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# UHF RFID Spiral-Loaded Dipole Tag Antenna Conception for Healthcare Applications

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## Abstract

This paper reports the characterization procedure of a radiofrequency identification tag powered by meandered L-matching configuration and placed directly on the planar layered anatomical model of a human arm. The tag antenna component and its matching system interface to the RFID chip are designed with the help of electromagnetic simulators. A new optimal tag structure is combining multiconductor strips and a meandering schema used to achieve the required inductance. The folded configuration of the proposed tag adds stretchability and more reduction of the antenna size, especially when attached to the non-uniform as the human body. It is demonstrated that the tag can communicate with a reader. The simulated performances indicate the robustness of the proposed tag structure and its ability to be deployed in several healthcare sensing applications.

*Keywords:* RFID; Biomedical Applications; Antena; WBAN; Propagation.

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## 1. Introduction

The design of efficient antennas for UHF RFID applications that involve the human body as an object to be tagged and sensed is still a significant challenge due to the strong interaction of the antenna with the human body, which is

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responsible for impedance mismatch and efficiency degradation. Several existing and emerging RFID applications require or can benefit from one or more antennas that can be directly mounted on a garment or integrated into a personal accessory such as shoes, glasses, buttons, and helmets [1].

These antennas are commonly referred to as textile antennas, body area network (BAN) antennas, antennas for body-centric communications, or wearable antennas. The latter is the term used in this paper, as it refers to an antenna that is small and light enough to be worn on the human body [2].

A novel tag geometry combining folded lines and modified L-matching circuit interface is examined here through numerical analysis using EM simulation by HFSS and CST solvers. The realized design, which is small in size, can be applied to the human arm. The tag antenna represents a sensitive component that affects the functionality of the whole RFID system. The tag antenna has to operate in close touch with the lossy human body [3]-[4]. Therefore, of the length of the communication between tag and reader. Moreover, there are two types of RFID tags. The passive one could be battery-less or battery-assisted but doesn't require any external power supply and harvesting energy from the reader to activate the microchip. And the active one that has an internal power supply. It's more complex and gives a long read range from the reader to passive tag [5].

The study of the radiation characteristic of the proposed tag concerning the coupling distance between the tag and the human body proves that our designed and optimized tag can simultaneously guarantee a good compromise between its performances a small size of the antenna. This is another crucial investigation for our proposed wearable tag, because the performance of the antenna increases for larger ground planes. However, this improvement contradicts one of the most important requirements of wearable RFID applications, which is the necessity to maintain the antenna's small size as much as possible [6]-[7].

This contribution presents a structure of our novel tag composed of multiconductor structure and meandering strips to match with the defined microchip. A novel design is suitable for UHF RFID on-body applications. The folded dipole antenna is fed via an L-matching system is placed on the human skin by a flexible PVC plastic layer, and is complex impedance matched to the microchip. Details of the antenna design are described, and simulated results of the proposed antenna's input impedance and radiation characteristics are presented and discussed.

## 2. Tag Antenna Design on Human Arm Tissues

A possible antenna layout that is compatible with the requirements of portable antennas (flexible and lightweight form, thin insulating materials) is the proposed planar spiral-loaded dipole with an L-matching structure tag. The designed tag consists of a conductive spiral dipole connected to the chip by meandered L-matching schema. This choice has an impact on the antenna impedance and provides an inductive reactance. It can also withstand the effects of the human body as a complex object that will absorb or attenuate the electromagnetic (EM) wave emitted/received by the RFID tag.

L-matching strips are designated for connecting to the tag chip (Alien Higgs 4, SOT232 package, $Z = 8-j142\ \Omega$). Moreover, the proposed tag will be placed around the layered anatomical phantom of the human arm at 870 MHz. This model consists of stratified parallelepiped boxes with defined properties such as thickness, dielectric constant, and conductivity. The tag antenna is designed using 0.05 mm of adhesive copper and 1.7 mm of PVC-Plastic substrate (permittivity of 2.7 and conductivity of 0.007 S/m at 870 MHz).

The proposed design can electrically isolate the antenna from the skin and permit the biocompatibility of the tag. The geometrical parameters of the proposed RFID tag antenna have been performed by parametric optimization using an HFSS solver.

The desired initial geometry of spiral-loaded dipole antenna was obtained by adding folded strips b, c, and d and the meandered L-matching structure e, f, g, and h as shown in Fig. 1. The reflection coefficient and resonant frequency of the initial 'five' loaded dipole antenna can be optimized by changing the L-matching parameters of the proposed antenna. All the basic parameters of the proposed spiral-loaded antenna are presented in Table 1. The L matching technique is applied to reach inductive reactance and to conjugate-matching with microchip impedance for a given dipole [8]. The equivalent circuit of the whole tag is shown in Fig.2.

The resonance frequency of the antenna (the frequency where $R_{in}$ reaches a maximum) is reduced by elongating the length of the spiral-loaded dipole (increasing e). The parameter e is thus adjusted so that the resonant frequency is 870 MHz. Increasing h and f mainly increases because it increases the length of the series inductance. Other parameters that have a similar effect as h includes the meander length g. In contrast, is weakly influenced by these parameters. By adjusting, the antenna matching can be reached in the desired resonant frequency.

The electrical properties of the human arm model (skin, fat, muscle) at 870 MHz are shown in Table 2. A model was added to the simulation scenario to analyze the body-antenna coupling. We chose a three-layer model, consisting of a skin layer (2 mm thick), a fat layer (4 mm thick) and a muscle layer (54 mm thick) and shown in Figure 3 [9].

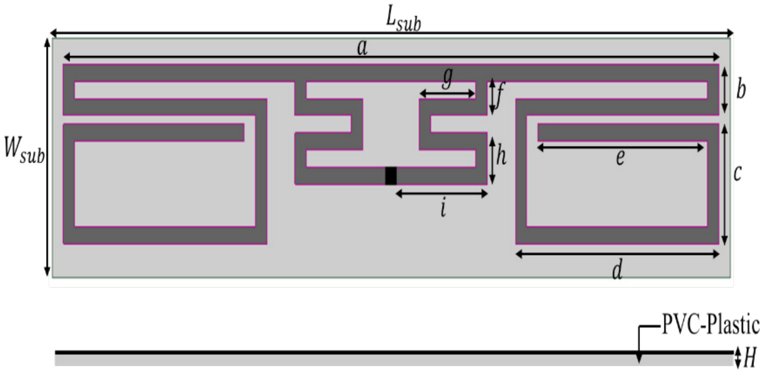

Figure 1. Layout of the spiral-loaded dipole RFID tag with L-matching structure.

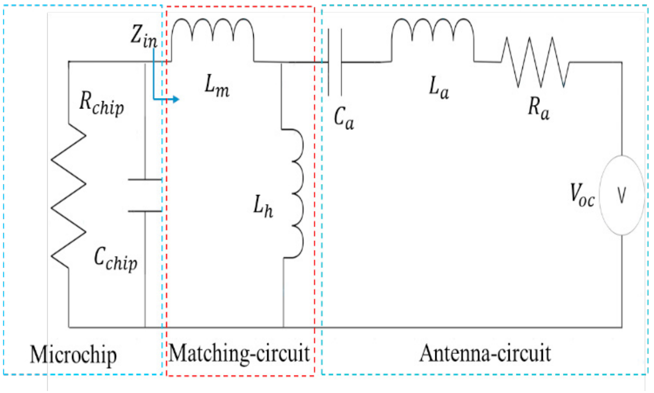

Figure 2. Equivalent circuit of the full spiral-loaded dipole tag

Table 1. Dimensions of tag antenna (in millimetres).

| Parameters | Dimensions |
|---|---|
| $L_{sub}$ | 14 |
| $W_{sub}$ | 60 |
| $a$ | 58 |
| $b$ | 3 |
| $c$ | 7 |
| $d$ | 18 |
| $e$ | 15 |
| $f$ | 2 |
| $g$ | 6 |
| $h$ | 3 |
| i | 8 |
| $H$ | 1.7 |

Table 2. simplified model of human tissues at 870 Mhz

| Layer | Relative permittivity | Conductivity [S/m] | Thickness (mm) |
|---|---|---|---|
| Skin | 14 | 0.25 | 2 |
| Fat | 55.1 | 0.93 | 4 |
| Muscle | 20.8 | 0.33 | 54 |

## 3. Results and discussions

This section presents the simulated results of the reflection coefficient, antenna input impedance, the gain, and the radiation characteristic of the desired geometry of spiral-loaded dipole antenna. Then, we analyze matching features of this conventional antenna to examine its performance close to the human arm.

To study the influence of the L-matching structure on the performance of the proposed antenna. Ansoft HFSS and CST simulators are used to evaluate the performance of the proposed antenna [10]-[11]. The microchip was modeled in this solver by introducing the lumped port and RLC Boundary that simulates the behavior of the IC (with its complex impedance feed).

The return loss of this antenna was calculated based on the power reflection coefficient, which considers the IC's capacitance as shown in this equation [12].

$$|s^2| = \left|\frac{z_{chip} - z_{ANT}^{*}}{z_{chip} - z_{ANT}}\right|^2 \tag{1}$$

$Z_{chip} = R_{chip} - jX_{chip}$ represents the impedance of the chip and $Z_{ANT} = R_{ANT} + jX_{ANT}$ represents the input impedance of the antenna with $z_{ANT}^{*}$ it's antenna's conjugate impedance.

Figure 3 shows the reflection coefficient S11 of our proposed tag placed on the planar model of human arm phantom versus frequency in the UHF band. We notice that the maximum reflection coefficient S11 has a value of − 39dB at the resonance frequency of 870 MHz. The maximum bandwidth (S11 < −10 dB) of the proposed tag antenna was 4.53% (860MHz-900MHz). Therefore, our proposed tag antenna can be functional within the UHF RFID band.

To validate the above results, in Figure 4, we present the input impedance of the proposed antenna placed on the human arm model both the input reactance and resistance of the antenna match well with those of the tag microchip (8-j142Ohm)—the variation of the tag's input impedance versus the length of L-matching schema. The simulated resistance for the antenna, in the UHF RFID frequency range, maintains a value close to 8 Ohms. The reactance part of the impedance, as shown in fig.4, have a positive value with a linear variation with frequency, related to the inductance that equivalently cancels the effect of the microchip capacitance.

To check HFSS simulation results of our proposed antenna characteristics, such as the S11, antenna input impedance, and the gain, we have compared the results obtained with HFSS solver with that of the CST simulator. This comparison indicates nearly similar matching features and radiation performance. The slight differences between the results of the two simulators can be attributed to the difference between the numerical codes of each one.

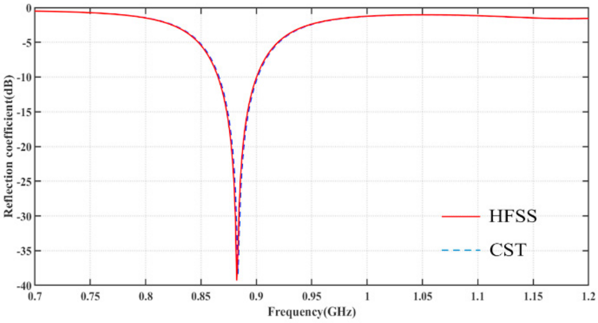

Figure 3. Return loss S11 versus frequency for proposed tag.

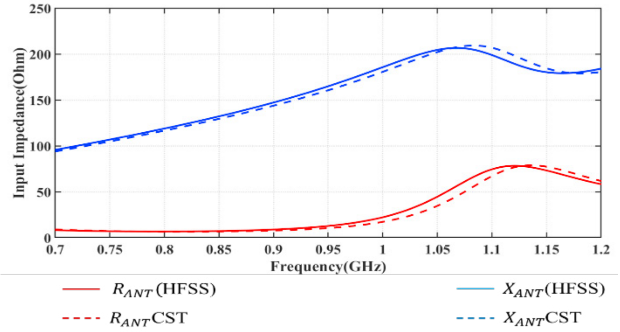

Figure 4. (a) Input resistance and (b) input reactance of proposed antenna in UHF band.

## 4. Radiation Performances of the Proposed Tag

### 4.1. Radiation Patterns

The 2D-Radiation Patterns of spiral-loaded dipole tag at resonant frequency 870 MHz attached on human arm model in the three planes xz (Ø = 0 °), yz ( Ø =90 °) and xy (θ = 90 °) are shown in Fig.5. It shows that the proposed antenna represents nearly Omni-directional radiation patterns since human tissues absorbed some electromagnetic radiation.

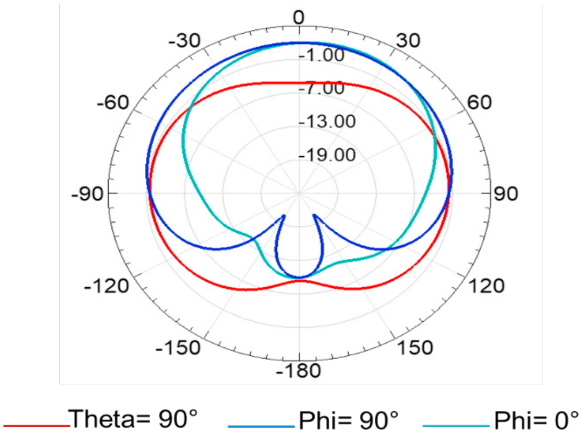

Figure 5. 2D-Radiation Patterns of the proposed tag in 870 MHz

Fig. 6 presents the far-field 3D view of the radiation pattern of the conceived tag at 870 MHz. The top red color indicated the far-field region that determines the antenna radiation pattern. In this region, The peak gain of the tag is found to be 2 dB at 870MHz. The gain in the rear of the proposed antenna is minimum due to the human tissue absorption.

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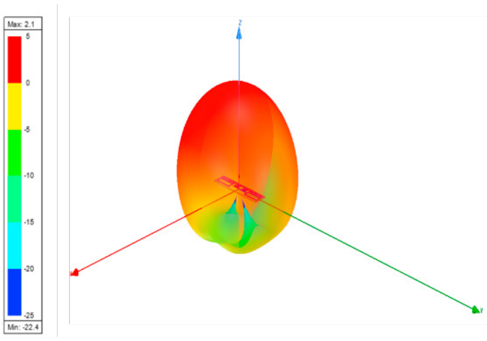

Figure 6. 3D far-field directivity Radiation Pattern of proposed tag in 870 MHz.

## *4.2. Gain, Efficiency and Read Range of the Conceived Tag*

The communication performance of the proposed tag has been verified by simulating the gain, which combining the radiation gain of the antenna and matching properties. Under the simplified hypothesis of free-space interactions, the power delivered by the reader to the tag, placed at mutual distance, is given by the Friis formula [13]:

$$p_{R\rightarrow T} = \left(\frac{\lambda_0}{4\pi d}\right)^2 P_{in} G_R G_{Tag} \tau . \eta_p \tag{2}$$

$G_{tag}$ is the gain of tag, $\tau$ is the power transmission coefficient between tag antenna and the microchip, $P_{in}$ is the power emitted by the reader, $G_R$ is the reader antenna gain, $\lambda_0$is the free-space wavelength, d is the distance between reader and tag antenna, $\eta_p$is the polarization factor between the reader and the tag [14]-[18].

According to different countries, the effective power EIRP transmitted by the reader is generally fixed to 3.2 W EIRP or 4W EIRP. The RF power required by the microchip to switch on and assure back-scattering modulation has to be fixed. According to the hypothesis of polarization matching between the reader and tag antennas, the maximum activation distance of the tag is then given by:

$$d_{max} = \left(\frac{\lambda_0}{4\pi}\right) \sqrt{\frac{EIRP.G_{tag}\tau\eta_p}{P_{chip}}} \tag{3}$$

The simulated gain of proposed tag, using a simplified model of human body, is shown in Fig.7. The maximum value of the realized gain of proposed tag along the frontal direction is 2dB at around resonant frequency 870 MHz. Better performances are achieved by our designed tag in close proximity of human arm model. Thanks to its small size and flexible ground plane substrate.

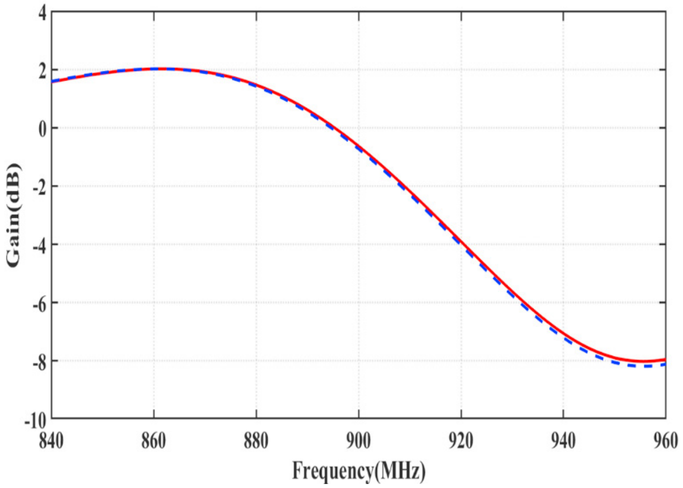

Figure 7. Gain versus frequency of proposed RFID spiral-loaded dipole tag simulated in HFSS And CST solvers

The antenna efficiency is defined as the ratio of the power radiated (Prad) by the antenna to the power supplied (Ps) to the antenna. It depends on the frequency and is expressed as a percentage. As represented in Fig. 8, the antenna efficiency of a spiral-loaded antenna is 85% at 870 MHz.

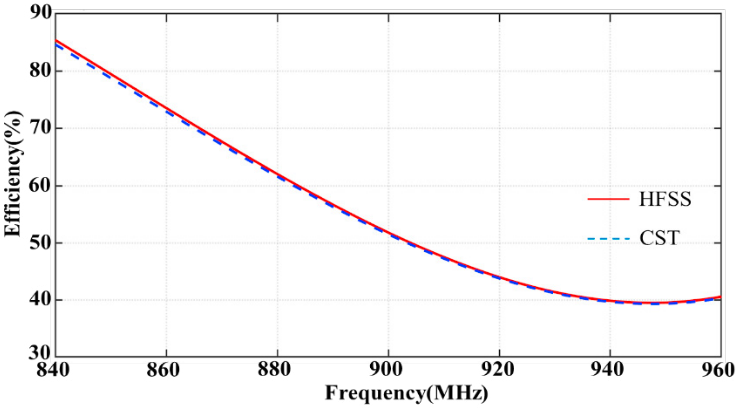

Figure 8. Efficiency (%) versus frequency of proposed RFID spiral-loaded dipole tag simulated in HFSS and CST solvers

In Figure 9, the estimated reading range of the second epidermal tag is plotted versus the frequency, when the tag is placed directly on the reference model of human body. the maximum reading distance is almost 6.4 m in the case of the reader with circular polarization ($\eta_p = 1$) and above 3.2 m in the case of the reader with linear polarization ($\eta_p = 0.5$).

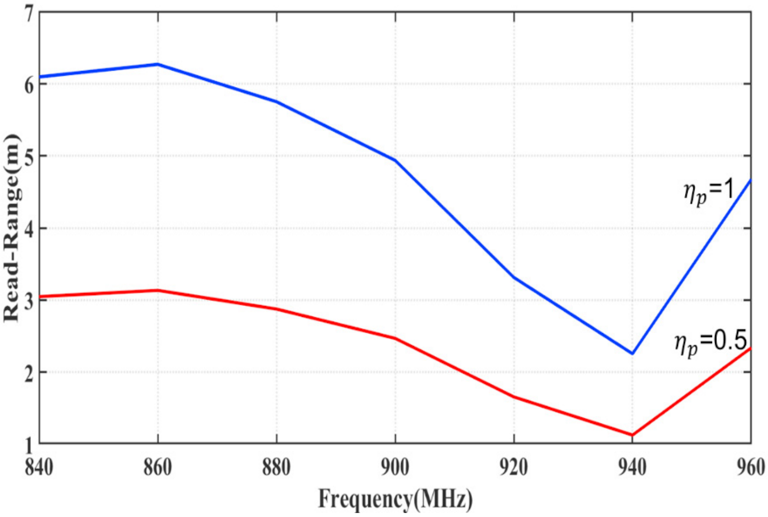

Figure 9. Read-range versus frequency of proposed RFID spiral-folded dipole tag.

## 5. Conclusion

This paper discusses the design and simulation study of the performance of our proposed wearable antenna placed on a planar model of the human arm. The design, simulation, comparative plots, and practical implementation of the proposed antenna were presented and discussed. The HFSS and CST software was used to optimize the RFID spiral-loaded dipole tag. The simulation results show that the proposed tag achieved satisfactory results near human tissues, which absorb and reflect the received electromagnetic waves. According to the simulation results, the proposed tag antenna placed on a human arm phantom provides better gain and good matching characteristics. In this way, the tag size was well reduced with a typical radiation pattern. The L- matching technique increases the operating frequency band and improves the efficiency of the antenna design.

The future research will address the replacement of the substrate and conductor substrate with more suitable materials to the human skin and develop the optimal tag layout by adding the sensing capability for healthcare uses.

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