Textile Dual Band Circular Ring Patch Antenna under Bending Condition

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***Abstract*—Textile flexible wearable antenna is becoming a popular study in antenna technology. In this paper, the dual band textile circular patch antenna under bending condition has been designed and analysed. The antenna characteristics such as scattered parameters and radiation pattern has been analysed and compared for normal and bended conditions. Main desired application for the antenna might be on body network which required the wearable condition which incorporated on human torso. The reflection coefficient of the antenna has been determined at 2.4GHz and 5.2GHz which make the antenna to be suitable for WLAN application. To make the antenna suitable to attach on human torso sizes, three bending radii has been chosen, which are 33.5 mm, 47.5 mm and 58.5 mm. The simulated and measured results have been presented and analysed. The antenna with smaller bending radius has shown severe effect on the antenna resonant frequency. However, only slight effect on radiation pattern with compared to the flat antenna. Hence, from the result and analysis, the developed textile antenna is seen to be immune towards the effect of bending and suitable for wearable especial for WLAN application.**

***Index Terms*— Bending Antenna; Circular Antenna; Dual Band; Microstrip Patch Antenna; Wearable Antenna; WLAN.**

I. INTRODUCTION

Flexible wearable high performance antenna development for on the body application is one of the major focus on the antenna design. Various technical literatures with some related studies on this recent application has been presented[1-4]. Flexible wearable antenna which utilized various types of fabrics has been a new trend developed and reported [5-6]. This technology can be applied in some applications especially in medical and military communications. In the military, the system introduced by the wearable antenna is important for communication between soldiers and other units on 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 [7-9].

To make the antenna to be flexible and wearable, the antenna has been designed and developed by using the suitable flexible substrate or fabric materials such as jeans, felt, and leather, so that it may be placed on clothing [10]. However, it is impossible to keep the antenna flat all the time as human makes movements every moment. Therefore, it is crucial to study the effect of bending the antenna on the antenna performance. Hence, the antenna should function properly even if under bent conditions. Previously, various researchers have reported on the antenna performances on flat condition [11-13].

In this paper, the design of a flexible dual band conventional circular ring patch for Wireless Local Area Network (WLAN) application has been presented. In the design, the textile material which is call as jeans with relative permittivity of 1.7 has been used as the antenna dielectric substrate. The conductive adhesion copper sheet with the thickness of 0.02 mm has been used as conducting material for the antenna and ground plane. The copper sheet is glued onto the jeans material using the conductive glue at the back of the material. This will enhance the conductivity within the dielectric and the ground plane as well as the microstrip.

The antenna under bended condition has been simulated and measured either for E-plane and H-plane of the antenna propagation.

For on body application, it is impossible to keep the flexible antenna to be maintained at flat condition, hence, the study of the bending effect has been conducted with three consecutive bending radii; 33.5 mm, 47.5 mm and 58.5 mm. Cylinder foams with same permittivity of air (ε_r=1) has been applied to represent the human torso; where 33.5 mm radius represents human wrist, 47.5 mm radius represents human arm, while 58.5 mm radius represents human thigh [14].

The antenna has been bent around the cylinder along two principal planes, E-plane and H-plane, which has been evaluated and analyzed. The radiation pattern for all the conditions have been tabulated and discussed in order to analyze the effect of bending to the radiation pattern. The effects of the bending results are presented throughout this paper which covers the dual wireless networking bands; 2.4 GHz and 5.2 GHz.

II. ANTENNA BACKGROUND

A. *Circular Ring Patch Microstrip Wearable Antenna*

Microstrip patch antennas have various advantages which contributed toward better antenna design. The known advantages could be easy to be fabricated, low cost, low profile and light weight. Due to several advantages of microstrip patch antenna, the telecommunication sector has been widely using this type of antenna for different applications. To enable the antenna to be suitable for on body application, this type of antenna should have a structure which can be comfortably worn on the body.

Flexible wearable antenna has been developed using various textiles with various characteristics such as their relative permittivity, thickness and tangent lost. The selected fabric substrates should be electrically conductive and needs to satisfy other design's requirements such as a low and stable electrical conductance in order to minimize losses. The material must be homogeneous over the antenna area [15], and the fabric should be flexible so that it can be deformed when worn[15]. In this design, a jeans fabric with the thickness and permittivity of 1.2 mm and 1.7 respectively has been used as the dielectric for the antenna. The conducting material jeans is a high quality material with low and stable electrical resistance of 0.05 Ohm/square[15].

Basically, the modes supported by the circular patch antenna are based on the patch, ground plane, and the materials between the circular cavities where z-plane is taken perpendicular to the patch. For the circular patch, there is only one degree of freedom to control which is the radius of the patch, *r*. Most of typical microstrip antennas have the substrate height h which is normally very small (typically $h < 0.05\lambda_0$) and the fields along z-plane are essentially constant. Therefore, the resonant frequency (f_0) of a circular patch can be determined by using the Equation (1) [16] based on the radius of the patch, *r*. The conductive part of the antenna is designed with a radius of a using a copper sheet with a thickness of 0.02mm

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

where ε_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. In this case, the wave number of the resonant mode are m=1 and n=1 since it is the dominant mode for circular patch. The value of x'_{11} that is used for dominant mode is 1.842. Fringing effect is included to make the patch look electrically larger. Therefore, an effective area A_e is determined to replace the actual radius α using Equation (2) [16]

$$A_e = r\sqrt{1 + \frac{2h}{\pi r \varepsilon_r}\left[ln\left(\frac{\pi r}{2h}\right) + 1.7726\right]} \quad (2)$$

where r, h, and ε_r are the radius of circular patch, the thickness of substrate, and the relative permittivity of the substrate respectively.

B. *Microstrip Line Feed*

There are various type of feeder which can be used for the microstrip patch antenna design. One of the most popular methods is known as line feed. For line feed technique, the edge of microstrip patch antenna is connected directly to the conducting strip in order to provide current flow to the patch. The conducting strip is always smaller in size with compared to the patch size, which will give an advantage that the feed can be etched onto the substrate and this will produce a planar structure.[17]

In order to match the impedance of the feed line of the patch antenna, an inset cut has been added, where the position of the inset cut need to be controlled properly in order to have the desired matching impedance. A small feed line is also important to minimize radiation from the feed. The feeding technique is an easy technique for the overall fabrication and able to provide better impedance matching.[18]

The feed length of a patch antenna can be calculated and determined by using Equation (3)

$$L_{feed} = \frac{6h}{2} \quad (3)$$

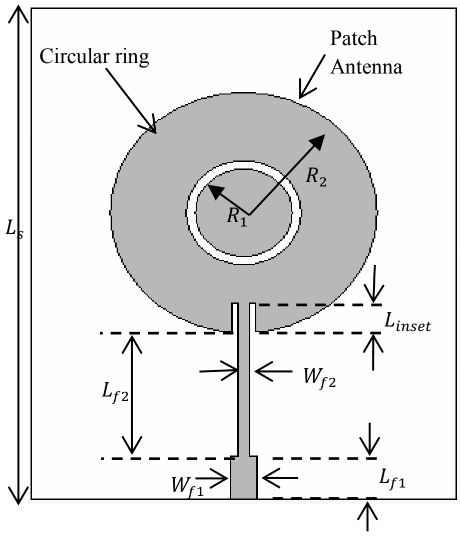
III. Dual Band Wearable Antenna Design

The microstrip patch antenna has been designed and developed to operate at dual band frequencies of 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 due to ground plane effect. Circular patch is selected as the patch shape due to its high bandwidth properties as studied in [19]. The circular patch antenna and the microstrip feed line has been designed with the matching impedance of 50Ω due to SMA connector which has maximum power radiation at this impedance. Table 1 and Figure 1 illustrated the proposed antenna optimized geometry for both operating frequencies.

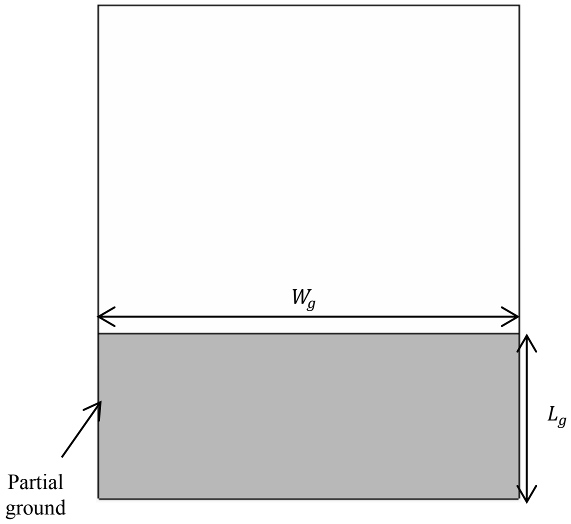
Table 1
Dimension of Proposed Circular Monopole Patch Antenna

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
Thickness of Substrate (h)	1.2
Thickness of Patch	0.02
Thickness of Partial Ground Plane	0.02

The circular ring as shown in Figure 1 is introduced to perform dual band frequencies, where basically, the outer ring influences the low frequency while the inner ring acts as the radiator at high frequency. The simulated return loss results for the flat condition as shown in Figure 2 illustrates that the antenna has a wider bandwidth of approximately 3.84GHz which the range of 1.95 GHz to 5.79 GHz. A wideband result is achieved due to additional reactance introduced by the partial ground plane [20]. Therefore, it is proven that the antenna is operating perfectly at both resonance frequencies of 2.4 GHz and 5.2 GHz as desired.



(a) Front view



(b) Back view

Figure 1. Geometry of circular monopole patch antenna

The circular microstrip patch with the dimension of the is 70 mm x 70 mm has been designed on the proposed textile dielectric, which makes it suitable to be placed on smaller human torso such as on arms, legs, and also on the larger parts of the body. It consists of circular patch made out of copper sheet which is placed on jeans textile with thickness of 1.2 mm.

The resonance frequencies of the antenna have been determined as 2.4 GHz and 5.2 GHz for lower and upper bands respectively. Figure 2 shows the simulated and measured return loss results for the antenna under flat condition. The results show good agreement between simulation and measurement of the antenna. The antenna operates well on both frequency bands; 2.4 GHz and 5.2 GHz respectively.

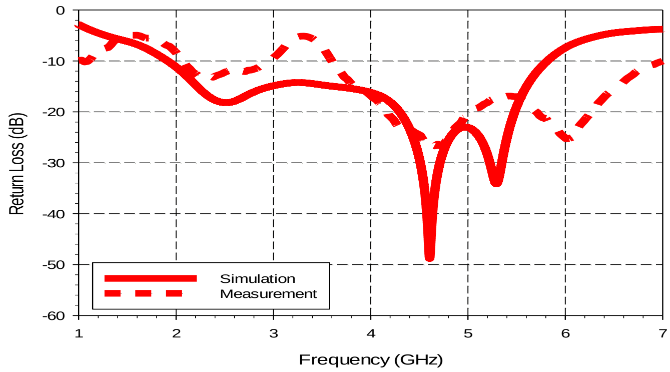


Figure 2 Simulated and measured return loss comparison on flat antenna condition

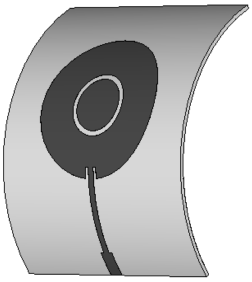
IV. Antenna Bending Characteristic

In this section, the characteristic of the microstrip circular ring patch antenna has been presented. Three cases of various bending radii have been simulated, measured and analyzed. In order to ensure a constant bending radius, the specific radius of the cylindrical foam with the dielectric constant of 1.07 which almost equivalent to air has been used. This type of material is chosen as its permittivity is approximate to air which may avoid the existence of mutual coupling between the cylinder and the antenna.

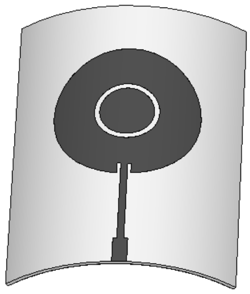
For Case 1, the bending radius is 33.5 mm while Case 2 represents the bending radius of 47.5 mm. On the other hand, another bending radius is 58.5 mm which is denoted as Case 3.

The antenna has been bent along two antenna propagation directions; E-plane and H-plane respective in order to analyze the effect in both conditions. Figure 3 shows the bending positions of the antenna along both planes for simulation purpose. For the measurement purposes, the setup as shown in Figure 4 has been utilized. In order to achieve the optimum result, an amplifier has been used to amplify the signal during the measurement process. The basic circuit diagram of the electrical and magnetic phenomenon of the structure is provided in Figure 5 [21].

In this section, the comparisons of simulated and measured return loss in all cases have been presented. Figure 6 and Figure 7 has shown the simulated and measured return loss results for all bending cases either in E-plane or H-plane direction respectively. From the simulation result, the bending along H-plane suffers the least effect as there is no significant changes in resonance frequencies have been identified. Meanwhile the return loss at the resonance frequencies when bending along the E-plane has shown larger effect, especially at the lower band of 2.4 GHz.



(a) E-plane bending



(b) H-plane bending

Figure 3 : Bending positions of the antenna along both planes

(a) E-plane bending

(b) H-plane bending

(c) Amplifier setup

Figure 4 : Experimental setup for measurement of antenna bending

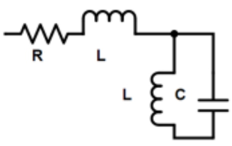


Figure 5 : Basic resonance circuit diagram [21]

Based on the circuit diagram presented in Figure 5, the bending affects the electrical field of the antenna, resulting a decrement in terms of the coupling present between the ground plane and the antenna patch [20]. Due to this condition, the reactance of the structure is affected. The bending does not gives much change on the capacitive loads of the structure, resulting minimum effect on the magnetic field. Hence, the curved nature introduced to the structure caused the antenna’s discontinuity to decline. This state of technology shows that the electrical field has high impact to the overall performance of the antenna.

Significant changes can be observed by referring to the measurement made for the bending along E-plane, compared to the H-plane. The best performance is obtained when bending the antenna at the larger v radius of 33.5 mm for both frequencies as shown in Figure 6. The result for this case shows the best return loss which is -24.03 dB at low band and -24.25 dB at high band. The other cases also show satisfactory results after bending along E-plane. Bending on the larger radius causes the return loss at both frequencies to decrease.

Moreover, the resonance frequency of the antenna shifted downward as the bending radius is increased. This is due to the fact that the bending along E-plane affects the resonance length of the antenna. More resonance length is increased when the antenna is bent on a larger diameter. Thus, the resonance frequency shifted down as happened to the Case 3.

Figure 7 presents the bending effect to the return loss of the antenna along H-plane. For all cases, the return loss slightly decreases especially at high band frequency with compared to the flat antenna performance. This result is due to the maximum bending is more severe for the outer ring of the patch. From measurement results, the lower return loss has been observed when the bending is at the smallest radius of 33.5 mm. This shows that the antenna has been most affected when the angle of bending increases, on the smaller diameter.

However, from the return loss result, antenna still having return loss less than -10dB for all cases, which show that the antenna structure is seen to be conformable to the effects of bending.

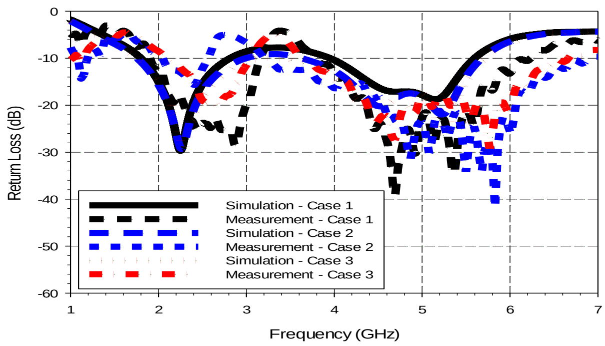


Figure 6 : Return Loss for all cases along E-plane bending

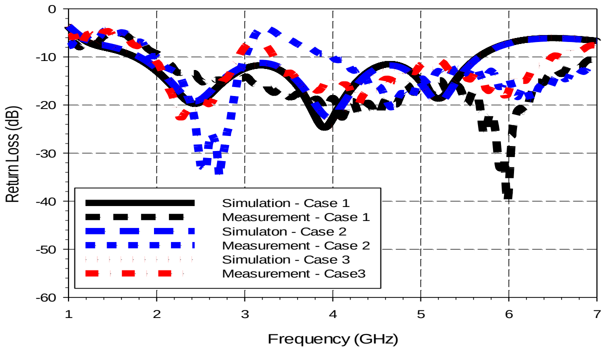


Figure 7 : Return Loss for all cases along H-plane bending

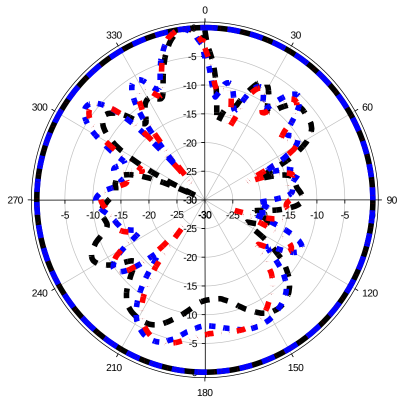
The radiation pattern of the antenna when being bent on cylindrical foam on the various bending radius have been measured in the anechoic chamber and the result are shown in Figure 8 and Figure 9. The radiation patterns have been analysed for both planes; E-plane and H-plane by referring to the azimuthal and elevation configurations at 2.4 GHz and 5.2 GHz. It is apparent from Figure 8 (a) to (d) that the simulation of the azimuth configurations at all conditions results in an omnidirectional pattern. However, the measurement of the antenna gives much discrepancy from the simulation result, especially in terms of the beamwidth which is much lower with compared to the simulated results.

Meanwhile, by referring to Figure 9 (a) to (d), it can be seen that the elevation result for both frequencies along different planes give better relation of measurement results with compared to the simulation results for all the cases. For all cases, the forward direction gain shows slight variation, where of Case 1 shows the lowest result. This is due to the high bending angle which gives some difficulties for the antenna to radiate properly. Different bending radius does not give major effect to the antenna radiation pattern, either in azimuthal or elevation configurations along the E-plane and H-plane at both resonance frequencies.

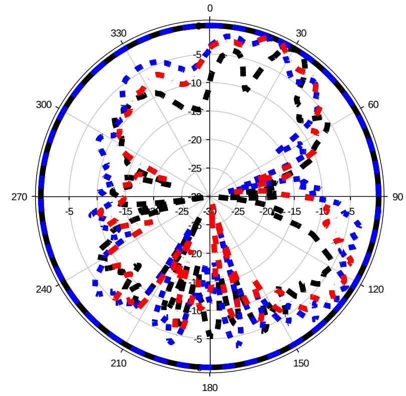
V. Conclusion

The analysis on the performance of flexible textile antenna has been analyzed on various bending conditions. Three bending cases have been analyzed for the purpose of this study where the bending radiuses are 33.5 mm, 47.5 mm and 58.5 mm. There are two prior performances that are being identified, such as the return loss and the radiation pattern of the antenna. The effect of bending has been analyzed to understand how the bending radius and the body movement can affect the antenna performances. From the simulated and measured result for the antenna, it can be concluded that the bending along E-plane has the dominant effect on the antenna performance.

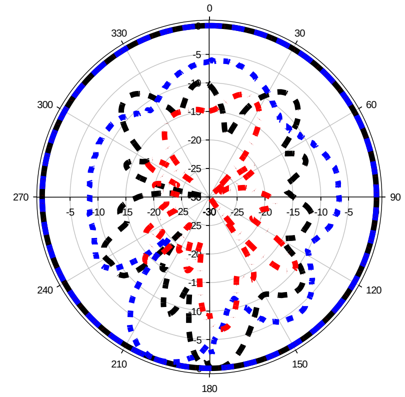
In all cases, the bending of antenna results in the change of resonance length due to bending has shown slight effect on the resonance frequency. The return loss of the antenna is most affected by bending on a smaller radius due to the decrement of the resonance length of the antenna. In addition, the effect on the bandwidth can be approximately negligible, provided that no resonance has been lost. In summary, it can be concluded that the effects are insignificant, thus proved that the textile antenna designed can be properly functioning under bending condition.



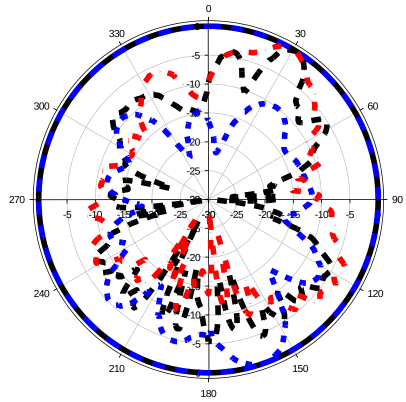
(a) Azimuth radiation pattern of E-plane at 2.4 GHz



(b) Azimuth radiation pattern of E-plane at 5.2 GHz



(c) Azimuth radiation pattern of H-plane at 2.4 GHz



(d) Azimuth radiation pattern of H-plane at 5.2 GHz

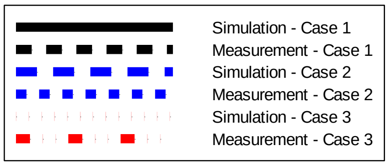
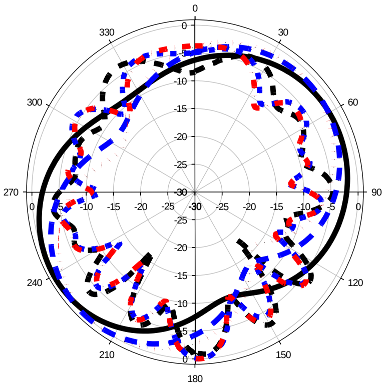
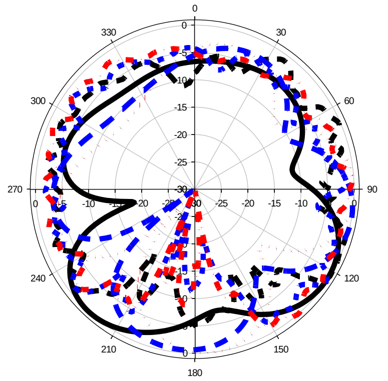


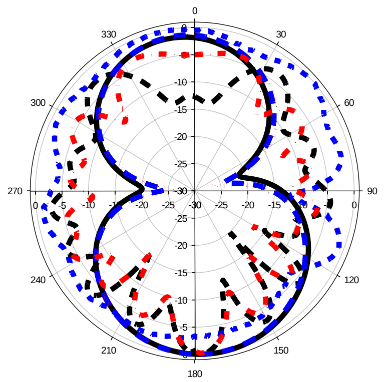
Figure 8 Simulated and measured azimuth radiation pattern for the antenna bent at H-plane and E-plane bending direction at 2.4GHz and 5.2GHz



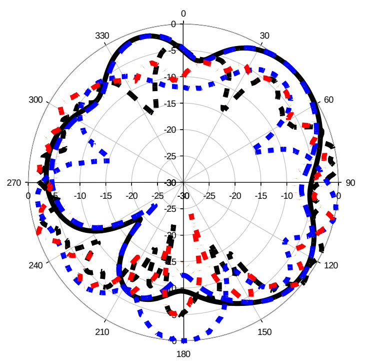
(a) Elevation radiation pattern of E-plane at 2.4 GHz



(b) Elevation radiation pattern of E-plane at 5.2 GHz



(c) Elevation radiation pattern of H-plane at 2.4 GHz



(d) Elevation radiation pattern of H-plane at 5.2 GHz

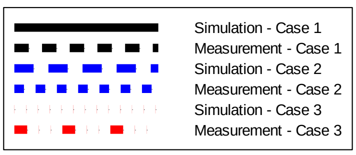


Figure 9. Simulated and measured elevation radiation pattern for the antenna bent at H-plane and E-plane bending direction at 2.4GHz and 5.2GHz

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