending radius. Therefore, this wearable textile antenna is suitable to be placed on body under bending condition and most effective at 300 mm bending radii.**

***Keywords—Microstrip patch antenna; dual band; antenna bending; WLAN***

## I. INTRODUCTION

Designing a wearable antenna which can be integrated into clothing has been a new trend reported in the literature [1]. This technology can be applied in some applications especially in medical and military communications. In military, the system introduced by the wearable antenna is important for communication between soldiers and other units of the battlefield. This purpose can be achieved by enhancing the situation awareness through some personal equipment such as GPS, digital radio, video recorder and wireless communication [2-5].

One possible application is to design an antenna using flexible substrate or fabric materials such as jeans, felt, and leather so that it may be placed on clothing [6]. However, it is impossible to keep the antenna flat all the time as human make movements every moment. Therefore, it is crucial to study the effect of bending the antenna on the antenna performance. The antenna should function properly even if under bent conditions. Previously, researchers have reported on the antenna performances on flat condition [6-8]. In this paper, the design of a conventional circular ring patch is presented to perform dual band frequencies for Wireless Local Area Network (WLAN) application. Finally, the effect of bending the antenna is discussed for simulation on both E- and H-plane of the antenna propagation. The bending is simulated on a cylinder surface with radius of 50mm, 150 mm, and 300mm. The cylinder represents the human torso [9] and the antenna is bent around the cylinder along two principal planes, E-plane and H-plane which will be evaluated in the next section. Later, the radiation pattern will be discussed to present the effect of bending to the radiation of the antenna.

## II. DUAL BAND WEARABLE ANTENNA

Due to several advantages of microstrip patch antenna, the telecommunication sector has been using this type of antenna widely for different applications. Microstrip patch antennas have various advantages that are important for antenna design, which they are easy to be fabricated, require low cost, low profile and light weight. Hence, this type of antenna has a structure which can be comfortably worn on body.

In this paper, a circular ring patch antenna is designed on a jeans as the substrate. The conductive part of the antenna is designed with a radius of $a$ using a copper sheet with a thickness of 0.02mm. The radius of the patch is calculated using (1)[10].

$$f_0 = \frac{c}{2\pi a\sqrt{\varepsilon_r}}x'_{mn} \qquad (1)$$

where $\varepsilon_r$ and $x'_{mn}$ are the relative permittivity of the substrate and the root of Bessel function respectively. The dominant Bessel function mode for a circular patch is $x'_{mn}$ which is equivalent to 1.842.

For wearable antenna, various textiles are suitable to be used as antenna substrate. Different substrates have different relative permittivity. Fabric substrates are electrically conductive and needs to satisfy some requirements such as a low and stable electrical conductance in order to minimize losses. The material must be homogeneous over the antenna area, and the fabric should be flexible so that it can be deformed when worn [11]. In this design, a jeans fabric with thickness and permittivity of 1.2 mm and 1.7 respectively has been used as the dielectric for the antenna. The conducting material jeans have a high quality material with low and stable electrical resistance of 0.05 Ohm/Sq.

The microstrip patch antenna in this paper is designed to operate at dual band frequencies; 2.4 GHz and 5.2 GHz. A partial ground plane is attached at the back of the substrate to prevent interference of the radiation around the patch. The circular patch antenna is matched with 50Ω impedance using microstrip feed line. Table 1 and Fig. 1 illustrated the proposed antenna optimized geometry for both operating frequencies.

The circular ring in Fig. 1 is introduced to perform dual band frequencies where the outer ring influences the low frequency while the inner ring acts as the radiator at high frequency. Results of return loss for flat condition in Fig. 3 and Fig. 4 show that the antenna covers a wider bandwidth range from 1.95 GHz to 5.79 GHz which is approximately 3.84GHz. Hence, the antenna is operating perfectly at both resonance frequencies of 2.4 GHz and 5.2 GHz as desired.

TABLE 1. DIMENSION OF PROPOSED CIRCULAR PATCH ANTENNA

| ***Parameters*** | ***Optimized dimensions (mm)*** |
|---|---|
| Width of Substrate ($W_s$) | 70 |
| Width of Ground ($W_g$) | 70 |
| Width of Microstrip Feed I ($W_{f1}$) | 4.3 |
| Width of Microstrip Feed II ($W_{f2}$) | 2 |
| Width of Inset Feed ($W_{inset}$) | 1 |
| Length of Substrate ($L_s$) | 90 |
| Length of Ground ($L_g$) | 30 |
| Length of Microstrip Feed I ($L_{f1}$) | 8 |
| Length of Microstrip Feed II ($L_{f2}$) | 23 |
| Length of Inset Feed ($L_{inset}$) | 5 |
| Radius of Slotted Circular | $R_1$ = 8 |
| Radius of Circular Disc | $R_2$ = 22 |
| Gap between slot (g) | 1 |

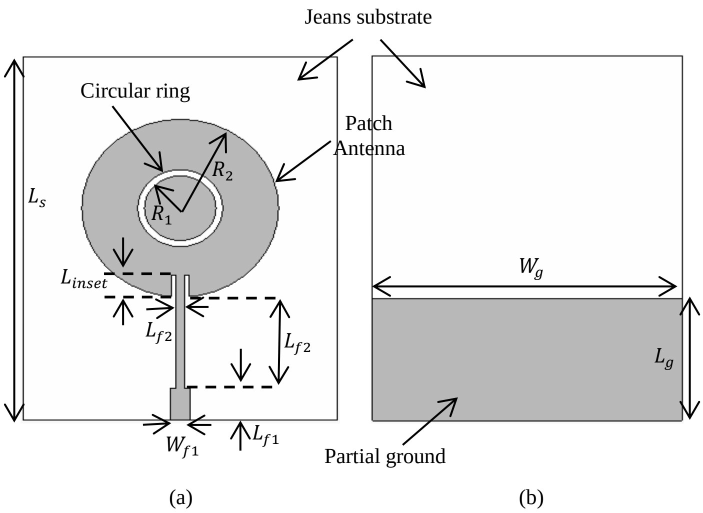



Fig. 1. Geometry of circular patch antenna (a) Front view (b) Back view

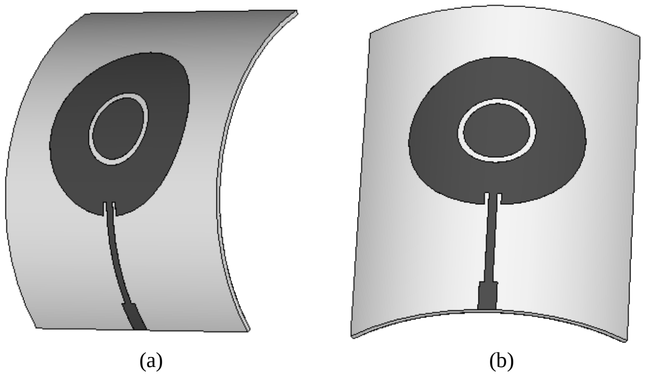



Fig. 2. Simulated bending antenna (a) E-plane bending (b) H-plane bending

## III. ANTENNA PERFORMANCE UNDER BENDING CONDITION

In this section, the effect of antenna under bending condition to the antenna performance will be analysed. The antenna is bent along two principle planes, E- plane and H-plane which are illustrated as in Fig. 2(a) and Fig. 2(b) respectively. The bending of the antenna are studied for four conditions; at flat condition, bent on 50 mm radius surface, bent on 150 mm radius surface, and bent on 300 mm radius surface. The radius of the bending are chosen to approximate human arm, human adult's leg, and the back of human body respectively. The surface for this analysis is considered as vacuum with permittivity of 1.

### *A. Reflection Coefficient*

Fig. 3 and Fig. 4 represent the effect of bending to the reflection coefficient of the antenna. In Fig. 3, the simulated result of the E-plane bending is illustrated. From the figure, it is shown that the resonant frequency shifted downwards with decrement of bending radius. This can be seen clearly at low band frequency. At low band, the resonant frequency shifts from 2.45 GHz to 2.26 GHz with bending radius of 50 mm while bending with radius 300 mm resulted in an upward shifting to 2.44 GHz. When analyzing the effect at high band, the resonant frequency shifted upwards as the bending radius increases. At 300 mm radii bending, the resonant frequency shifted from 5.21 GHz to 5.36 GHz. The reflection coefficient of the antenna increased by approximately 10 dB at low band and decreased by almost 15 dB at high band with bending radius 300 mm.

The results in Fig. 4 illustrated the H-plane bending effect at four different conditions. When the textile is bent along H-plane, the resonant frequency of the antenna is nearly unchanged at different bending radius. At all bending radius, the resonant frequency shifted upwards from 2.44 GHz to 2.46 GHz at low band and from 5.21 GHz to 5.2 GHz at high band. The reflection coefficient of the antenna increased by 3 dB at low band while there is a return loss reduction by 8 dB at high band.

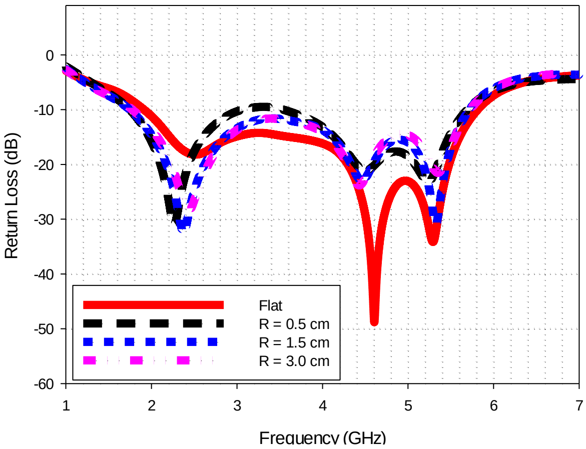



Fig. 3. Simulated reflection coefficient of E-plane bending

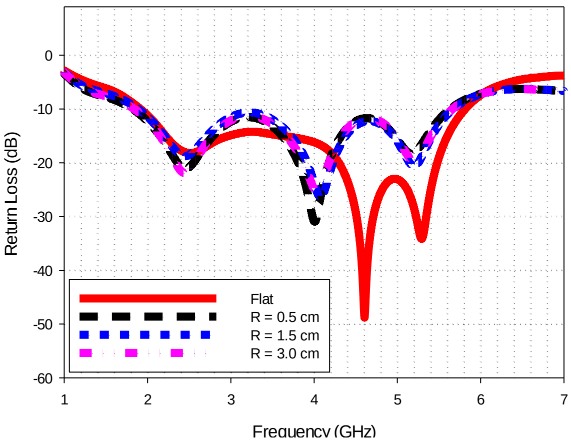
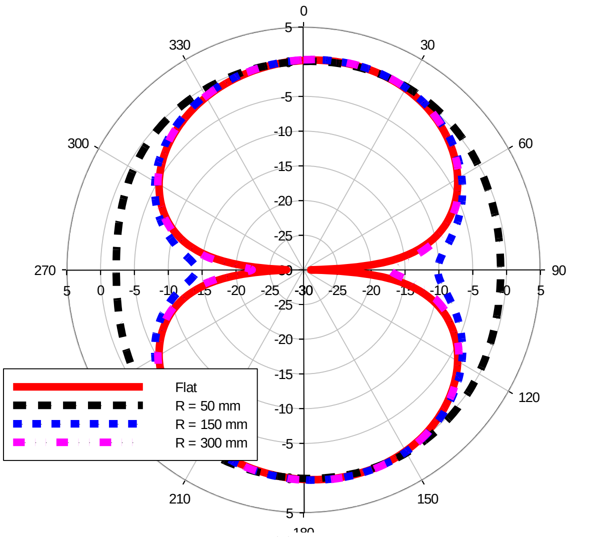
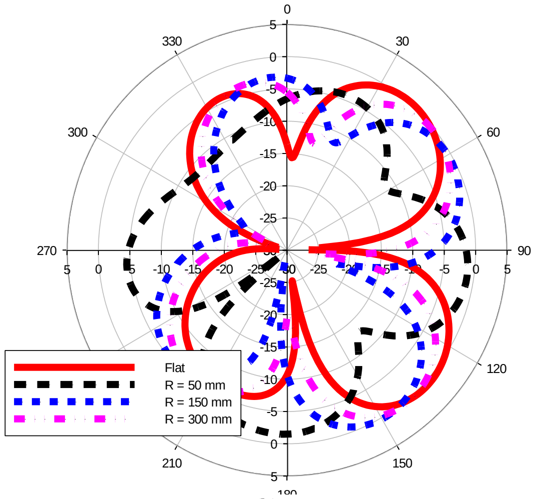



Fig. 4. Simulated reflection coefficient of H-plane bending




(a)

Fig. 5 (a). Simulated elevation radiation pattern gain of antenna in E-plane bending condition at 2.4 GHz




(b)

Fig. 5 (b). Simulated elevation radiation pattern gain of antenna in E-plane bending condition at 5.2 GHz

From the results, it is shown that bending along E-plane gives vulnerable effect compared to the bending along the H-plane. Therefore, in this paper, the analysis of radiation pattern effect from bending will only focus on the E-plane performance since the H-plane performance shifts are barely noticeable.

### *B. Radiation Pattern*

Fig. 5(a) and Fig. 5(b) illustrates the effect of antenna bending to the radiation pattern at both frequencies respectively.

From Fig. 5(a), no significant changes is seen when the antenna is bent on a larger bending radius. This is due to the propagation during bending at large radius is most likely as the flat condition. Bending the antenna has a slight effect for most extreme 50 mm radius case. An increment of 20 dB gain has been found at 90$^{o}$ and 270$^{o}$ when the bending is 50 mm in radius. This might due to the propagation along the feed line which is more directive when the antenna is critically bent.

Fig. 5(b) shows significant changes on the radiation pattern especially on smaller bending radius due to the interference at the inner ring of the patch during bending. This shows that the radiation pattern is more affected at the middle area of the patch when the antenna is bent along E-plane. The gain of the antenna at bending condition is approximately similar for all cases. For worst bending case of 50mm, the back lobe gain of the antenna is higher. For other cases, the radiation pattern with slightly increment in gain for approximately 5 dB compared to the flat patch antenna has been observed.

## IV. Conclusion

The paper has demonstrated the effect of bending to the reflection coefficient and radiating performance of the textile antenna. The study has shown good performance of antenna under bending condition. The effect of bending is severe along the E-plane with compared to the bending along the H-plane for both frequencies. For the bending along E-plane, the resonant frequency of the antenna reduced with small bending radius at both respective bands where as for H-plane, there are no severe effect on the performance of the antenna. The radiation pattern has also been studied for E-plane bending. The radiation pattern at high bending radius shows approximately similar performance as the flat patch antenna for both frequencies; 2.4 GHz and 5.2 GHz. From the analysis, the best performance can be achieved at large bending radius of 300 mm radius. This bending is made to represent human body. Hence, the performance of the antenna is highest when placed around the human body especially at the back of the body.

## Acknowledgment

The authors would like to thank University of Sheffield for their facilities. Great gratitude to Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education for their “Research Acculturation Grant: RAGS/2012/FKEKK/TK02/2 B0005“.

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