Numerical Simulation of EM Environment and Human Exposure When Using RFID Devices

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Abstract— In this work, RFID readers and active tags, operating at 2.4 GHz and 5.8 GHz, are simulated to calculate the electromagnetic field distribution generated in their surroundings, considering the presence of the user’s body and possible scattering obstacles, and including the analysis of the specific absorption rate (SAR) in the human models (which can be very close to the tag). The finite-difference time-domain (FDTD) method and the finite elements (FE) method are used. Results show that significant field level can be found in regions far from the tag-reader direction. This fact could constitute a risk because of the possible presence of general public and eventual eavesdroppers. Nevertheless, the calculated values of SAR are always below the basic restrictions.

1. INTRODUCTION
Radio frequency identification (RFID) systems have become a very important and raising researching area in the past few years. This wireless communication technology uses radio waves for automatic identification and information, and is being efficiently applied in a wide variety of activities, such as tracking and tracing materials, goods, or people, improving theft prevention, security, and medical care. Distinction is made between more or less high-performance systems (low-end through high-end), depending on the field of application and the task to be performed. Among the most highly growing uses are real time location systems (RTLS), which is currently being used in schools and hospitals and reach a range of up to 200 m, and the electronic passports issues in the last years by many countries, which can be read from more than 10 m away. Thus, it becomes essential that the implementation of RFID technology takes place under a legal framework that affords citizens effective safeguards for fundamental values, health, environment, data protection, privacy and security [1, 2]. Moreover, the fast development and the expanding applications of this electromagnetic (EM) field-producing technology is demanding further work to tackle potential associated risks in terms of privacy, security and health issues, specially in complex electromagnetic environments, where signal reflections and other related effects may arise in unintended ways in presence of metallic objects.

The RFID working principle is based on a signal sent by a reader — interrogator — via a radio frequency to a tag — transponder —, which receives the signal and reflects a unique coded signal back to the reader from certain distance range. The operating frequencies are generally defined in four ranges within the unlicensed part of the electromagnetic spectrum, known as ISM (industrial, scientific and medical): Low frequency (LF) in 125 and 134 kHz, high frequency (HF) in 13.56 MHz, ultra high frequency (UHF) in 868–915 MHz, and microwave in 2.45 and 5.8 GHz [3]. Normally, LF and HF tags are passive tags without battery, and are inductively powered through a coil in the reader and a tiny coil in the tag, while UHF and microwave tags are active tags with battery and on-chip tag, relying on backscattering to communicate. LF and HF tags may be read in a shorter radio — typically a few cm — whilst UHF and microwave tags may communicate through longer distances — up to 200 m —.

In this paper, the operation of RFID readers and tag antennas is numerically simulated in possible actual environments where a user is placed. The objective is to analyze how the presence of possible obstacles can influence the electric field levels in different regions around the RFID user, so that possible unexpected security risks could arise. In addition, health issues during the use of the RFID devices can also be considered by comparing the electric field values obtained in both situations with the limits established in the exposure guidelines (reference levels), and comparing the SAR values inside the human body model with basic restrictions. In Section 2, a description of the used methodology is made. We also describe the geometrical configuration which simulates an operating environment where a user, wearing a personnel tracking badge, is located in front of a
metallic cabinet. This could be a common situation in an office, a school or a hospital. Examples of results are shown and discussed in Section 3. Finally, conclusions are presented.

2. METHODOLOGY AND MODELS

In order to carry out the analysis of the proposed problem, the finite-difference-time-domain (FDTD) method is used. The FDTD method is a well known computational technique in which the Maxwell differential equations are discretized by means of a finite differences scheme implemented in a mesh of cubic cells, named Yee cells, where the geometries under study are spatially approximated. The cell size must be small enough to permit accurate results at the highest frequency of interest, taking into account the effect of the different materials on the wavelength. A lattice of 10 cells per wavelength usually gives accurate results. Once the cell size is selected, the maximum time step is determined by the Courant stability condition. Then, absorbing boundary conditions are fixed at the limits of the space under study to avoid undesired reflections [4].

Among the frequency bands assigned to the RFID applications, we’ll focus on the 2.45 and 5.8 GHz operating frequencies. Most of the antennas can be simulated as half wavelength dipole antennas. They have an omni-directional radiation pattern and represent a worst case for dosimetry studies. Nevertheless, as the operating frequency rises into the microwave region, the conformal structure and compact size are also main concerns within the design process. Thus, we have used λ/2 dipole antennas at 2.45 and 5.8 GHz, and have also simulated an actual miniature folded-slot antenna suitable to be included in a 5.8 GHz personnel tracking badge. The geometrical and electrical parameters of this antenna can be found in [5].

A FDTD problem space of 400 × 260 × 400 cubic cells has been generated to include a human body model and a metallic plate simulating a perfectly conducting obstacle. The greater size of the cells is 5 × 5 × 5 mm³, imposed by the stability condition for 5.8 GHz, and an adaptive mesh with 0.3 × 0.3 × 0.3 mm³ cells has been used when needed to accurately simulate the folded-slot antenna. For simulating a free space situation, perfectly matched layer (PML) boundary conditions (8 layers) are introduced at the limits of the computational space. A vertical metallic flat plate, with a width of 1.9 m and a height of 1.5 m, is modelled at a distance of 80 cm in front of the user’s chest, to simulate the existence of a metallic cabinet before the user of the RFID tag.

To simulate the user’s body, a 3D high-resolution body mesh provided by REMCOM (State College, PA, USA) has been used. It also has 5 mm³ cubic cells, has been obtained from the Visible Human Project data in collaboration with the Hershey Medical Center (Hershey, PA, USA), and includes 23 different tissues. Their densities and dielectric properties at 5.8 GHz are obtained from Gabriel et al. [6]. The antennas are simulated in the middle of the chest — as a hanged badge —, at a distance of 1 mm from the body and 1.40 m above the floor. The maximum radiated power is 25 mW [7]. A schematic view of the problem configuration is shown in Figure 1, where the geometry of the folded-slot antenna can be appreciated in the inset.

3. RESULTS

The numerical computations have been made by using the widely used commercial program XFDTD — produced by REMCOM — which accurately implements the FDTD technique. Results obtained with this commercial program have previously been compared by the authors with those obtained

Figure 1: Schematic view of problem geometry.
by means of other numerical methods, with very good agreement [8]. In order to validate our simulations, we have compared the XFDTD results for the radiation patterns of the dipole antennas with the results obtained after simulating the antennas using COMSOL, a well known simulating platform which is based in the finite-elements method. In this case, a tetrahedral mesh consisting of 193241 elements is employed to simulate the folded-slot antenna and a sphere to truncate the computational domain, using infinite elements available for COMSOL as boundary conditions at infinity. Calculations with both numerical techniques show a very good agreement.

Firstly, values of the electric field, \( E \), and SAR in the proximity of the user have been calculated for both studied frequencies when there are no obstacles in the surroundings, simulating a free space situation. Values for whole body averaged SAR (SAR\(_{wb}\)) and local SAR averaged over 10 g of contiguous tissue (SAR\(_{10g}\)) have been calculated. Then, the conducting flat plate is included in the model to simulate the existence of a metallic cabinet in front of the user of the RFID tag. The maximum memory required for the calculations is 1.81 GB, and the longer calculation time for a simulation, including SAR averaging, has been 5 h 33 min in a Pentium D 3.2 GHz processor with 2 GB of RAM memory.

As an example of the obtained results, contour plots of the calculated electric field generated by the tag antenna in the user’s surroundings are shown in Figure 2. A comparison is made of the electric field \( E \) obtained in both simulated configurations within the horizontal plane containing the antenna feed. As can be observed, the presence of the conducting obstacle clearly increases the field level in regions of the space where almost no direct field from the tag is found in free space situations (obviously, the antenna radiation pattern is greatly modified due to the presence of the user’s body). This fact has to be taken into account when analyzing security risks during the operation of sensible identification devices.

The calculated values of SAR\(_{wb}\), so as the maximum SAR\(_{10g}\) values, in both configurations, are shown in Table 1. It can be appreciated that SAR\(_{wb}\) and maximum SAR\(_{10g}\) values are far below the corresponding basic restrictions for both geometries. Due to the large distance between the body and the obstacle, no difference is appreciated in the maximum averaged local SAR obtained in both situations. The whole body averaged SAR is only slightly higher when the obstacle is included, but the difference is insignificant.

<table>
<thead>
<tr>
<th></th>
<th>Free space</th>
<th>In presence of a metallic obstacle</th>
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<tbody>
<tr>
<td>SAR(_{wb}) (W/kg)</td>
<td>2.985 × 10^{-4}</td>
<td>3.039 × 10^{-4}</td>
</tr>
<tr>
<td>Max. SAR(_{10g}) (W/kg)</td>
<td>0.748</td>
<td>0.748</td>
</tr>
</tbody>
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Table 1: SAR\(_{wb}\) and max SAR\(_{10g}\) for the simulated exposure situations.

Figure 2: Contour plots of the calculated electric field \( E \), generated by the active antenna of the badge tag within the horizontal plane containing the antenna feed (1.40 m above the floor) in the user’s surroundings. (a) In a free space situation. (b) In presence of a metallic obstacle. Frequency: 5.8 GHz. Body-obstacle distance: 80 cm. Tag radiated power: 25 mW.
4. CONCLUSION

In this work, RFID readers and active tags, operating at 2.4 GHz and 5.8 GHz, are simulated to calculate the electromagnetic field distribution generated in their surroundings, considering the presence of possible scattering obstacles, and including the analysis of the SAR in human models which can be very close to the tag. The FDTD method has been used to simulate the antennas, using the FE method for validation. Results show that significant field level can be found in regions far from the tag-reader direction (which in an ideal case is expected to be that of the main lobes of the antennas). This fact could constitute a risk because of the possible presence of general public and eventual eavesdroppers. Nevertheless, the calculated values of SAR are always below the basic restrictions.

ACKNOWLEDGMENT

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