

## A wearable UHF RFID tag antenna-based metamaterial for biomedical applications

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### ABSTRACT

The development of miniature antennas for bio-medical applications has attracted the attention of many researchers in the last years. In this letter, we provide a miniature antenna for the RFID tag for identifying patients in African and European hospitals. The proposed antenna is designed on a flexible silicon substrate with a relative dielectric constant of 11.9 and a thickness of 1.6mm. An in-depth study of the proposed wearable antenna was made in free space and on human tissue. The achieved results showed good performance in terms of miniaturization, bandwidth, impedance matching and, reading distance. The presented tag antenna is designed and simulated by using CST-MWS solver and the results were validated by HFSS and both results are in good agreement.

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## 1. INTRODUCTION

The RFID technology is an automatic identification technology using radio waves. An RFID system is composed of two main components, the reader and the tag [1-3]. Recently, this known technology has a great resonance in several bio-medical fields. We can classify hospital applications in terms of functionality into five categories: tracing, identification and verification, detection, interventions, alerts and triggers [4-6]. Thanks to the advance in the RFID technology, it is now feasible to control and locate patients in real time inside a hospital, a home, or in open space [7, 8]. In this case, the RFID tag must be deposited on the human body and equipped with biosensors. Once the tag is activated by the reader, the tag identifier and the bio-signals can be transmitted, recorded and processed.

Currently, RFID technology uses four frequency bands ranging from the HF band around the 12.25 KHz frequency to the microwave band around the 2.45GHz and 5.8GHz frequencies [9, 10]. Whatever the frequency band used, the main difficulty of antenna design for biomedical communication devices remains the effect of the lossy medium; in our case it is the human tissue on which we will deposit the proposed antenna which reduces the performance of the antenna, especially in terms of bandwidth and efficiency [11]. Figure 1 represents scenario of a wireless health network. The growing demand for RFID devices in the biomedical field has underlined the need for their miniaturization and the increase of their efficiencies, in order to favor more comfort when they are deposited on the human tissue [12]. These devices are composed by a chip and an antenna. Since the size of the RFID chip is of the order of a few millimeters it means that the size of the antenna will determine the performance of the entire system (antenna-chip).

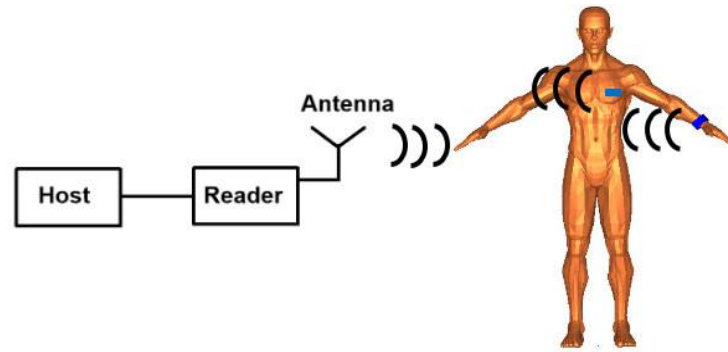


Figure 1. Scenario of a wireless health network

Several circuits have been proposed for the RFID tag antenna based on several methods, we mention the fractal geometry [13], the use of slots [14], folding [15]. But these structures, either they have a miniature size and high performance or they have good performance but the size is very large which is not suitable for the intended applications. In our work, we have chosen to use metamaterial structures that are known by the power of miniaturizing microwave circuits and improving performance under certain conditions.

Among the most critical parameters to consider in antennas design which are destined for on-body applications are the problems of impedance matching and the read range. During our design, we took into consideration these parameters in order to design a miniature antenna with good performance. In this letter, we present a miniature antenna for the RFID tag that will be used by patients in hospitals in the African and European UHF RFID band. This paper is organized according to the following plan: at first, we present the design stages of the antenna, in a second time, we present the obtained results and, in the last part, an in-depth study of the antenna on the human tissue will be approached.

## 2. ANTENNA DESIGN

RFID tag antennas are non-standard antennas. They are formed by a chip, a radiating part and, an impedance matching circuit. In the following sections, we present the description of the RFID chip that we used in this work after, we present the radiating element which is a metamaterial cell and, finally, we present the final geometry of our antenna.

### 2.1. RFID chip

In this work, we used the RFID chip "NXP Alien H3" which is characterized by an input impedance of  $27-j110$  Ohms at 868MHz frequency. This frequency is allocated in North Africa and Europe for the UHF RFID band. The proposed RFID chip follows the second-generation EPC Class one standard and has a minimum activation power about 20 dbm. We have simulated its equivalent electrical model and the obtained results in terms of input impedance are shown in Figure 2.

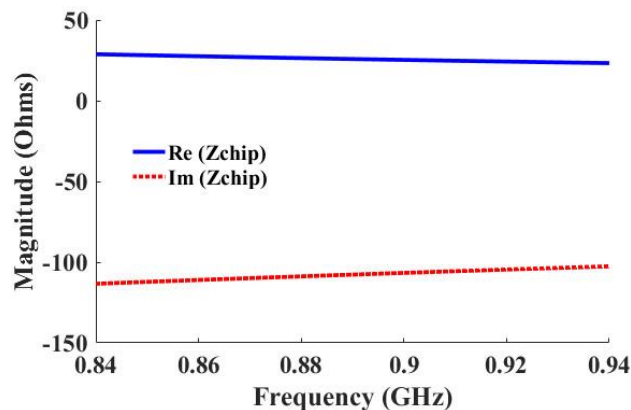


Figure 2. Input impedance of the Alien H3 chip

## 2.2. Metamaterial unit cell

Metamaterials are homogeneous structures or materials with criteria that are not found in ordinary materials [16]. The theoretical concept of this type of material was first introduced in the sixties by Vector Veselago (Veselago et al., 1968). [17]. Thirty years later, the first fabrications were made by J. Smith's team [18]. After this work, the metamaterials have had a great following by researchers in many fields and especially in the microwave field [19-20]. The structure that we have designed for this work is formed by two ring resonators slotted at their extremity and connected to each other by a stub as shown in Figure 3(a). The metamaterial structure was simulated under the CST MWS software to extract its effective parameters in order to verify the metamaterial effect around the desired band at the operating frequency of our antenna. Figure 3(b) presents the S-parameters.

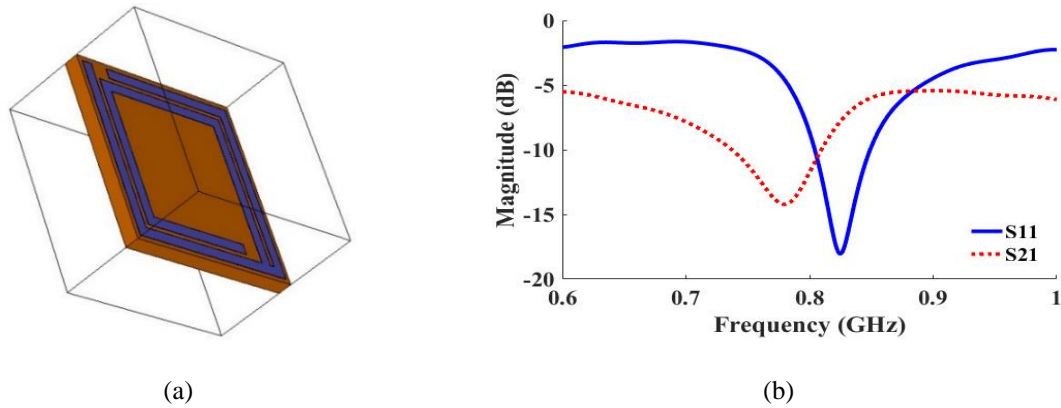


Figure 3. (a) The metamaterial structure in TEM box, (b) S-parameters of the metamaterial structure

The method that we have used for extracting the actual parameters is known as the Nicolson-Ross-Weir method [21-23]. It uses the following characterization equations:

$$S_{11} = \frac{i}{2} \left( \frac{1}{z} - z \right) \sin(nkd) \quad (1)$$

$$S_{21} = \frac{1}{\cos(nkd) - \frac{i}{2} \left( \frac{1}{z} + z \right) \sin(nkd)} \quad (2)$$

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (3)$$

$$n = \frac{1}{kd} \cos^{-1} \left[ \frac{1}{S_{21}} (1 - S_{11}^2 + S_{21}^2) \right] \quad (4)$$

where:  $n$  is the refractive index,  $z$  is the wave impedance,  $S_{11}$  is the reflection coefficient,  $S_{21}$  is the transmission coefficient,  $k$  is the wave number and,  $d$  is the metamaterial unit cell thickness. The electric permittivity  $\epsilon = n/z$  and magnetic permeability  $\mu = n \cdot z$ .

The results of the effective parameters are presented in Figure 4. It is remarkable that this structure has a negative permittivity around the 868 MHz frequency, which validates the metamaterial effect of the proposed cell.

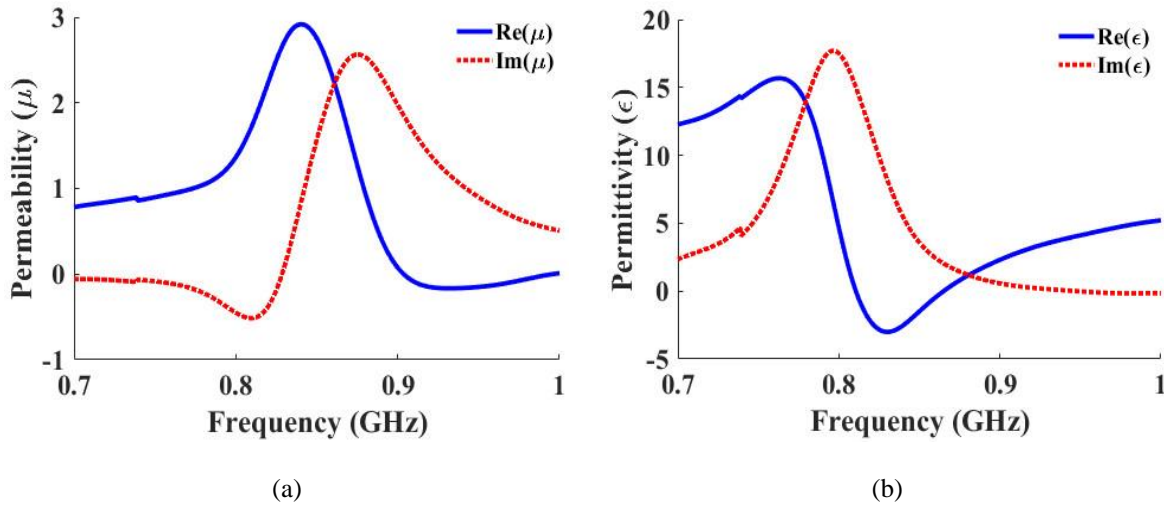


Figure 4. (a) Permeability of the spiral SRR, (b) Permittivity of the spiral SRR

### 2.3. Antenna geometry

After designing the metamaterial cell, we started designing a matching circuit between the cell that serves for radiating element and the Alien H3 chip. To maximize the power transfer between the antenna and the microchip, it is necessary that the input impedance of the antenna  $Z_a$  must equal the impedance of the RFID chip " $Z_{chip}$ ". However, " $Z_{chip}=27-j110$ " Ohms is an impedance that is highly capacitive so the impedance antenna must be inductive. The matching circuit that we proposed is in the form of a spiral as shown in Figure 5(a). The final geometry of the designed Tag antenna is presented in Figure 5(b).

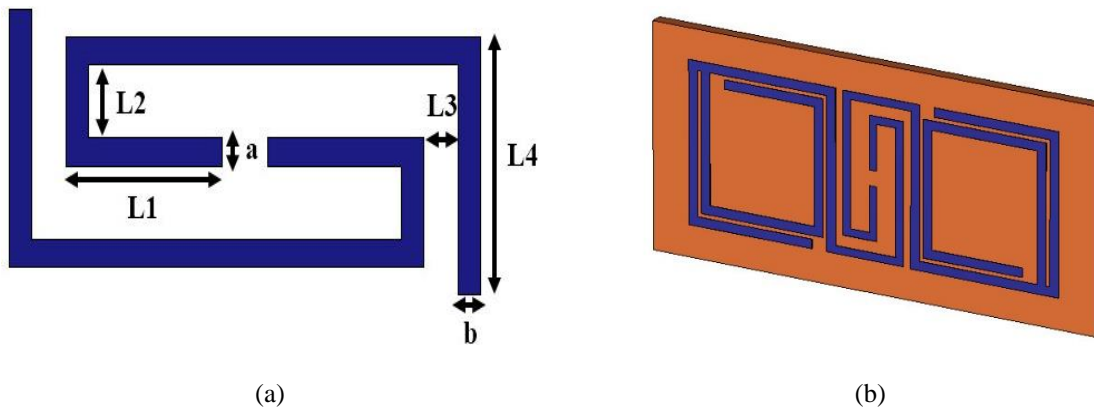


Figure 5. (a) Impedance matching structure of the antenna, (b) 3D layout of designed antenna

The optimal parameters are obtained using a parametric study on its parameters by changing only one parameter while keeping all the other parameters constant. To illustrate this study, we present in this paper two parameters  $L1$  and  $a$  to see their effect on the input impedance of the antenna. According to Figure 6(a) and Figure 6(b), it is found that the parameter  $L1$  has a large effect on the input impedance of the antenna. Both  $\text{Re}(Z_a)$  and  $\text{Imag}(Z_a)$  parts increase with the increase of parameter  $L1$ . In another side, the impedance varies a little with the variation of the parameter  $a$  in a way that the real part  $\text{Re}(Z_a)$  increases with the increase of " $a$ " while the imaginary part decreases. This means that we can control the impedance of the antenna by controlling the parameters of the adaptation circuit. Table 1 presents the dimensions of the tag antenna.

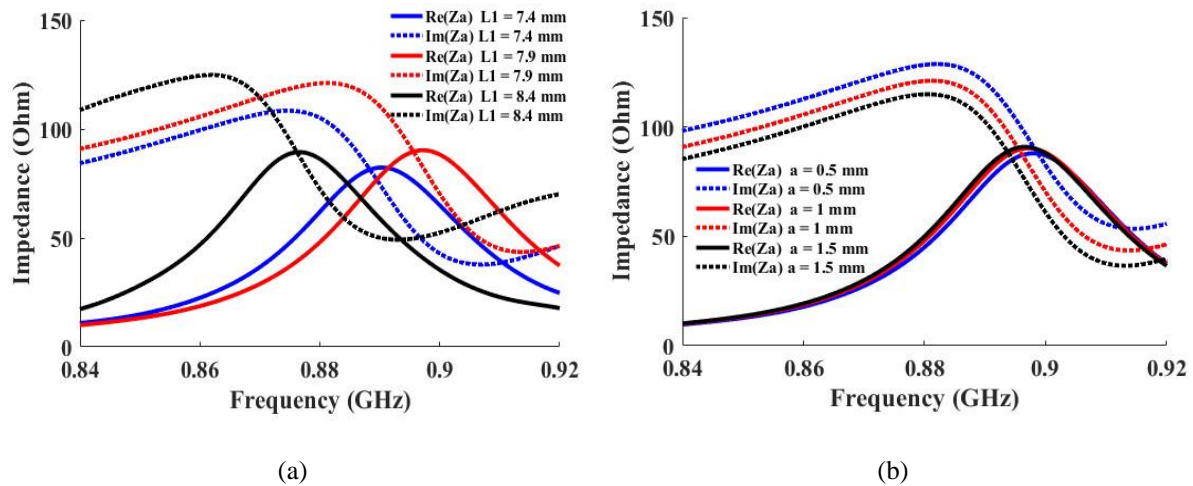


Figure 6. (a) Effect of parameter L1 on the antenna input impedance, (b) Effect of parameter a on the antenna input impedance

Table 1. Parameters of the antenna			
Parameter	Value (mm)	Parameter	Value (mm)
Want	50.2	Lant	20
L1	7.9	L2	4.1
L3	1	L4	12.2
a	1	b	1

### 3. RESULTS AND ANALYSIS

After optimization of the antenna using the parametric study by CST software, we noted the simulation results in terms of input impedance, which is reported in Figure 7(a). It can be seen that, the impedance of the antenna  $Z_a = 26 + j112$  Ohms. This impedance is close to the conjugated antenna. Figure 7(b) reports the reflection coefficient of the designed antenna. Note that this antenna has an impedance matching around -27dB and a bandwidth of the order of 24Mhz. In order to verify the simulation results, we have launched another simulation by the HFSS software, these results are in good agreement with the one obtained by CST and they are drawn on the same figure. The radiation pattern of the antenna in the E and H planes are drawn in Figures 8(a) and 8(b) respectively. Thus, the antenna presents a bi-directional radiation.

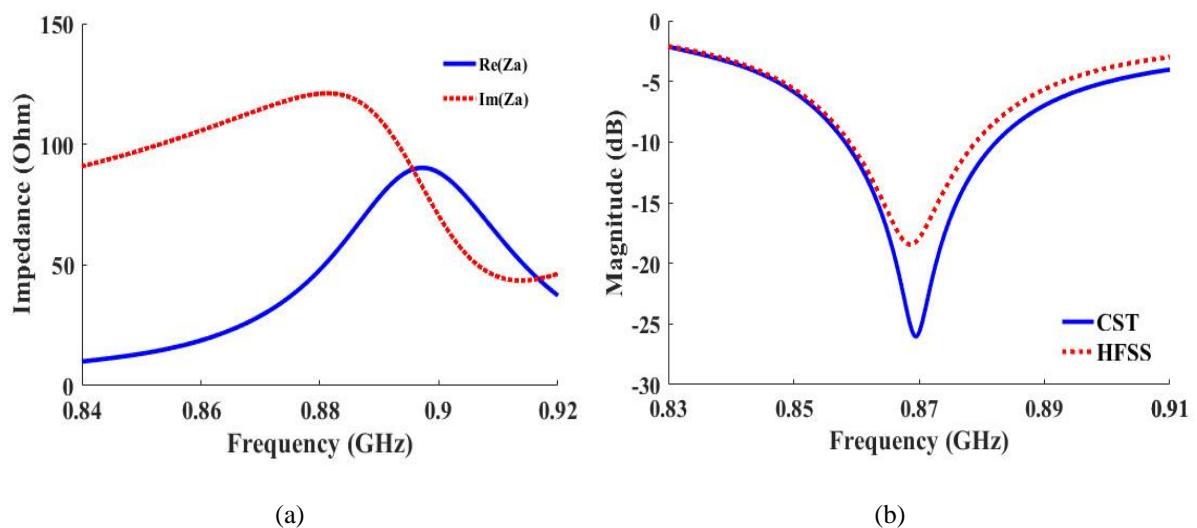


Figure 7. (a) Input impedance of the designed antenna, (b) S11 of the antenna

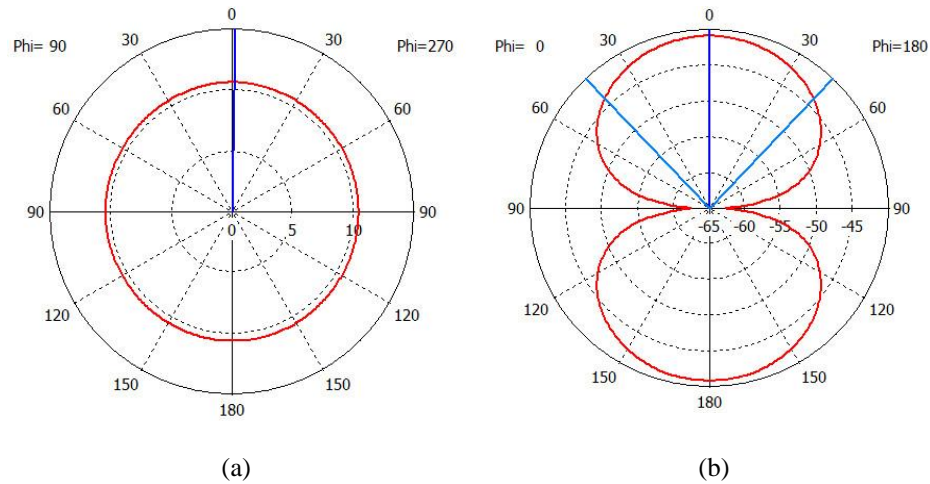


Figure 8. Radiation pattern at, (a) E-plan, (b) H-plan

In order to better understand the effect of metamaterial cells on the behaviour of the antenna, we present in Figure 9(a) the distribution of surface currents. Therefore, the maximum of the currents concentrates of the two metamaterial cells and around the circuit of adaptation. One of the most critical parameters to consider when designing RFID tag antennas is the reading distance. For our antenna, we drew the range depending on the frequency in Figure 9(b) and we obtained a reading distance up to 14m. It was obtained by the Friss equation [24].

$$R_{\max} = \frac{c}{4\pi f} \sqrt{\frac{EIRP \cdot G_{\text{tag}} \cdot r}{P_{\text{chip}}}} \quad (5)$$

Where;  $c$  is the light speed,  $f$  is the resonance frequency, EIRP is the effective isotropic radiated power,  $G_{\text{tag}}$  is the Tag antenna gain,  $\tau$  is the power transmission coefficient and,  $P_{\text{thip}}$  is the minimum sensitive power of the chip.

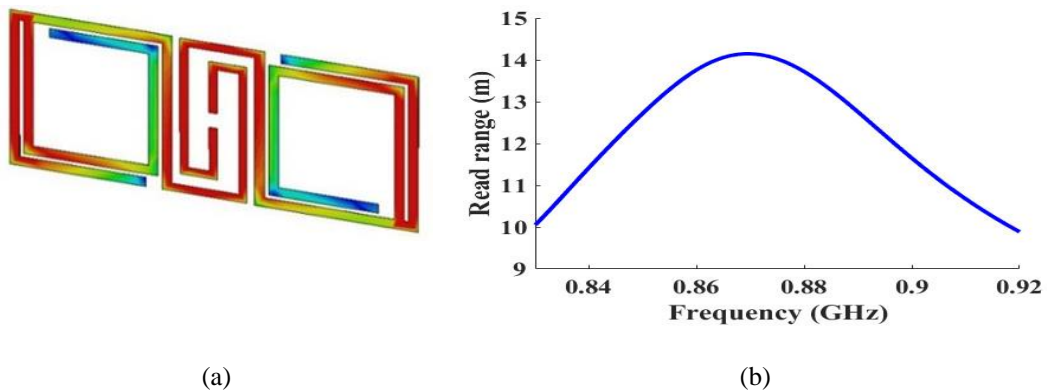


Figure 9. (a) Surface current distribution, (b) Read range of the antenna

#### 4. ANTENNA PERFORMANCE ON HUMAN BODY

The proposed antenna is intended to be worn by patients and since the antennas of the UHF band is very sensitive to the surrounding environment, it was necessary to model the human tissue to see its effect on the performances of the proposed antenna. As a result, scientists have made a simplified model of a reference man [25]. This consists of a set of laminated elliptical cylinders; each cylinder is characterized by some physical parameters referring to a certain tissue, Figure 10(a) illustrates a schematization of the designed antenna on the homogeneous human model. Due to the reduced size of the proposed antenna

that does not exceed the size of the human hand reference, to simplify the design and, to reduce the simulation time, we designed the simplified model with one hand, as represented in Figure 10(b).

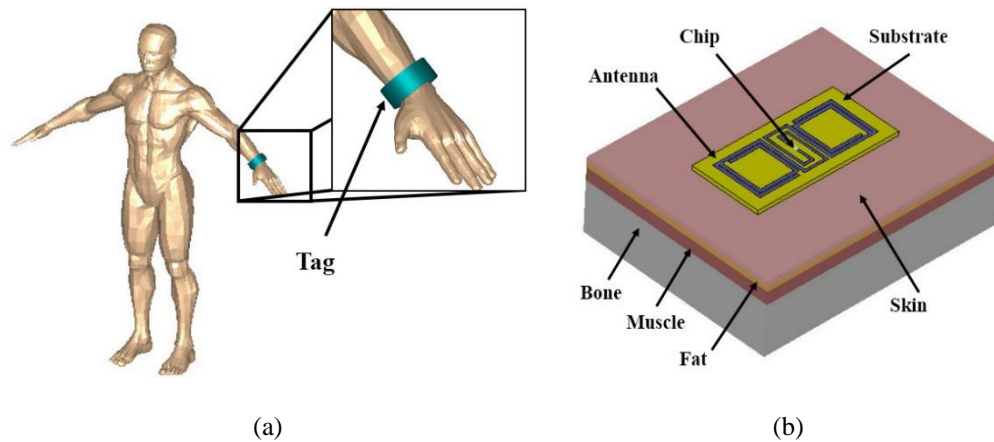


Figure 10. (a) Schematization of the designed antenna on the homogeneous human model, (b) Antenna on human arm model

Firstly, we start by representing the reflection coefficient  $S_{11}$  on human tissue, which indicates the rate of impedance matching in the desired frequency band. For our antenna, we have obtained a good bandwidth ranging from 0.7 MHz to more than 1.3 GHz, allowing better operation and better interoperability. From Figure 11(a), we can notice that the impedance bandwidth is improved compared in human tissue compared to free space. Another study was made on the reading distance to ensure the proper functioning of the antenna, the result is shown in Figure 11(b). It is remarkable that we lost at the reading distance this is due to loss of gain in the presence of the human body but we still have a good read range that ensures the proper functioning of our antenna for the desired applications.

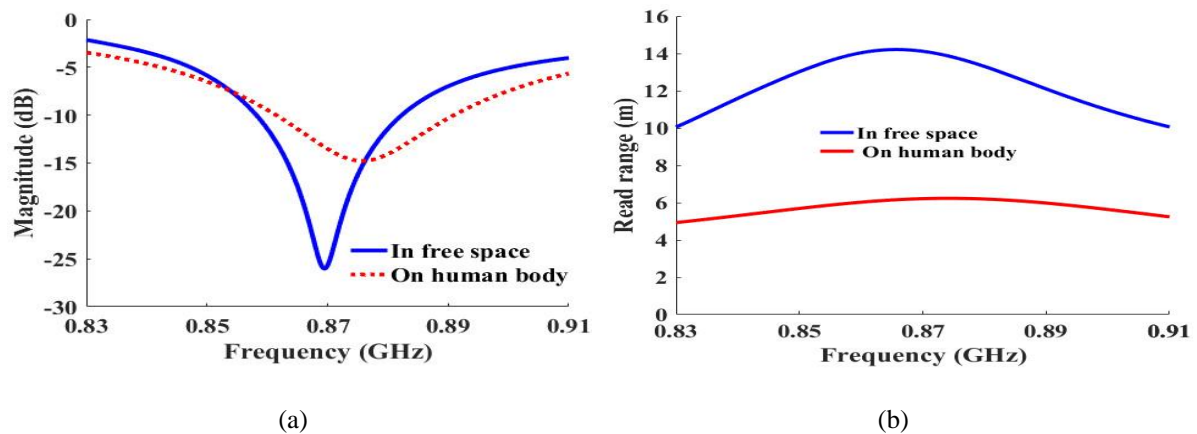


Figure 11. (a)  $S_{11}$  of the antenna in free space and on human body, (b) Read range of the antenna in free space and on human body

## 5. CONCLUSION

In this paper, we presented a miniature antenna for the RFID tag based on metamaterials designed to work in the presence of human tissue. The proposed antenna was designed and optimized by the CST MWS software on a flexible substrate of high permittivity to reduce the effect of the surrounding environment. The use of the metamaterial structure aims to reduce the size of the antenna and improve its performance at the same time which is not possible by other techniques. Since the RFID antennas in the UHF band are very sensitive to the surrounding environment and to make sure that the antenna works, we validated our antenna

in the presence of the human tissue and we reassured that the antenna presents good performance even in the presence of human tissue which is suitable for the intended application.

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