Design of Folded Dipole with U Shaped Slot UHF RFID Tag using Genetic Algorithm Optimization for Healthcare Sensing Applications

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Abstract. A novel folded dipole with double U slots RFID Tag antenna for epidermal RFID sensing applications is designed and studied. The compact tag structure consists of a folded dipole and two U slots shapes for miniaturization of the antenna radiating part and enhancing its radiation performance in the UHF band. A Genetic Algorithm optimization technique has been utilized with HFSS software to optimize the proposed tag dimensions to achieve better return loss and good realized-gain. The proposed epidermal tag was placed at very close proximity of human skin, which represents the big challenge due to the high losses of human tissues that could strongly degrade the tag's radiation efficiency. The simulations and numerical study show that our novel RFID tag presents good gain, the well-matching impedance across the operational bandwidth.

Keywords: Radio frequency identification (RFID), epidermal RFID tag, UHF band, sensing applications.

1 Introduction

Nodaway, the great growing in Radio Frequency Identification for human health monitoring applications has exploded various collection of wearable, implanted, and epidermal electronic devices available on the recent research and markets. Recent works demonstrated the possibility of developing electronic skin and integrating sensors deployed over thin, bio-compatible membranes suitable for direct placement [1].

RFID epidermal tag is composed of a miniaturized antenna and biocompatible ground plane for cohabitation with human skin. Therefore there is a need to develop the advanced antenna design, including adaptable impedance matching, universal UHF RFID band (840 MHz-960 MHz), omnidirectional radiation pattern, and ultra-low and compact profile which can integrate the sensing capabilities [2].

To design an appropriate epidermal RFID tag the solution must be flexible and able to deal with the on-body effects. Indeed, the human body presents the complex dielectric constant within its tissues, which absorbs the RFID tag's electromagnetic waves emitted/received. Moreover, if the RFID tag is close to the human body, the radiation performances, efficiency, and matching features will be attenuated [3]. Many different techniques are used in the previous research to improve the realized-gain and read the RFID tag [4, 5, 6]. The easiest way to improve the reading range for an on-body RFID tag monitoring application is to use an active RFID tag assisted by battery as presented in [4]; nevertheless, such a method will increase the cost and size of the RFID tag.

Various developments in the UHF RFID technology for human monitoring applications presented so far are interested in the innovative biosensor/tag with miniaturized size and reduced cost for on-body applications. Like a famous slotted patch tag combined with a motion sensor, or fabricated with textile materials, it permits to decouple the antenna from the lossy human tissues [7, 8] and double the T-slotted patch tag designed for wristbands applications [9]. However, much less attention has been paid to the investigation and design of RFID antennas placed in direct contact with human skin and operated in the UHF band. Recently considerable works on a dual-loop tag placed in different body regions (stern, abdomen, limb, and head) [10,11] show the effects of each body region of various volunteers on the antenna-matching features and realized gain. In [4], the authors proposed a miniaturized dual-loop tag for temperature monitoring applications, with a T-match configuration and tuning mechanism, to adapt its response to the specific placement over the body.

Recently, several methods have been used to optimize compact antennas. The techniques are based on nature-inspired metaheuristic optimization algorithms such as genetic algorithm (GA), particle swarm optimization (PSO) algorithm, and ant colony optimization (ACO) algorithm. These techniques are the most used to face with antenna optimization design challenges [12], [13].

The Genetic algorithm (GA) concept is one of the powerful optimization algorithms used today to optimize the antenna performances, such as reducing antenna size, the achievement of good matching features, and the enhancement of bandwidth. The work is based on a stochastic model formalized by Holland and extended to operational optimization by De Jong that involves using optimization strategies, which is modeled after the Darwinian concepts of natural selection and evolution [14].

In the antenna design field, the method of GA is to dive the antenna radiating part into a set of symmetrical squares and select with genetic code the useful and powerful radiating squares from the antenna [15].

In this paper, the proposed RFID tag antenna's geometrical parameter, placed near the human torso, has been optimized by the Genetic algorithm for epidermal applications to reach a small size, more flexibility, and better radiation performances. Details of a folded dipole with double U slot shape RFID tag antenna design, simulation results, and analysis study will be discussed in the following section.

2 Energetic constraint for UHF RFID system

It is widely known that the passive and semi-active tags collect the energy from the reader. To setup the wireless communication between the reader and tag, first, the reader has to send an EM wave that bears the necessary energy to activate the tag. In this step, the microchip has an input impedance $Z_{chip} = R_{chip} + jX_{chip}$, where R_c is the microchip resistance and $X_{chip}$is the capacitive reactance.

The impedance mismatch between the antenna $Z_{ANT} = R_{ANT} + jX_{ANT}$ and the tag is described by the power transfer coefficient [16]:

$$\tau = \frac{4R_{chip}R_{ANT}}{\left|Z_{chip} + Z_{ANT}\right|^2} \leq 1 \qquad (1)$$

This account for the impedance mismatch between the antenna and microchip and is maximum in case, where the microchip can use the entire power available at the tag antenna, and conjugate impedance condition is achieved, $Z_{chip} = Z^*_{ANT}$.

In the next step of the wireless communication, the activated tag receives signal from the reader, and finally sends back the data stored in the microchip memory through a backscattered modulation of the EM wave transmitted by the reader.
Within the hypothesis of free-space interactions, the direct link power represents a power balance between the power transmitted from the reader towards the tag, and the power needed to activate the microchip, whereas the backward link power, quantifies the capability of the reader to detect the tag response. These powers are given by the Friis formula and the radar equations [17]:

$$P_{R\to T} = \left(\frac{\lambda_0}{4\pi d}\right)^2 P_{in}. G_R(\theta,\phi). G_\tau(\theta,\phi). \eta(\theta,\phi) \quad (2)$$

$$P_{R\leftarrow T} = \left(\frac{\lambda_0}{4\pi d}\right)^4 P_{in} {G_R}^2(\theta,\phi). G_T^2(\theta,\phi)\eta^2(\theta,\phi). \tau \frac{4R_A^2}{|Z_c + Z_A|^2} \, (3)$$

Where $G_\tau(\phi,\theta) = G_T(\phi,\theta).\tau$ is the realized gain of the tag, $P_{in}$is the power emitted by the reader, $G_R$is the reader antenna gain, ɳ and d are respectively the polarization factor and the read range distance between the reader and tag antenna, and λ_0 is the free-space wavelength.
The realized gain$G_\tau(\phi,\theta) = G_T(\phi,\theta).\tau$ is given by the radiation gain $G_T$of the tag antenna reduced by the power transfer coefficient τ between the tag antenna and the microchip.
$G_\tau(\phi,\theta)$ can be expressed in terms of the minimum input powerP_{in}^{to}, emitted by the reader, to activate the microchip P_{chip}:

$$G_\tau(\theta,\phi) = \left(\frac{4\pi d}{\lambda_0}\right)^2 \frac{P_{chip}}{G_R(\theta,\phi).\eta(\theta,\phi). P_{in}^{to}(\theta,\phi)} \, (4)$$

The return loss of this antenna was calculated based on the power reflection coefficient which considers the impedance of the microchip Z_c and the antenna's conjugate impedanceZ_{ANT}^*as shown in the equation below [18]:

$$|S^2| = \left|\frac{Z_{chip} - Z_A^*}{Z_c - Z_A}\right|^2 \, (5)$$

3 RFID Antenna configuration and application of GA technique

3.1. Antenna Design

In this section, we present the geometrical design of folded dipole with double U slot tag antenna for UHF RFID applications with the goal of miniaturization and the ability to host sensors and other electronic devices presented in [19], for industrial objects.

In our case we conceived tag for human body application, the proposed tag antenna has a small size, contains a flexible PVC plastic substrate (permittivity =2.7, 0.007 loss tangent, thickness 2 mm) in the ground surface and is covered by the adhesive copper. The proposed antenna is connected to the microchip (Alien Higgs 4, SOT232 package, Z_{chip}= 34–j142 Ω), then we placed the tag on the planar phantom of human torso to discuss its radiation performance, efficiency and matching impedance. The layout and geometrical parameters of our tag are presented respectively in Fig.1and table 1. Our modulations are based on the supposition that tag is placed on an estimated model of layered anatomical phantom of human torso at 915Mhz.This model consists of stratified parallelepiped boxes with defined properties such as thickness, dielectric constant and conductivity. We took these parameters from the database given in ref [20], (Fig.2). All the numerical simulations of the tag performed via HFSS (high frequency structure simulator) software [21].

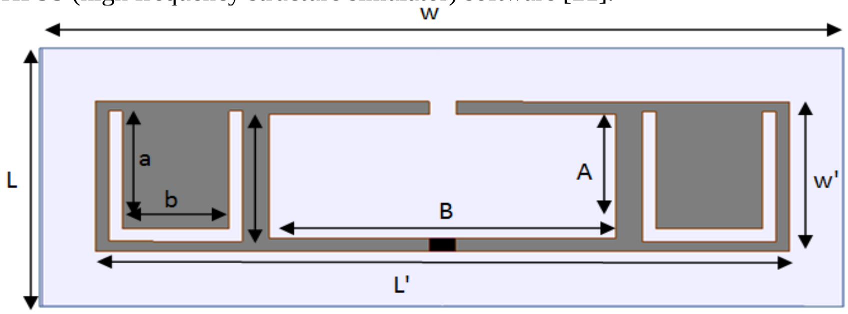

Fig.1. Geometrical design of proposed folded dipole with double U slot RFID tag

Table 1. Dimensions of proposed epidermal RFID tag antenna before optimization

Geometrical parameter	Dimensions (mm)
W	120
L	50
L'	110
w'	23
A	20
B	40
a	20
b	20

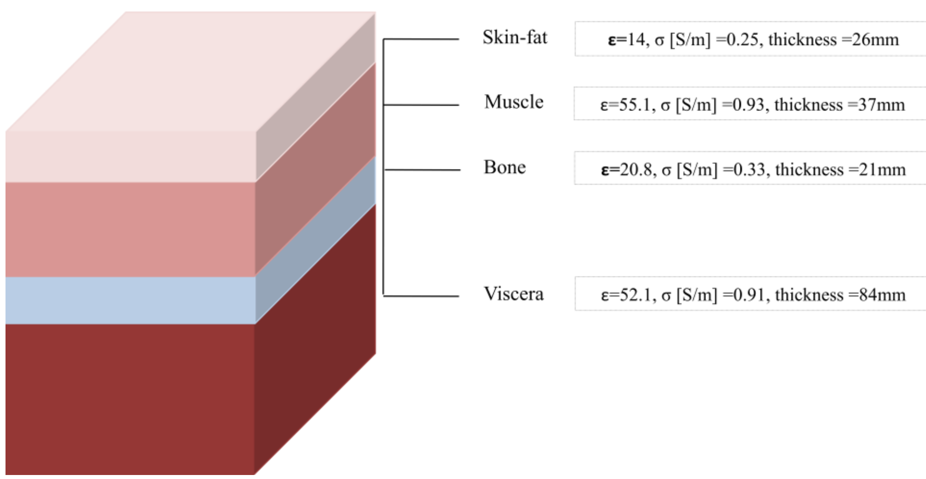

Fig.2. Thicknesses and electrical properties of the layered anatomical phantom of human torso at 915MHz.

The simulated reflection coefficient versus frequency of the proposed tag antenna when it is attached to the planar form of human torso phantom in UHF band is plotted in this Fig.3.

The maximum simulated $S11$ of this tag has a value of $-$ 18 dB at the resonance frequency of 889MHz.

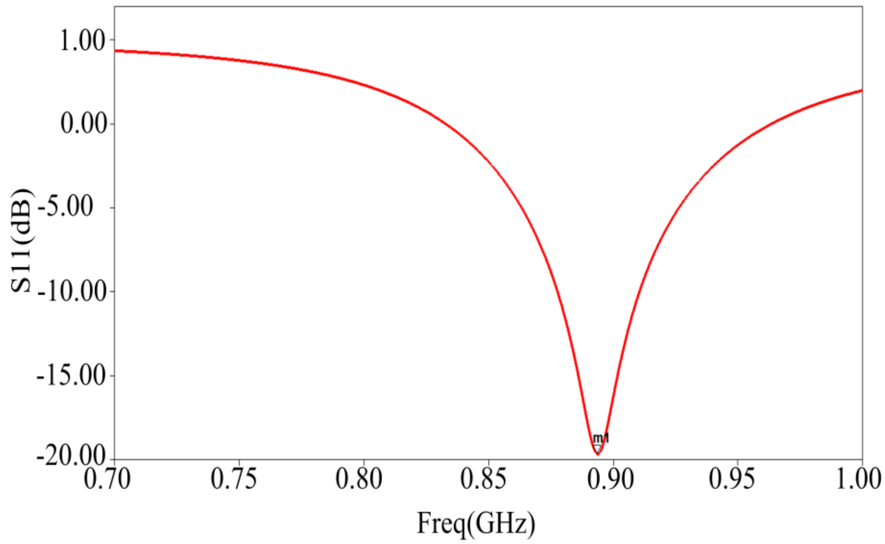

Fig.3. Reflection coefficient of proposed RFID tag before optimization

Fig.4 shows the realized-gain simulation versus frequency of proposed tag in UHF band. The peak realized-gain is 1.640 dB obtained around 840MHz.

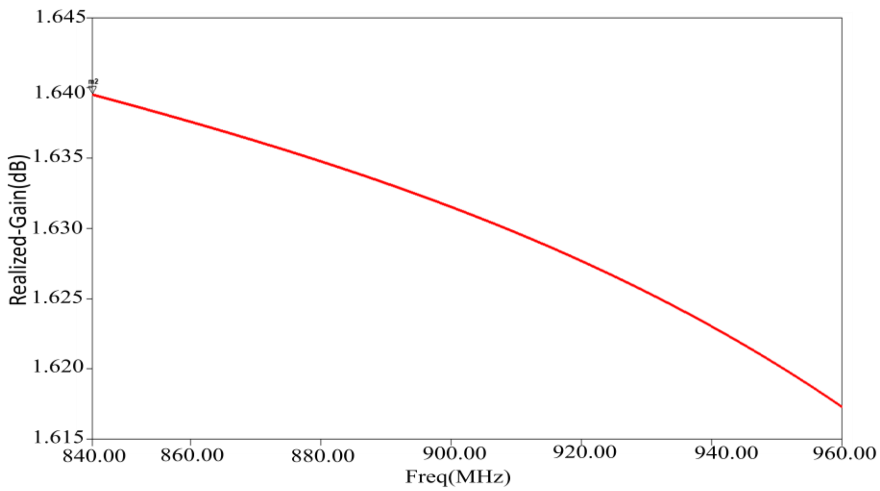

Fig.4. Realized-Gain (dB) of proposed RFID tag before optimization

3.2. Genetic Algorithm

During a GA optimization, each individual's parameters are usually presented as a set of bits (chromosomes). The initialization of individuals (generation) is created randomly, and then the fitness function of each individual is evaluated by the cost function. The more set of individuals are selected and given a greater chance of reproducing. Crossover and mutation are used to permit the global improvement of the cost function. The best individual may be passed unchanged to the next generation. This iterative process creates multiple generations until a stop criterion is reached [21].

The radiating part of the proposed tag antenna is divided into $n \times m$ cells. The conducting or non-conducting property of each cell is defined using binary encoding. If a cell is conducting, then the corresponding gene is assigned 1, and if a cell is non-conducting, it is assigned 0. A flow chart of genetic algorithm optimizer applicable to our proposed tag antenna is presented in Fig.5.

The fitness function is the link between the initial problem and optimization procedure. The appropriate solution depends on the mathematical formulation of this function. Several researchers [22, 23] use the relationship (Eq 7), to express the cost function. We notice that they take a large number of generations, and the algorithm converges from 40th or 50th generations.

$$Cost = \left|\frac{1}{N}\sum_{i=1}^{N} Q(f_i)\right| \qquad (6)$$

$$Q(f_i) = \begin{cases} |S11(f_i)|, for\ S_{11} \geq -10dB \\ +10dB, for\ S_{11} \leq -10dB \end{cases}$$

fi: Sampling frequency ;

N: Total sampling points;

The GA algorithm is implanted into MATLAB and interfacing with HFSS solvers. The starting antenna is divided into 20×20 cells, and an initial population of 50 individuals is generated using a random string of binary numbers. A random single point crossover method is used with a 100% probability of crossover. For the mutation operation, five bits at maximum are randomly chosen for each individual. The convergence is obtained after 20th generation.

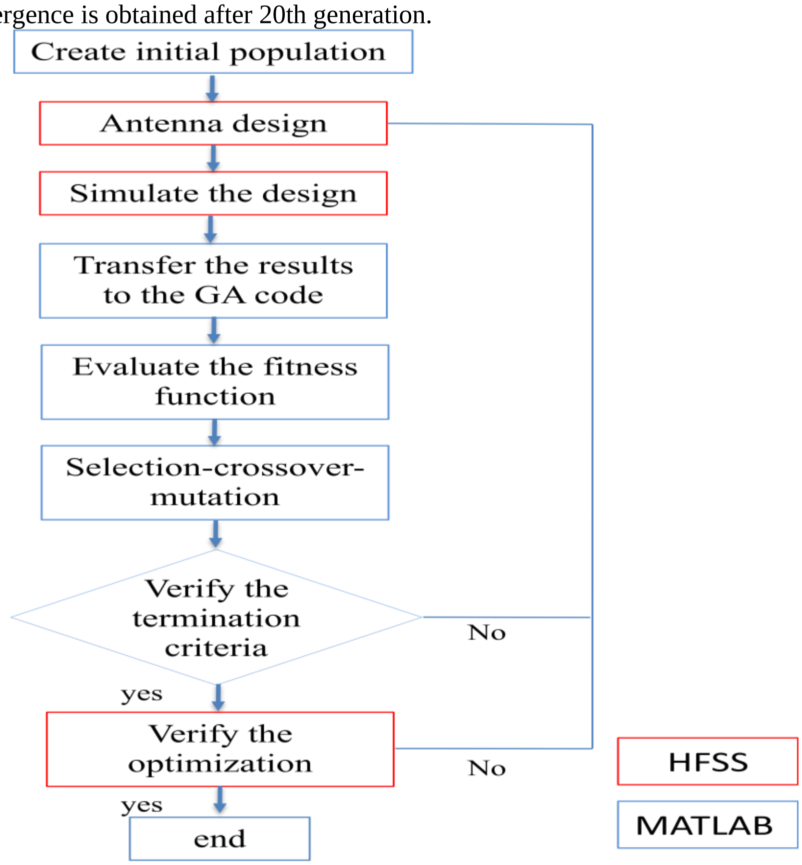

Fig.5. Flow chart of Genetic Algorithm Optimization

3.3. Simulated results of optimized Antenna

The dimension of optimized tag antenna with GA is represented table 2. The reflection coefficient of optimized antenna is shown in figure; we can see that S11 is performed. The resonant frequency of the optimized antenna shifted to 886 MHz and the band width cover the universal UHF band.

Our objective is accomplished by applying the GA optimization, we have reduced the antenna size and the operational bandwidth of the proposed tag antenna has been improved in the UHF band.

Table 2. Optimized dimensions of proposed tag antenna

Geometrical parameter	Optimized Dimensions (mm)
W	100
L	50
L'	80
w'	25
A	19
B	40
a	19
b	19

We know that the passive RFID tag harvest the energy from the reader for the activation of the microchip and sends back the information stored in the microchip, by modulating the back scattered signal [24]. The matching impedance between the antenna and the microchip plays a key role in the RFID system performance; the reflection coefficient gives the information about the mismatch between the antenna and the microchip.

Fig.6 shows the reflection coefficient S11 plot versus frequency in UHF band of the proposed tag antenna, when it is placed on the planar model of human torso phantom.

The maximum simulated reflection coefficient S11 of the proposed tag have a value of − 28dB at the resonance frequency 886 MHz.

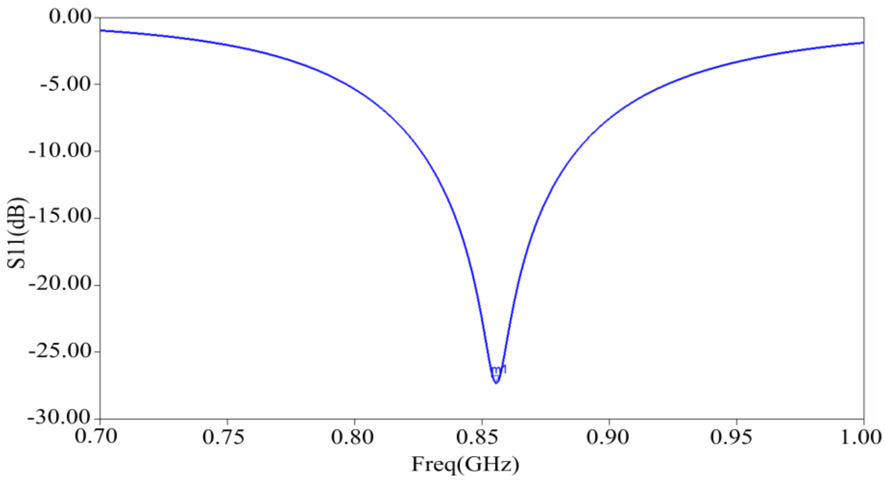

Fig.6. Reflection coefficient S11 of proposed RFID tag after optimization

The input resistance and reactance of our tag antenna after optimization is plotted in Fig.7. We can notice from the graph that the input impedance of the antenna, at the resonance frequency 900 MHz, is $Zin = 34 + j142$. The optimized antenna input impedance is well matched to that of the microchip.

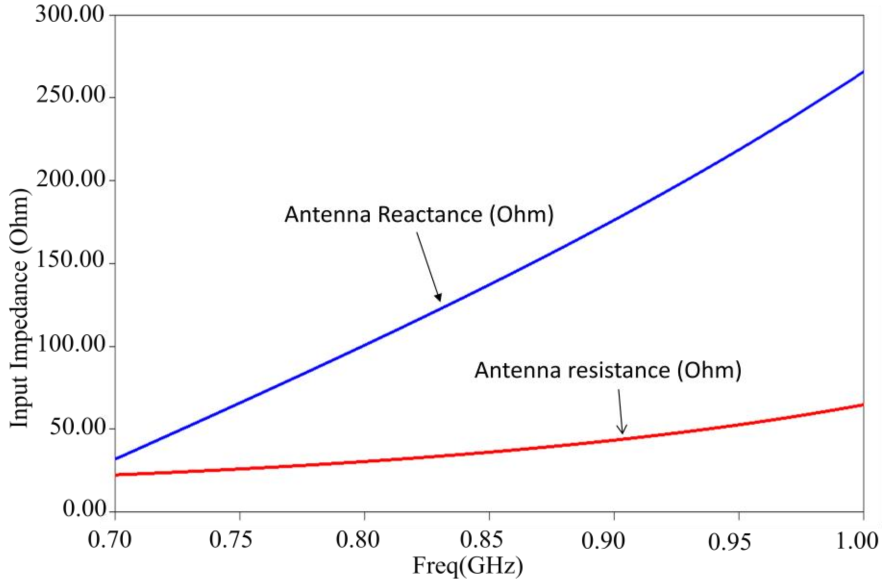

Fig. 7. Input impedance of proposed RFID tag after optimization.

Fig.8 shows the total-gain simulation versus frequency of proposed tag after optimization in UHF band. The peak gain is.1.75dB obtained around 960MHz.

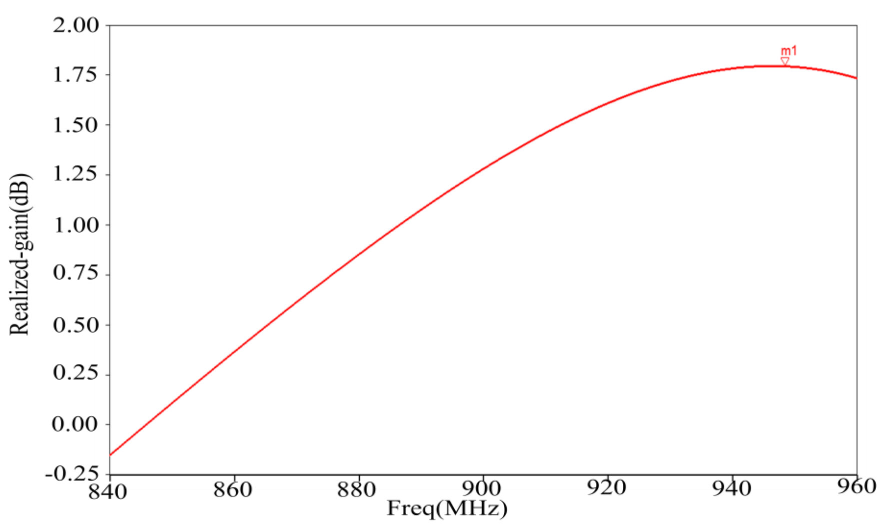

Fig.8. Realized-gain of proposed RFID tag after optimization versus frequency.

As shown in Fig.9, good bidirectional patterns of proposed tag antenna after optimization placed on the planar form of human torso phantom are observed in (x-y) plane.

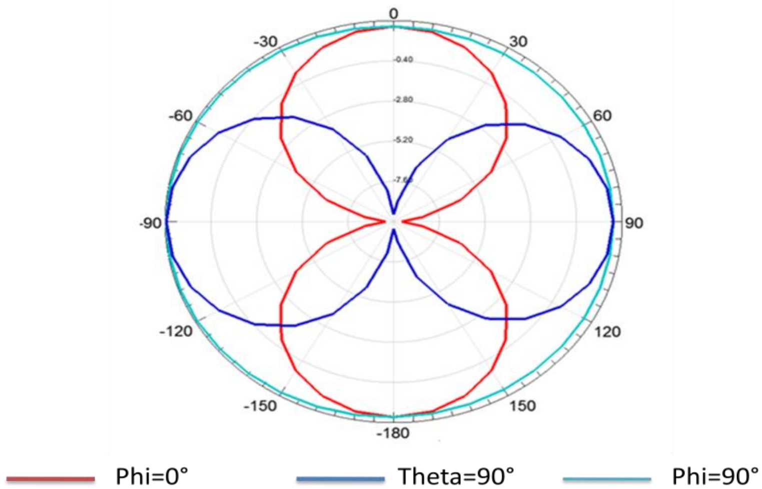

Fig.9. 2D radiation pattern of proposed tag antenna after optimization.

The maximum Specific Absorption Rate (SAR) occurs in the skin of human torso in close proximity of GA-optimized RFID antenna is simulated in operative frequency.
The maximum amount of power radiated from the antenna is evaluated by the SAR. As a simulated result, the maximum SAR performance of proposed optimized antenna has a value of 1.558 W/kg, by considering that the power supplied to the antenna is one Watt.
The U.S. Federal Communications Commission (FCC) regulation: SAR_{max} = 1.6 W/kg, [17]. The SAR_{max} of optimized antenna is well under the SAR_{max} limit of FCC regulated SAR_{max}. Fig. 10 shows the local SAR distribution on the human torso skin at 886 MHz. It can be clearly seen that the proposed GA-optimized antenna follows the FCC regulations.

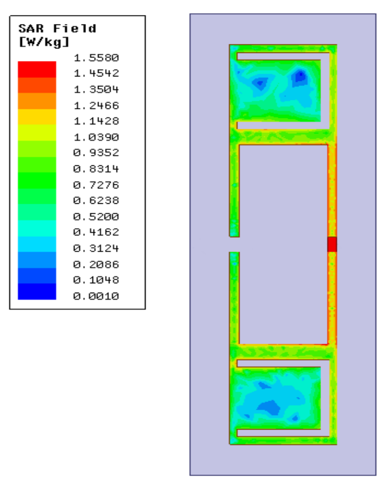

Fig.10. Local SAR distribution on the human torso skin at 886MHz.

The RFID could be integrated with hospital information systems (HIS) and electronic health records (EHRs) and support it by clinical decision support systems (CDSS), it facilitates processes and reduce medical, medication and diagnosis errors [25]-[31].

4 Conclusion

In this paper, a simple-low profile and flexible RFID folded dipole with a double U-shaped slot with a flexible PVC plastic ground plane was proposed. The antenna is compatible with human body tissues. It has been successfully optimized with a genetic algorithm minimized with a typical radiation pattern and good matching features compared with the conventional tag in the universal UHF band. Therefore, the simulated studies proved the well realized gain and matching impedance results when attached to the human torso, allowing the tag's use to track and monitor patients' health in future healthcare applications.

5 Reference

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