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# Novel printed passive ultra high frequency radio frequency identification antenna using meander technique

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**ABSTRACT**

In this paper, a novel radio frequency identification (RFID) antenna using a meander technique associated with a slotted patch is studied for RFID applications in the ultra high frequency (UHF) band [867.5-868 MHz]. The proposed RFID antenna is designed on a Kapton substrate with dielectric constant 3.5 and loss of 0.0027. It consists of two opposite meander line antennas of 8 turns each one and interconnected to ALIEH H3 microchip associated to two slotted patch's with a global size $105\times25\times0.1$ mm$^3$. The proposed RFID antenna is designed and simulated using CST MWS as an electromagnetic solver. The results of the simulation show a return loss of -22.64 dB at 868 MHz, a reading distance of around 5 m, and a simulated input impedance of the antenna are 31.72+j109.68 Ω at the operating frequency 868 MHz.



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## 1. INTRODUCTION

Radio frequency identification (RFID) is an automatic technology that uses radio waves to identify physical items. An RFID system is consisting of an RFID tag, transceiver, and RFID antennas, the interaction of the RFID tag and reader/antennas leads to collect an electronic product code (EPC) in real-time, as shown in Figure 1. This technology has great promise for diversified use in many industries with various applications. The RFID tag is classified into three main technologies passive tags, active tags, and battery assisted passive (BAP) tags. This classification is based on the type of power source: internal source power or external source power. Passive tags can use three bands of frequencies: ultra high frequency (UHF) from 960 MHz to 860 MHz, high frequency (HF) at 13.56 MHz, and low frequency (LF) from 125 KHz to 134 KHz, each frequency band has a specific range: UHF offers a range typically minimum 30 ft, HF provides a range less than 3 ft and LF offers only about a foot [1]−[8].

Recently, RFID technology has been integrated into public life and industries, due to the excellent performance that RFID technology offers as a wireless communication technology such as data rate and reduction of antenna size required by applications. In a market of RFID tags various designs of RFID tags with different substrates (rigid, flexible, and semi-flexible), RFID designers aim to attempt a miniaturized tag with a good read range and a good matching between RFID microchip and RFID antenna. Many techniques have been presented in the literature for miniaturization: insertion of short pins, insertion of slots, and meander structures.

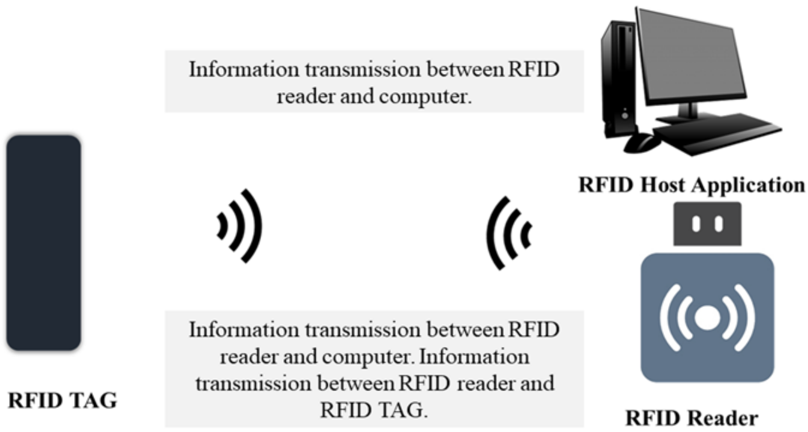


Figure 1. Basic RFID system

The performance of an RFID system depends on the RFID antenna. Half-wave dipoles are the most common Design for RFID antennas due to their simple structure, low cost, and high gain. Besides the size of the half-wave antenna is large quite in the UHF band, which makes it not appropriate for applications that need small RFID antennas. Therefore, new techniques are required to reduce the size of RFID antennas [9]. To design an electrically and low-profile RFID tag, two slotted patches has been integrated in both sides of the inverted meander line arms to enhance the matching impedance. The proposed topology achieves the main criteria of electrically small $ka \prec 0.5$, as has been exhaustive in theory and analysis of meander line structure behaviors in many researcher papers in this field, small electrically are defined when the total size less than 0.1 wavelength and the exposed input impedance is very low. Therefore, the integration of feeding by slotted patch to remove the capacitive effects and to match of the RFID microchip which is defined by the manufacture as highly inductive [10]−[12].

The paper is organized as the following outline: the theory of meander line antennas will be presented in section 2. Section 3 will be dedicated to the presentation of the characteristics and design of the proposed RFID antenna. Section 4 devoted to the interpretation, and discussion of simulation results using electromagnetic solver and in last section a conclusion of results of this work.

## 2. THEORY BEHIND MEANDER LINE ANTENNA

The meander line antenna (MLA) is a type of microstrip antenna used generally in microwave bands, it allows the designing of small antennas and provides high performance. The MLA is considered an electrically small antenna, it consists of a set of horizontal and vertical segments, and the combination of vertical and horizontal segments forms turns. The number of turns is related directly to the resonance frequency, enhancing the number of turns decreases the resonance frequency. MLA provides good radiation efficiency and excellent antenna size reduction [13]. The meander line antenna behaves as a resonant LC circuit, where the horizontal segment presents acts as a capacitor and the vertical segment reacts as an inductor, as illustrated in Figure 2.

The lumped inductance and capacitance are computed from [9]. Additionally, the theoretical length and characteristic impedance of the meander line antenna are determined.

– Lumped inductance:

$$L_A = L_l/2 \tag{1}$$

With L being inductance per unit length.

– Lumped capacitance:

$$C_B = C_l \tag{2}$$

With: C is the capacitance per unit length and l is the length of the line segment.

– The theoretical length of meander line antenna is defined by (3):

$$N \times S = \lambda \div 10 \quad (3)$$

With: N: number of turns and S: spacing between two meander lines.

– The characteristic impedance of each meander section is given in (4)

$$Z_0 = 276 \times log(2S/d) \quad (4)$$

With d: monopole wire diameter.

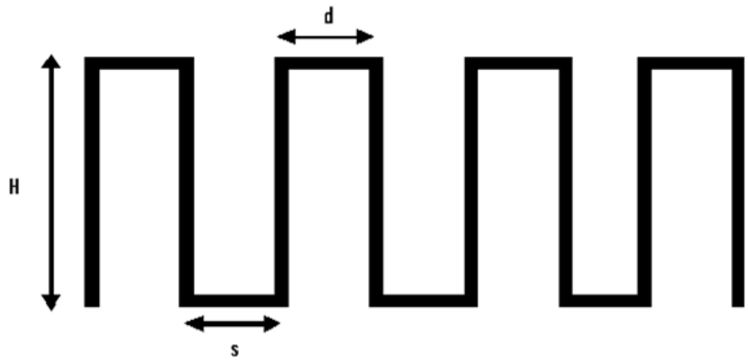


Figure 2. Basic design of meander line antenna

## 3. PROPOSED RFID ANTENNA: CHARACTERISTICS AND DESIGN

### 3.1. Characteristics of the proposed RFID tag

A passive RFID tag is a general term encompassing labels, cards, and tags. It consists of two elements: an RFID microchip and an RFID tag antenna, with each element characterized by a complex impedance [14]. The input impedance of the RFID tag antenna is defined by (5):

$$Z_{Antenna} = R_{Antenna} + j \times X_{Antenna} \quad (5)$$

The impedance of an RFID microchip is defined by (6):

$$Z_{Microchip} = R_{Microchip} + j \times X_{Microchip} \quad (6)$$

The matching impedance between the RFID and the antenna is a crucial consideration in passive RFID antenna design. A well-matched impedance ensures the transfer of maximum power from the antenna to the microchip, ensuring a reliable transmission of tag ID to the RFID reader. Optimal matching impedance is achieved when the input impedance of the antenna equals the conjugate of the microchip impedance, as shown in (7).

$$Z_{Antenna} = Z^*_{Microchip} \quad (7)$$

The proposed antenna is designed to match the ALIEN H3 microchip, which is modeled as an electrically parallel RC circuit, as demonstrated in (8) and (9):

$$R_P = (Re(Z^2_{Microchip}) + Im(Z^2_{Microchip})) \div Re(Z_{Microchip})^2 \quad (8)$$

$$C_P = Im(Z_{Microchip}) \div (2 \times \ pi \times f(Im(Z_{Microchip})^2 + Re(Z_{Microchip})^2)) \quad (9)$$

### 3.2. Design and parametric study of proposed RFID tag

The reported RFID antenna comprises a series of elements: two inverted meander lines, each with 8 turns, and a slotted square patch on each side of the meander lines. The proposed antenna is designed on a Kapton substrate with a dielectric constant of 3.5 and a loss of 0.0027. The RFID antenna geometry has been designed using CST MWS as an electromagnetic solver and optimized to resonate within the UHF band [867.5-868 MHz]. The topology of the RFID tag antenna was designed to achieve matching and high efficiency at the operating frequency. Figure 3 illustrates the proposed RFID antenna structure and the placement of the microchip, which is modeled as a feeding element of the antenna. The structure comprises two inverted meander line arms associated with slotted patches, each meander line arms are created of 16 turns and a width of 1mm, it is separate with a gap of 0.5 to connect the RFID microchip. The insertion of two slotted patches is used to enhance the bandwidth, shift the resonance frequency at the operating frequency, and to cancel the capacitive effects to achieve the desired matching at 868 MHz. A concentrated study is done to analyze the behaviour of the structure with regard to define the impact of the insertion of the slotted patches and the width of the gap at 868 MHz.

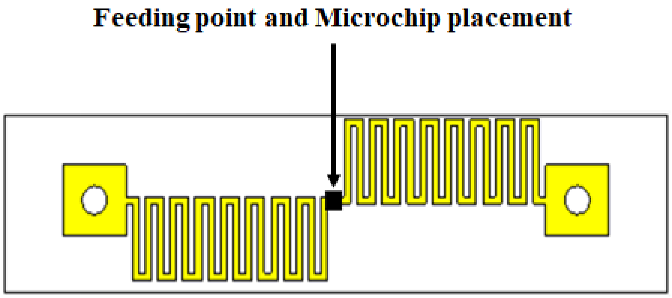


Figure 3. Proposed RFID tag antenna

### 3.3. A slotted patch affects

In the case of a conventional meander line antenna, the input impedance's are very small. Therefore, increasing the matching impedance is essential, and various matching techniques are employed in the design. The simulated input impedance of the meander structure at 868 MHz is approximately 12.85-j47.99 $\Omega$, representing a high mismatched impedance. Each inverted meander arm is connected to patches with a slot, each with a radius of 2 mm, to enhance the input impedance of the RFID tag antenna with a full length of around $\lambda \div 10$. The study results are presented in Table 1 and Figure 4, the key achievement of the proposed antenna is the improved gain, indirectly implying an enhanced read range. The insertion of the slotted patches has increased the input impedance of the meander antenna by raising the resistance Ra and reactance Xa of the input impedance of the proposed RFID tag. Consequently, this leads to a maximum reading distance and a wide beamwidth [15]$-$[18].

Table 1. Parametric study on insertion of microstrip structure with a meander structure antenna

| Design | Radiation effecency (%) | Beamwidth (°) | Gain (dBi) |
|---|---|---|---|
| Meander structure | 98.7 | 91.3 | 1.7 |
| Proposed antenna structure | 95.72 | 86.4 | 2 |

### 3.4. A gap effects

By assigning different gap widths 'g' (3 mm, 2 mm, 1 mm, and 0.5 mm, respectively), as presented in Figure 5. It can be seen as illustrated in Figure 6, that more the gap width is smaller, the resonance frequency is swept nearly to the operating frequency with a return loss $\preceq -10$ dB respectively -21.65 dB at 855 MHz, -22 dB at 859 MHz, -22.6 dB at 862.8 MHz to -22.64 dB at 868 MHz. Figure 7 present how the change in gap width affects the input impedance of the proposed RFID tag antenna at 868 MHz, correspondingly $Z_A = 34.12 + j124.14\ \Omega$ with 3 mm, $Z_A = 33 + j117.86\ \Omega$ with 2 mm, $Z_A = 31.85 + j111.88\ \Omega$ with 1 mm and $Z_A = 32.8 + j117.3\ \Omega$ with 0.5 mm.

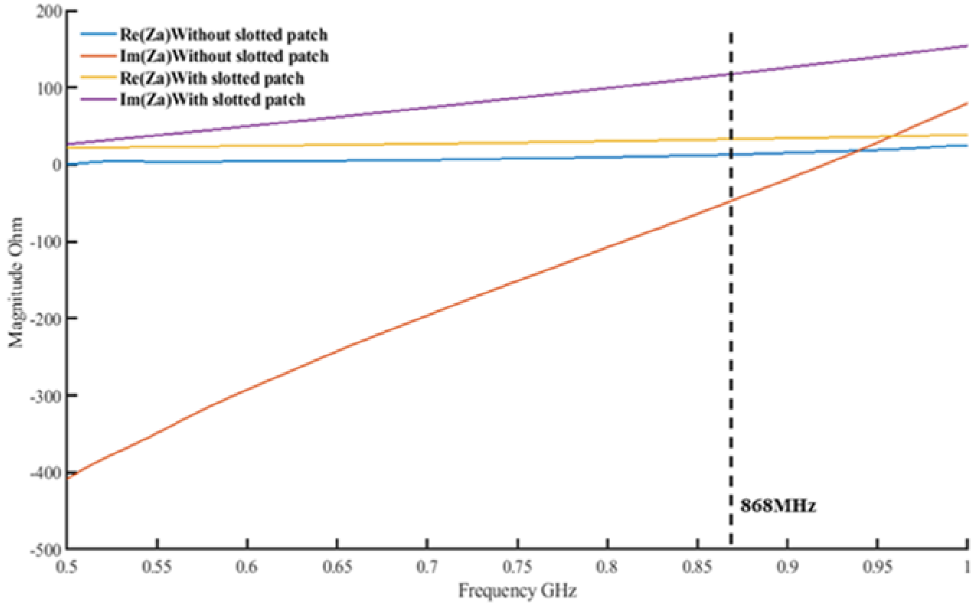


Figure 4. Comparison of the input impedance variation with/without the insertion of a slotted patch

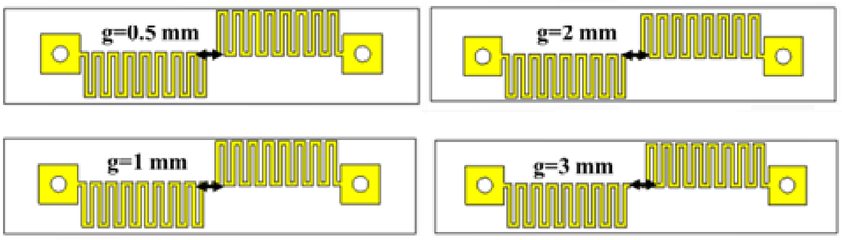


Figure 5. The gap dimension

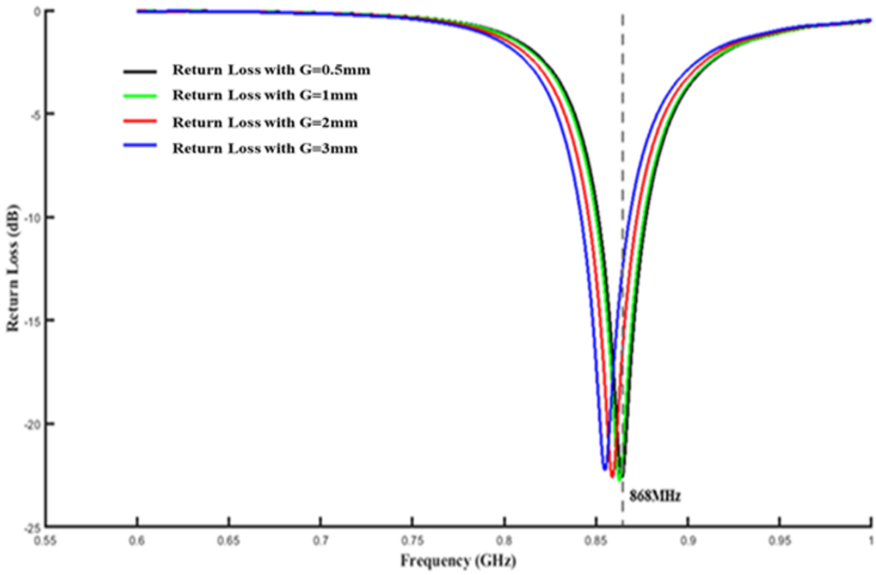


Figure 6. Effect of variation of gap width on the return loss of the proposed antenna

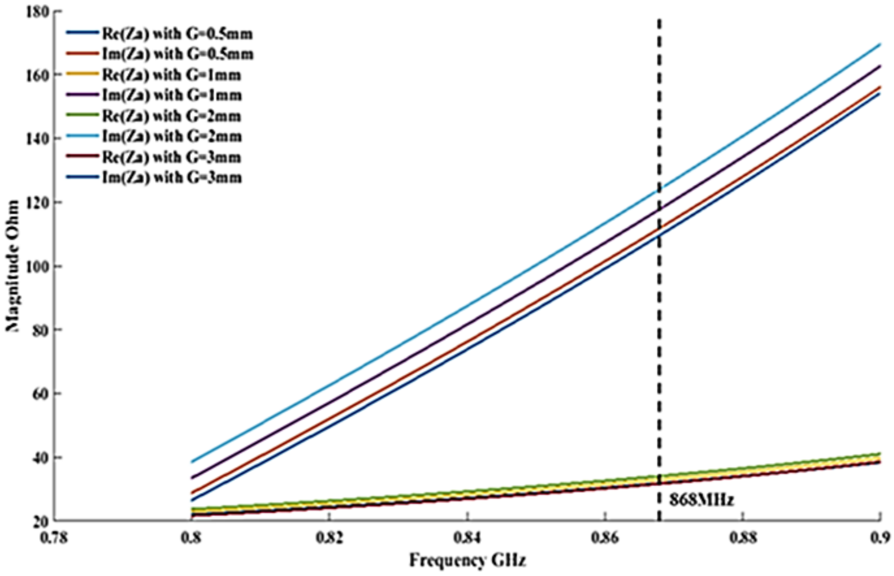


Figure 7. The input impedance vs gap width

### 3.5. Optimal parameters of the proposed RFID tag

The meander structure shows a reactance with capacitive effects and small resistance at 868 MHz which doesn't match the microchip impedance, after insertion of the two slotted patches with a length less than $\lambda_0 \div 2$. The input impedance has been increased with a highly inductive effect at 868 MHz with a gap width of 0.5 mm. After the optimization and parametric study, the results are investigated to get the optimal parameters at the Moroccan UHF band as shown in Table 2 and Figure 8.

Table 2. Optimal parameters for the proposed RFID antenna

| Design part | Physical parameter | Value (mm) |
|---|---|---|
| Substrate | $L_s$ | 105 |
| | $W_s$ | 25 |
| Meander line | e | 1 |
| | L | 11.85 |
| | d | 3 |
| | W | 1 |
| | g | 0.5 |
| Slotted patch | $L_p$ | 10 |
| | $W_p$ | 10 |
| | S | 2 |

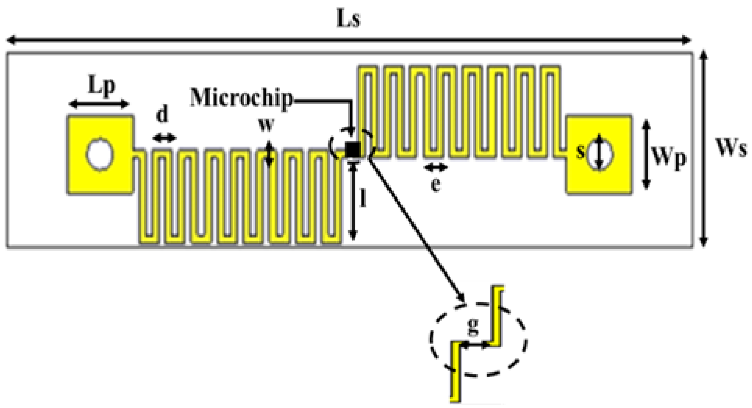


Figure 8. Proposed RFID tag antenna geometry with physical dimensions

## 4. SIMULATION RESULTS AND DISCUSSION

The proposed RFID antenna has been designed and simulated using CST MWS to evaluate the performance and provide an accurate antenna design. Figure 9 presents, the simulated return loss as a function of the frequency. The proposed RFID tag exhibits an excellent $S_{11}$ about -22.646 dBi, which is less than -10 dB and a bandwidth of 27 MHz, which can cover other sub-bands. The main parameter for evaluating the cost of power transmitted or reflected between the RFID integrated circuit (IC) and antenna is the voltage standing wave ratio (VSWR). The proposed RFID antenna offered a VSWR of about 1.15 at 868 MHz, which describes 99.5% of the power, is transmitted from the antenna to the RFID IC and 0.5% is reflected as a loss. As shown in Figure 10.

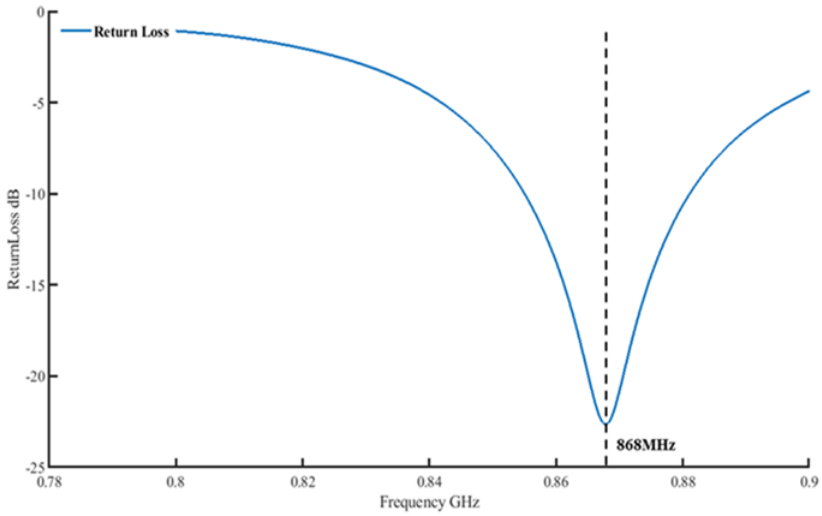


Figure 9. Return loss of the proposed RFID antenna

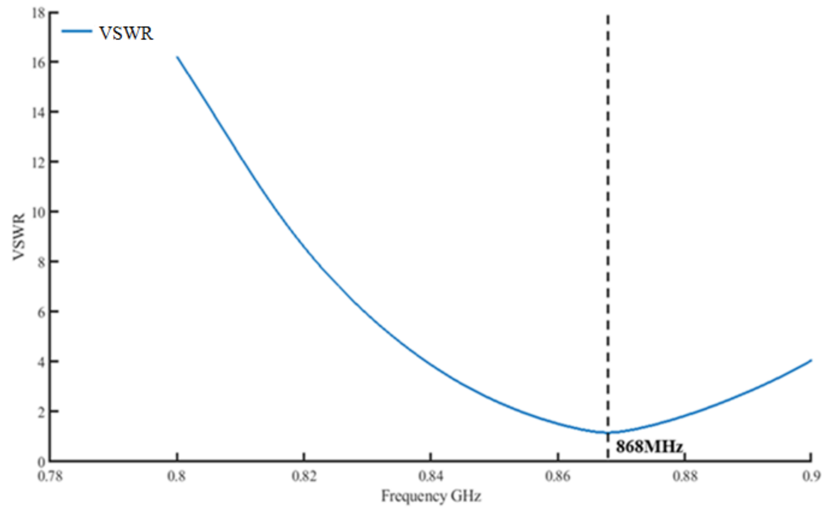


Figure 10. VSWR of the proposed antenna

The proposed RFID antenna demonstrates good gain at 868 MHz, approximately 1.65 dBi, as shown in Figure 11. The surface current distribution is more efficient in all meander line structures, but the density of the distribution becomes more irregular and less efficient. The current is predominantly located on the microchip placement and dispersed to all regions of the design, as illustrated in Figure 12. Additionally, the proposed antenna offers a directivity of 1.969 dBi at 868 MHz, as depicted in Figure 13.

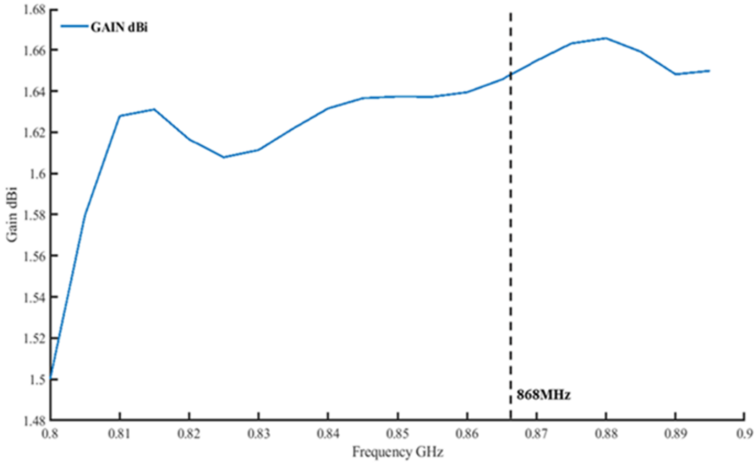


Figure 11. Gain vs frequency of the proposed RFID antenna

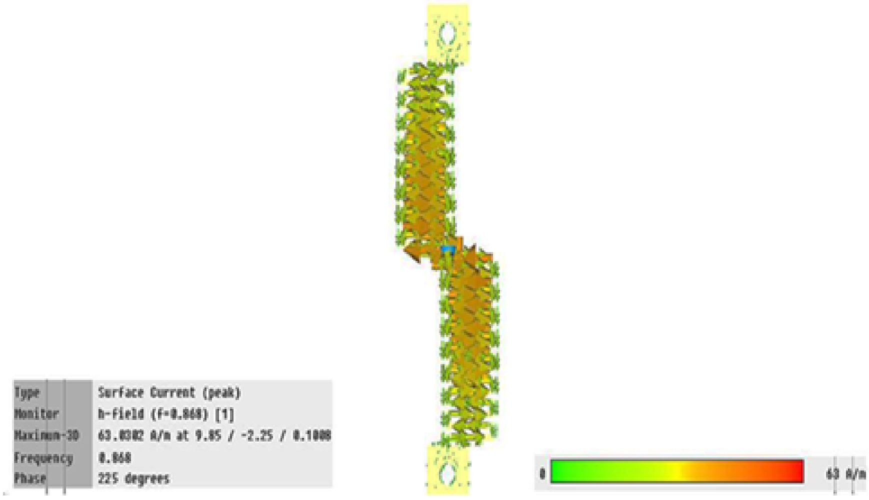


Figure 12. Surface current of the proposed RFID antenna

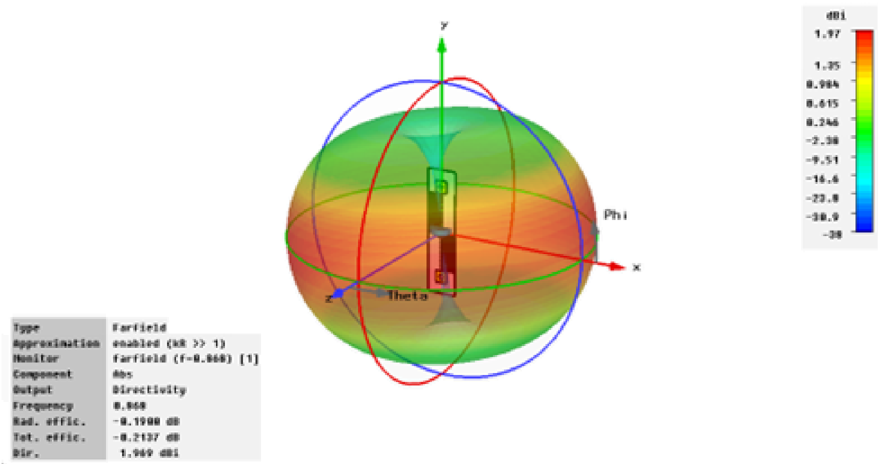


Figure 13. Far-field of the proposed RFID antenna

RFID applications generally required a high read range, so the more the agreement between the RFID tag and RFID station offers a high read range more the system is suitable to be used in applications. The main purpose of an RFID designer is to develop RFID tag antennas with high reading distance or read range, it's an important parameter linked to many parameters defined by the Friis equation as demonstrated in (10). Using CST MWS simulation results and a MATLAB script for determination of the theoretical read range as illustrated in Figure 14, the proposed RFID tag antenna provides a read range of about 5 m at 868 MHz. The simulated input impedance has been also evaluated using CST MWS and MATLAB organized to ensure the matching impedance at the operating frequency, as has been explained and demonstrated in [9]. Therefore, the simulated input impedance is nearly equal to $Z_{Antenna}$ at 868 MHz, which is around $Z_{Microchip}$ =32.8+j117.3 Ω, it shows a good matching impedance as had been mentioned the microchip impedance conjugate is about 27+j110 Ω. As presented in Figure 15. The theoretical read range is considered as an important factor to validate the performance of RFID tag, The flexibility of the substrate material can impacts this parameter and reduce the loss and missmatch, thereby Table 3 is summarized a comparison of the proposed RFID tag Vs some exits works and the effects of diffrents substrates on read range of RFID tag [19]−[27].

$$R_{range} = C \div (4 \times \pi \times f)\sqrt{EIRP_R \div S_{Microchip}}\tau \times G_{tag} \tag{10}$$

with

$$\tau = 4 \times R_{Microchip} R_{Antenna} \div (|\ Z_{Microchip} + Z_{Antenna}|)^2 \preceq 1 \tag{11}$$

with $C$: velocity equal to $3 \times 10^8$ m/s, $f$: operating frequency 868 MHz, $G_{tag}$: Gain of the antenna tag, $S_{th}$: sensitivity threshold of the microchip and $EIRP$: equivalent isotropically radiated power 500 mw.

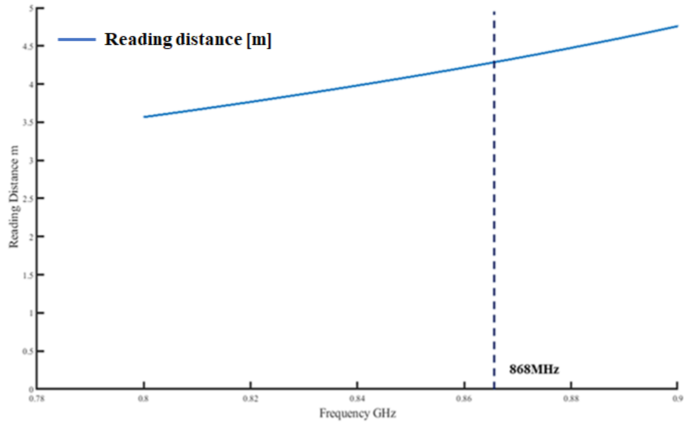


Figure 14. Read range of the proposed RFID antenna

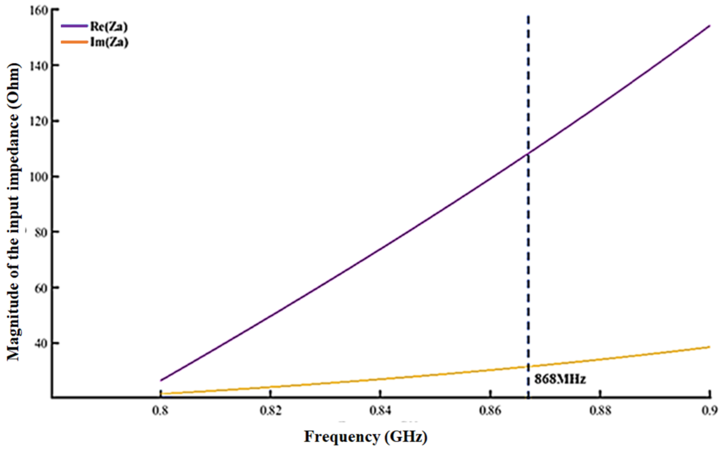


Figure 15. Simulated input impedance of the proposed RFID antenna

Table 3. Comparison table of the proposed RFID tag with existing RFID tags

| Reference | Material | Read range (m) | size ($mm^2$) |
|---|---|---|---|
| Xuan *et al.* [28] | PET | 3 | 48×13.7 |
| Faudzi *et al.* [29] | FR4 | 2 | 58×34 |
| Zhang and Long [30] | FR4 | 4 | 56×26 |
| Proposed RFID tag | KAPTON | 5 | 110×25 |

## 5. CONCLUSION

This paper presents a novel RFID antenna design with favorable characteristics for UHF RFID applications. The proposed structure is designed to operate in UHF band [867.5- 868.5 MHz] based on a combination of a meander antenna with a slotted patch on a flexible substrate allows for high read range and good performance. The RFID tag is designed on Kapton substrate with a global size of 105×25×0.1 $mm^3$. The simulation results were as follow: a return loss of -22.46 dB, a VSWR of 1.15, a gain in directivity of 1.65 dBi and a matching impedance cost of 96%. These simulation outcomes collectively affirm the viability and efficiency of the proposed RFID tag. Its suitability for UHF RFID applications is underscored by the high read range achieved, coupled with the flexibility of the tags integration into various items, making it particularly well-suited for applications such as identification and tracking. The paper thus presents not only a technological advancement in RFID antenna tag design but also a practical solution for applications demanding both flexibility and an extended read range.

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