# Wearable RFID Tag Antenna: Feasibility Study on Bending and Wet Condition Performances

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**ABSTRACT** This project presents the performance of a wearable RFID tag antenna in bend and wet conditions. The performance of the RFID tag antenna has been designed, simulated, optimized, and analyzed in CST Studio Suite. CST Studio Suite is a high-performance 3D EM analysis software. The overall project is completed in simulation analysis only. The RFID tag antenna is designed to operate at 915.2 MHz resonant frequency. Materials used to design the RFID tag antenna are felt for the substrate and Shieldit for the conductor. At the initial stage of the design, a microstrip dipole antenna was used, then followed by meandering the designed microstrip dipole antenna to reduce the size of the RFID tag antenna. A parametric study has been done to achieve the best optimized RFID tag antenna. The gain value of 2.76 dB is achieved in this design. In the end, the performance of the RFID tag antenna has been analyzed in bend and wet conditions. The RFID tag antenna performs better in bend condition than the wet condition.

**KEYWORDS** RFID tag, wearable tag antenna, felt substrate, bend and wet conditions studies.

## I. INTRODUCTION

When it comes to the evolution of technologies RFID is one of the important inventions. RFID stands for Radio Frequency Identification which uses radiofrequency waves to transmit and receive data. In the early stage, the barcode was used to track objects for instance in grocery stores every item has a barcode labelled with its specified data which cannot be rewritten. Hence, RFID can rewrite data, store more data, and is easy to relocate manually. This shows the efficiency of the RFID.

RFID system uses an automatic identification technology consisting of three major components, namely, (i) a transponder (tag), (ii) scanner-unit (reader), and an (iii) antenna [1]. Hence, there are three types of RFID tags in the market today which are passive, active, and semi-active. The differences among those three tags are powered by a battery or a standalone. However, the most used and manufactured RFID tags are passive tags. Passive tags do not need a battery backup as they are known as standalone devices, they reflect signal back from the RFID reader. Passive tags can be manufactured at a very low cost. Besides, an RFID reader which is technically known as an interrogator is used to receive information or data from the RFID tag. An RFID reader is a device that emits radiofrequency waves to identify a tagged object. Moreover, the antenna is the bridge between the reader and the tag. The antenna is the major component that affects the reading range, bandwidth, and accuracy of communication. Hence, the tag antenna is usually manufactured with a tag chip for specific usage.

Usually, an RFID tag system can be classified into three types based on the operating frequencies. Low frequency (LF), high frequency (HF), and ultra-high frequency (UHF) are the common operating frequency around the globe, yet the values could vary depending on the specified country [2]. The specification of the operating frequency is given in Table 1.

TABLE I
RFID TAG ANTENNA FREQUENCY

| | Operating frequency |
|---|---|
| Low Frequency (LF) | 125 kHz to 134 kHz |
| High Frequency (HF) | 13.56 MHz |
| Ultra-high frequency (UHF) | 860 MHz to 960 MHz |

Globally, in many sectors, RFID technology has a major role play compared to the barcode due to its capabilities and efficiencies. It has become very common in many fields, including tracking, inventory management such as taking orders, storing, and keep track of the items. Applications are evolving to comply with shipping products automatically processing transactions based on the RFID technology.

Recently, wearable RFID tag antenna has been increasingly investigated as wearable antenna ought to provide flexibility, robustness, and lightweight. The material for the substrate plays a key role in flexibility. The substrate ought to be chosen wisely due to the deformation that occurs during the experiment and analysis of the bending test [3]. However, the bent test condition during the simulation and measurement would differ in terms of resonant frequency and return loss (S11).

Despite the bend test, the wettability test also should be taken into consideration as wearable RFID tags could be exposed to wet conditions, for instance it is worn during heavy rain. In detail, the presence of water with a high dielectric constant strongly influences the relative permittivity of the substrate which would affect the resonant frequency and the return loss (S11) of the RFID tag antenna [4].

The purpose of this project is to design a wearable RFID tag antenna to be used under specific circumstances. In detail, a study should be conducted of the RFID tag antenna when it is exposed under bend and wet conditions. The designed RFID tag antenna then will be simulated using a flexible material. Furthermore, the performances of the RFID tag antenna have to be analysed in terms of return loss (S11), gain, and other parametric value under both wet and bend condition. Lastly, the designs, bendability, and other relevant simulations and optimizations will be done using Computer Simulation Technology software (CST Microwave Studio Suite).

## II. ANTENNA DESIGN AND SPECIFICATION

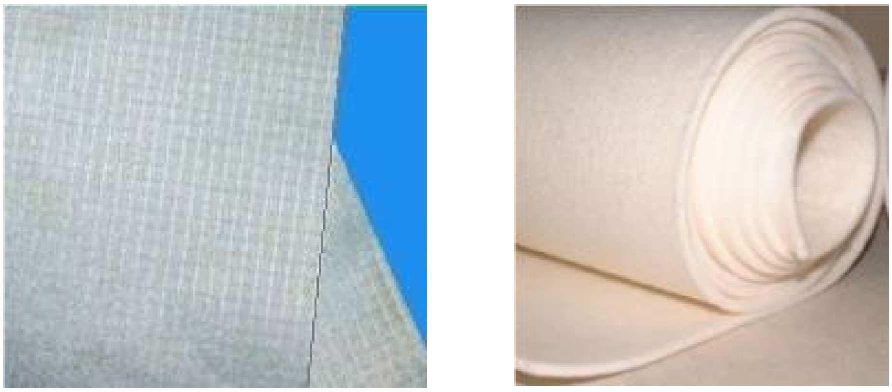
These two significant aspects, the antenna design and specification must be included in the design process of a wearable RFID tag antenna. Firstly, ensure that the RFID tag antenna operates correctly and has decent efficiency with minimum return loss. Secondly, in terms of versatility, size, weight, and structure, the design of the antenna is suitable and convenient for wearable applications. In this instance, the material properties of the RFID tag antenna are one of the key selections. The desired RFID tag antenna design specifications are shown in Table 2.

TABLE II
DESIRED RFID TAG ANTENNA DESIGN SPECIFICATIONS

| Type | Specification |
|---|---|
| UHF Band | 860 – 960 MHz |
| Operating frequency | 915 MHz |
| Return loss, S11 | Less than -10 dB |
| Physical Profile | Small and Compact |
| RFID Chip | NXP SL3S1203_1213 |
| RFID Chip impedance | 23 – j224 Ω |
| Gain | More than 2.19 dB |
| Radiation Pattern | Directional |

As a wearable RFID tag antenna is often worn by humans, whether applied usingtextiles or lightweight material, mechanical deformation such as bending is unavoidable [5]. It is well-bounded that bending the RFID tag antenna in any direction degrades its output for the intended use. Two materials were chosen in this project to design for the conductor and substrate plane. One of the chosen conductor materials is a Shieldit super which is a conductive fabric that is well known as an electrotextile, which is made of polyester substrate conductive nickel and copper-plated then backed with non-conductive hot metadhesive for radiofrequency and microwave shielding. Figure 1 shows the Shieldit super fabric and Felt fabric and their specifications are shown in Table 3.

The process of designing the RFID tag antenna has many stages. It is start by designing a microstrip dipole antenna as shown in Figure 1. The dimensions needed forthe radiating element to be designed for the microstrip dipole antenna are calculated by using dipole antenna equations which the half-wavelength of a dipole antenna, L the wavelength in meters, λ, and the feeding gap, G. The calculations are shown below.



(a) (b)

Figure 1: (a) Shieldit super fabric, (b) Felt fabric

TABLE III
CONDUCTOR PARAMETER

| Material | Parameter | Value |
|---|---|---|
| Shieldit super (conductor) | Thickness | 0.17 mm |
| | Conductivity | 1.18 × $10^5$ *s/m* |
| Felt (substrate) | Thickness | 3 mm |
| | Permittivity | 1.44 |
| | Loss tangent | 0.044 |

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{915\ 000\ 000\ \text{kHz}} == 0.32786\ m = 327.86\ mm \qquad (1)$$

$$L = \frac{\lambda}{2} = \frac{327.86\ \text{mm}}{2} = 163.9\ \text{mm} \qquad (2)$$

$$G = \frac{L}{200} = \frac{163.9\ \text{mm}}{200} = 0.8195 \qquad (3)$$

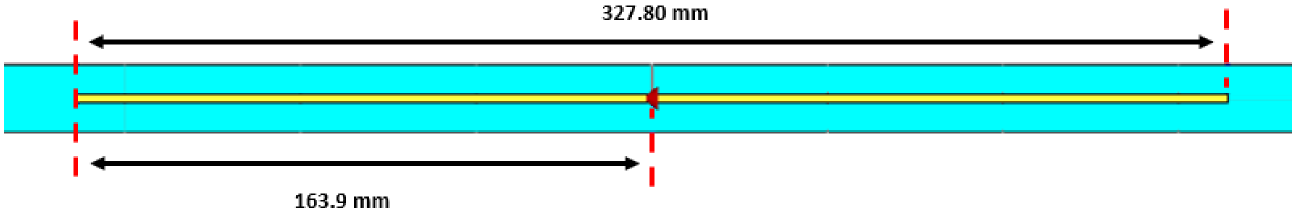



Figure 2: Microstrip dipole antenna

The designed microstrip dipole antenna is then optimised by reducing the transmission line to achieve the desired resonant frequency of 915 MHz. Since the total length of the dipole antenna design is nearly 327.8 mm which is very long, therefore, length of the antenna design needs to be reduced by using the meandering technique. By applying the meandering technique in the dipole design, the overall size of the RFID tagantenna could be reduced.

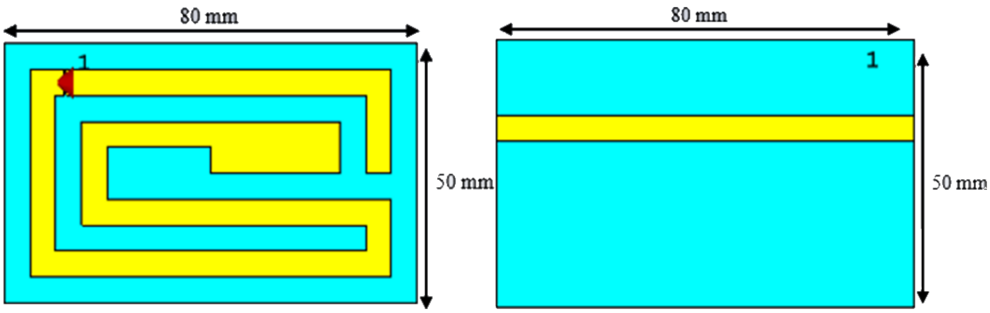
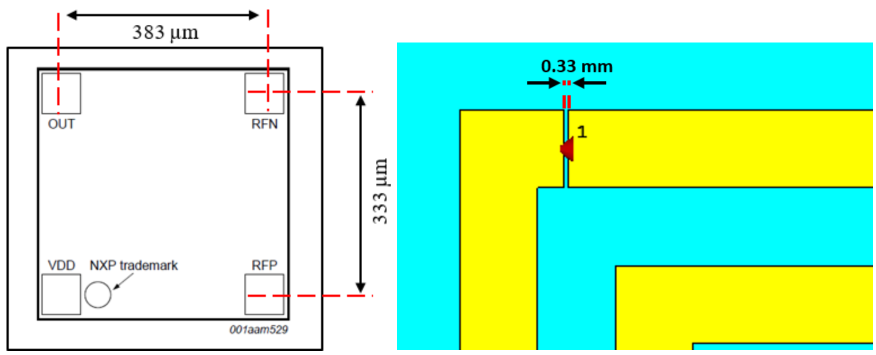



Figure 2: Meandered microstrip dipole antenna (a) Front view, (b) back view

Figure 2 show the front and the back view of the meandered microstrip dipole antenna. However, after meandering the design in the 3D simulation, the same design needs to be simulated in the Schematic simulation with the impedance value of NXP SL3S1203_1213 RFID chip is 23 – j224 Ω [6]. The dimension of the RFID chip needs to be considered since the RFID chip will be fabricated in the future. Figure 3(a) shows the dimension of the NXP SL3S1203_1213 RFID chip used in this design. The initial design of the feedline gap needs to be changed according to the dimension of the RFID chip which is from 0.8195 mm to 0.333 mm. The redesigned dimension of the feedline gap is shown in Figure 3(b). The operating frequency of the redesigned RFID tag antenna will be changed due to the different dimensions from the calculated design. The RFID tag antenna design is then optimised in the schematic simulation to achieve the desired parameters result whichis the return loss (S11), gain (dB), resonant frequency, radiation pattern, and impedance matching of 50 Ω. The front view and the back view of the optimised redesigned RFID tag antenna in the schematic are shown in Figure 4 and Figure 5 respectively. The dimensions of the front and the back view of the design are shown in Figure 6, 7 and in Table 4 respectively. The height and the length of the substrate used in this design are to make sure that it is applicable in the wearable application as it is small and compact. The reflector is designed in the back of the substrate to act as a directive antenna.




(a) (b)

Figure 3: (a) RFID chip dimensions, (b) Feedline gap of the RFID tag antenna (Schematic)

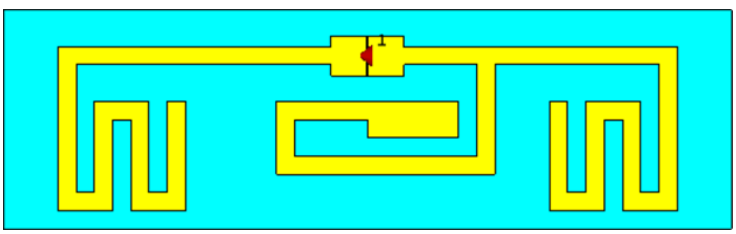



Figure 4: Optimised RFID tag antenna (Front view)

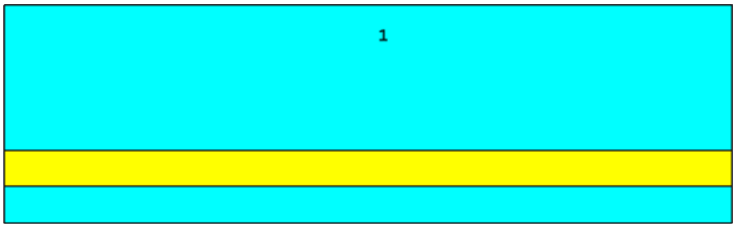


Figure 5: Optimised RFID tag antenna (Back view)

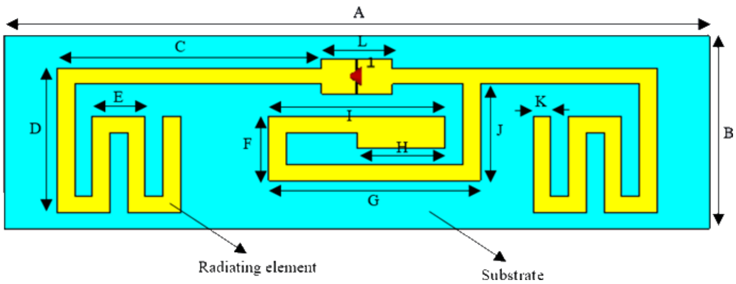


Figure 6: Dimensions of the front view

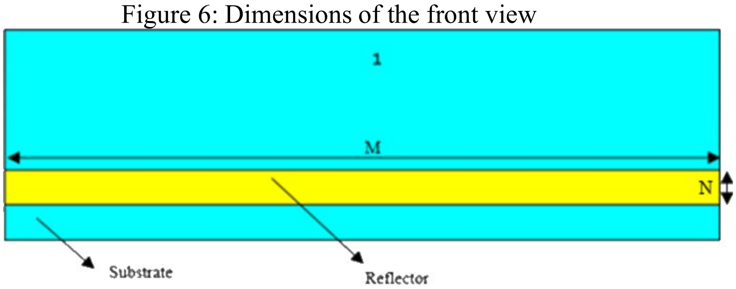


Figure 7: Dimensions of the back view

TABLE IV
CONDUCTOR DIMENSIONS

| DIMENSIONS | VALUE (MM) | DIMENSIONS | VALUE (MM) |
|---|---|---|---|
| *A* | 200 | *H* | 25 |
| *B* | 60 | *I* | 50 |
| *C* | 75 | *J* | 30 |
| *D* | 45 | *K* | 5 |
| *E* | 15 | *L* | 20 |
| *F* | 20 | *M* | 200 |
| *G* | 60 | *N* | 10 |

In this project design, bending analysis ought to be taken into consideration as theRFID tag antenna is designed with a wearable material. Therefore, the possibility of affecting the RFID tag antenna performance is high. The bending has been investigated in different angles which are 20, 30, 40, 50, 60, 70, 80, and 90 degrees respectively. In order to perform the bending analysis, a cylindrical structure has been used as a referenceas shown in Figure 8 to bend the RFID tag antenna towards the cylindrical structure. However, the RFID tag antenna which is bent towards the cylindrical structure could affect the performance due to the dielectric constant and permittivity of the material usedin the cylindrical structure. To avoid this to happen, the cylindrical structure needs to be deleted once the RFID tag antenna is bent towards the cylindrical structure. Figure 9 shows the difference of the RFID tag antenna structure before and after bending.

The different angles of the cylindrical structures are designed in millimetres by calculating the outer radius of the cylindrical structure by using the arc length equation which is in (Eq. 4)

$$S = r \times \emptyset \quad (4)$$

Where:

$S$ = Arc length,

$r$ = Radius of the circle,

$\emptyset$ = Measure of the central angle in radians.

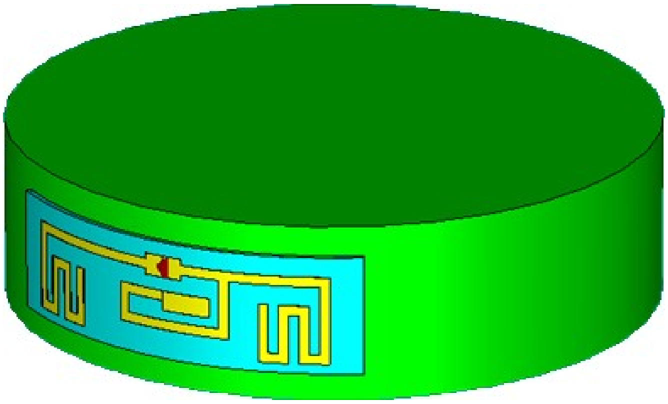
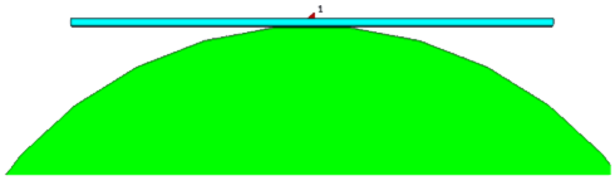
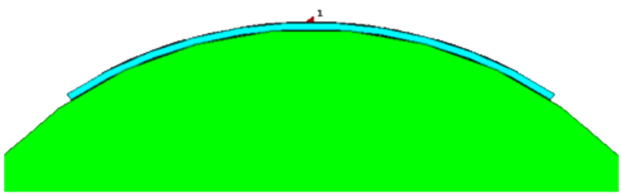


Figure 8: Cylindrical structure for bending



(a)



(b)

Figure 9: (a) Before bending and (b) After bending

The measurements of the RFID tag antenna used to calculate the angles of the bending are shown in Figure 10. The width of the RFID tag antenna was used as the arc of the length where S = 200 mm. By using Eq. 4, the outer radius (mm) of the cylindrical structure is used to calculate for different angles from 20 degrees to 90 degrees.

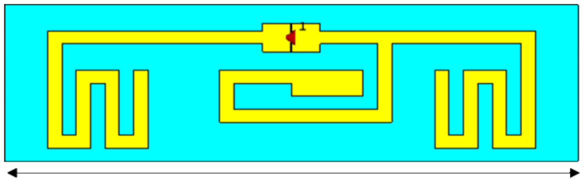



Figure 10: Arc of length measurement

Since the RFID tag antenna is not fabricated in this project, it has been investigated in the wet condition by using the default parametric values available in the CST software. The wettability is performed in four different stages in terms of full, three-quarters (3/4), half (1/2), and quarter (1/4) water level as shown in Figure 11. Moreover,the wettability analysis is performed only on the substrate material which is Felt as it is afabric material that is capable of absorbing water, unlike the radiating material which is Shieldit which is not water absorption material. The performance of the RFID tag antenna under wet conditions can affect the resonant frequency.

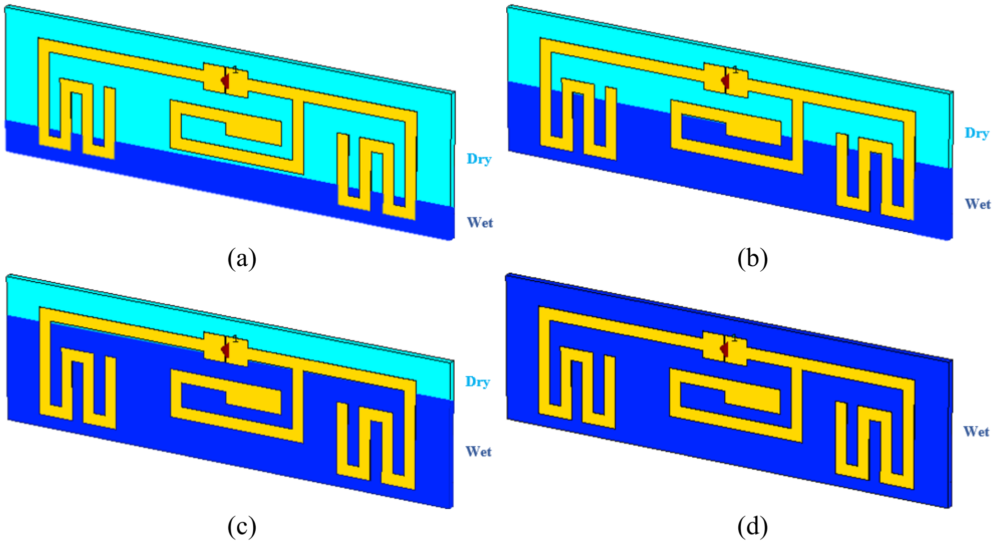



Figure 11: Water Level Analysis. (a) Quarter ¼, (b) Half ½, (c) Three-quarter ¾, (d) Full

## III. Result and Discussion

The good performance of the RFID tag antenna is when the return loss is below -10 dB. The return loss -10 dB means 90 % of the energy is radiated and 10 % of energy is reflected. Therefore, lesser energy is reflected better in the performance of the RFID tag antenna. Figure 12 shows the return loss of -17.92 dB for the simulated RFID tag antennain which the resonant frequency is at 915.2 MHz with the difference of 0.2 MHz of the requirement. The optimum performance of the RFID tag antenna is at the center frequency of 915.2 MHz. The shaded region in the return loss graph is the reading rangeof the RFID reader which is from 902 MHz to 928 MHz as shown in Figure 12. The RFID tag antenna has been designed in terms of the desired resonant frequency which lies in between the reading range of the RFID reader.

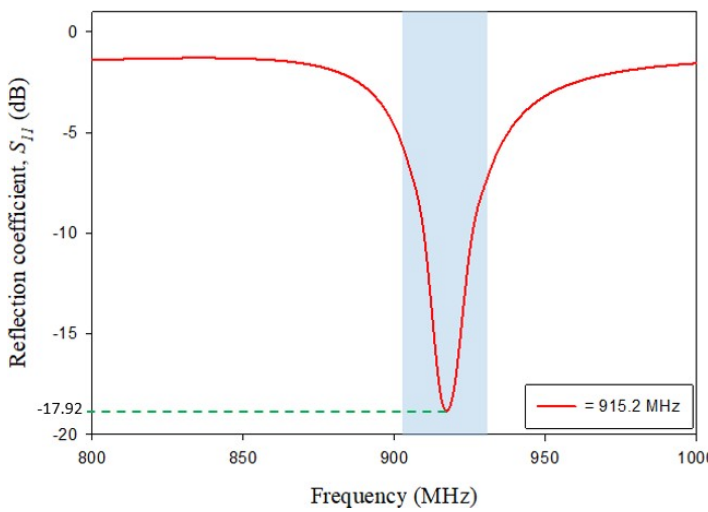
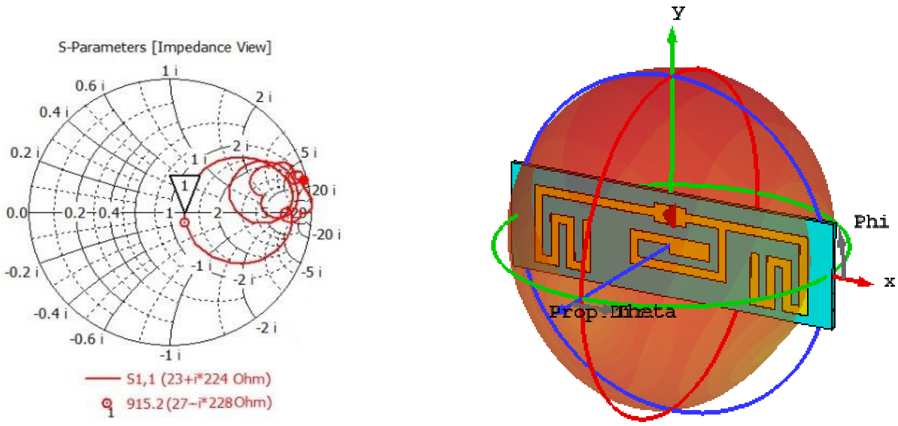


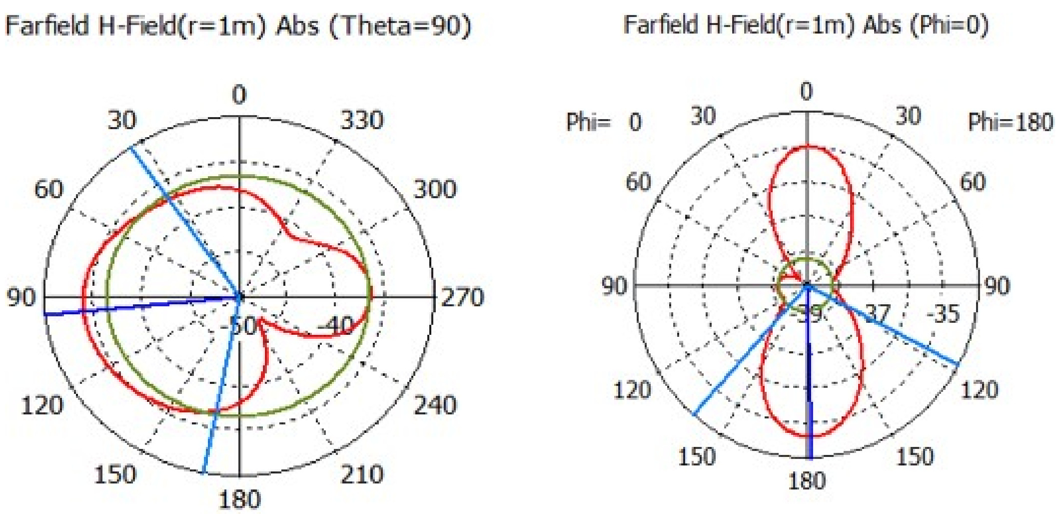

Figure 12: Return loss of the RFID tag antenna

Another important factor to be considered in the performance of the RFID tag antenna is the gain which indicates the signal transmission strength in a specified direction. Figure 13(a) shows the smith chart plot of the designed RFID tag antenna. In orderto achieve 100 % impedance matching the design has to obtain the output impedance of 50 Ω, in other words, to obtain a unity circle in the smith chart plot. Based on the smith chart, the impedance matching is nearly 100 %. By adding both the real part of the impedance value is 50 Ω and the imaginary part needs to be in the complex conjugate. Figure 13(b) shows the RFID tag antenna gain of 2.76 dB at 915 MHz which is thehighest gain value obtained among the other optimised design. Since the gain is 2.76 dBwhich is considered a high gain for an RFID tag antenna, therefore it will not affect the RFID tag antenna's performance when it is worn. In other words, a high gain RFID tag antenna is not suitable and compatible for wearable applications due to the amount of energy radiated in a particular direction will be high. [7-10]. Figure 14 shows the performance of a polar radiation pattern for the RFID tag antenna at 915.2 MHz. The E-plane and the H-plane are the two planes that form the polar radiation pattern. Based on Figure 14, the radiation pattern obtained is directional. In E-plane at 915.2 MHz, the main lob magnitude is -34.1 dB with a direction of 96˚ and half-power beamwidth (HPBW) is 135.4˚ while in the H-plane, the main lobe is -34.6 dB with a direction of 178˚ and the HPBW is 103.9˚.




(a) (b)

Figure 13: (a) Smith chart of the RFID tag antenna, (b) Gain of the RFID tag antenna

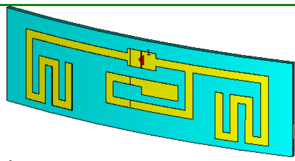
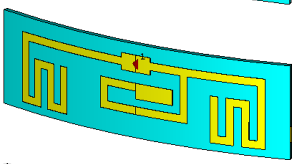
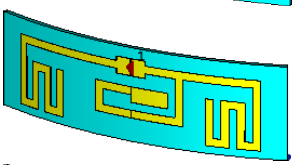
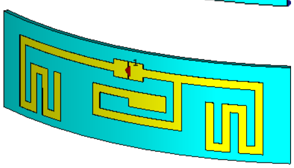
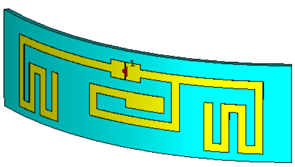
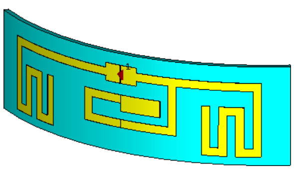
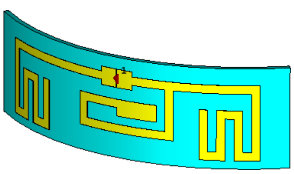
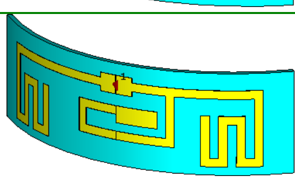



(a) (b)

Figure 14: (a) E-Plane and (b) H-Plane radiation pattern of the RFID tag antenna

The designed RFID tag antenna is analysed in various angles which are from 20,30, 40, 50, 60, 70, 80, and 90 degrees respectively. Table 5 shows the performance of each different angle bending of the RFID tag antenna.

TABLE V
PERFORMANCE OF THE RFID TAG ANTENNA IN BEND CONDITION

| **Description** | **Bend condition** | **Gain (dB)** | **Return loss,S11 (MHz)** |
|---|---|---|---|
| 20 degree |  | 2.44 | 915.2 |
| 30 degree |  | 2.51 | 915.2 |
| 40 degree |  | 2.2 | 914.8 |
| 50 degree |  | 2.3 | 915.2 |
| 60 degree |  | 2.46 | 920 |
| 70 degree |  | 2.01 | 915.2 |
| 80 degree |  | 2.85 | 917.2 |
| 90 degree |  | 2.01 | 915.2 |

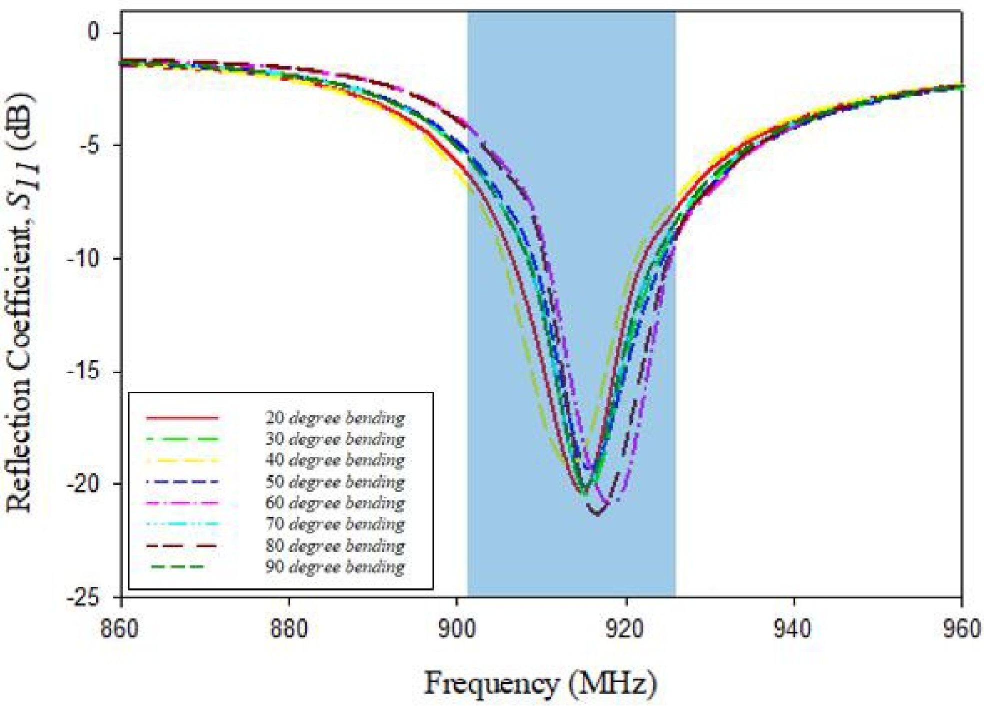



Figure 15: Return loss of the RFID tag antenna in bend condition

Figure 15 shows the return loss of all the different angles RFID tag antenna in bent condition. Slight differences of the return loss can be observed at 40-degree bend (yellow line) which is at 914.8 MHz, 60-degree bend (pink line) which is at 920 MHz, and 80-degree bend (brown line) which is at 917.2 MHz. In terms of gain, the highest gain is obtained at an 80-degree bend which is 2.85 dB while 70-degree bend and 90- degree bend are obtained at to lowest gain which is 2.01 dB. The shaded region in the return loss graph is the reading range of the RFID reader which is from 902 MHz to 928MHz as shown in Figure 4.8. Based on the return loss plot nearly all the bending angles are between the RFID reading ranges which is from 902 MHz to 928 MHz. The result shows the return loss of the RFID tag antenna in bend condition is greater compared to theRFID tag antenna if flat condition (0 degrees).

The RFID tag antenna is analysed in four different states of water level which is quarter (1/4), half (1/2), three quarter (3/4), and full respectively. The water properties used in this analysis are done by using the default water properties available in CST software. Table 6 shows the performance of the RFID tag antenna in wet condition in different levels of water used. Figure 16 shows the return loss of the RFID tag antenna in wet condition. Based on the result, the performance of the RFID tag antenna in all the water level conditions is affected. As the water level increases in the RFID tag antenna, the return loss of the RFID tag antenna is reduced significantly. In terms of the gain value, the RFID tag antenna in all wet conditions obtained a negative gain value. The performance of the RFID tag antenna is affected in the wet condition is due to the high dielectric constant of the water.

TABLE VI
PERFORMANCE OF THE RFID TAG ANTENNA IN WET CONDITION

| Water level | Gain (dB) | Return loss, S11 (MHz) |
|---|---|---|
| Quarter (1/4) | -2.59 | 910.4 |
| Half (1/2) | -3.78 | 1688 |
| Three- quarter (3/4) | -40.5 | 175 |
| Full | -35.4 | 238.4 |

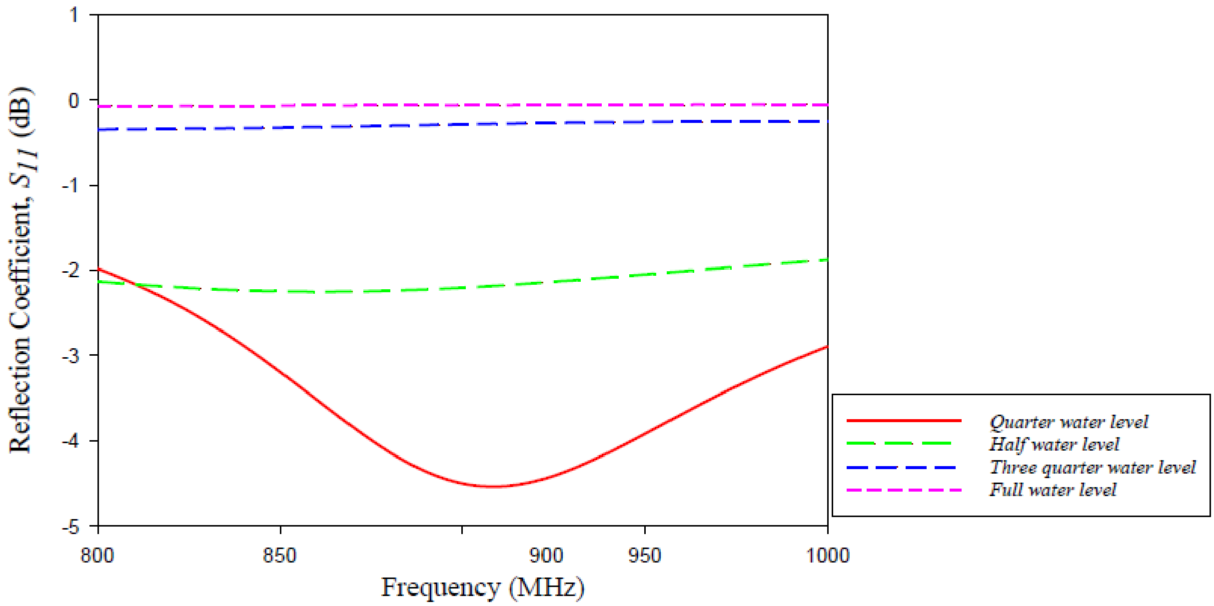



Figure 16: Return loss of the RFID tag antenna in bend condition

## IV. CONCLUSIONS

The purpose of this project is to investigate the performance of a wearable RFIDtag antenna in bend and wet condition using fundamental study, design, and simulation using CST Microwave Studio. In terms of the project analysis, the objective has been fulfilled by designing a small wearable RFID tag antenna by using the meandering technique. By using the technique, the physical length of the RFID tag antenna has been reduced which gives an advantage of cost efficiency to design such a small RFID tag antenna. In a nutshell, the overall performance of the RFID tag antenna designed before analysed in the bend and wet condition is good. The RFID tag antenna designed providesoptimum result at 915.2 MHz and sufficient gain of 2.76 dB for a wearable application. The directional radiation pattern provides radiation in a particular angular direction. Moreover, the gain obtained provides no harm to the human body when it is used.

In the aspect of bend and wet analysis, both the condition provides different results in terms of the performances. The RFID tag antenna in bend condition provides better results compared to the wet condition. This is due to the high dielectric constant ofthe water properties which affects the return loss of the RFID tag antenna. However, in bend condition the return loss and the have slight fluctuation due to the uneven currentdistribution in the radiating element.

In this project, the performance obtained in this RFID tag antenna is sufficient interms of gain and return loss. However, the design could be further improved by using different materials. The materials used in this design are Felt (substrate) and Shieldit (conductor). Since the substrate used is a fabric material, therefore it has more water absorption characteristics. Perhaps, with minimum water absorption characteristics flexible material used for the wearable application, the performance of the RFID tag antenna in wet condition could be improved.

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