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A Design Rule to Reduce the Human Body Effect on Antennas for Short Range NF-UHF RFID Systems

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Abstract

Antennas for Short Range Near Field UHF RFID Systems usually operate in proximity with the human body. Therefore, the robustness of such antennas with respect to body-coupling effects is a critical problem for the designer. For grounded antennas, a criterion for choosing a proper shape and extension of the antenna ground plane is specified, based on the relationship between the grounded antenna performance and the distribution of the electric and magnetic energy densities in the antenna near-field region close to the ground plane border. Following these rules, it is possible to increase the antenna robustness with respect to the body-coupling effects, but with a minimal impact on the antenna size.

1. Introduction

Several modern communication systems make use of radio links in the antenna near-field (NF) region. For these links, the most critical point is the NF coupling between antennas, especially for short-range radio systems, such as NFCs (Near Field Communications) [2], microwave wireless power transfer [3], and RFID (Radio Frequency IDentification) systems. In particular, NF-UHF RFID exploit the electromagnetic coupling in the near-field region to obtain the high reading and data rates typical of UHF systems. The rapid development of these systems has been facilitated by the recent progress in miniaturization of communicating devices and in design of smart networks, body area networks (BANs) and personal area networks (PANs), which have become increasingly interesting, due to their very strong potential for near future applications, such as military, personal healthcare, sport, space, entertainment, smart home, etc. Therefore, the designer has to deal with antennas and sensors that can be easily integrated into clothes and to the build-up of high-data-rate wireless devices, so as to allow the user to communicate wirelessly with many other devices, giving rise to these new communication opportunities.

Unfortunately, usually in Short Range Near Field UHF RFID Systems the transmitting and receiving antennas operate in proximity with the human body, and this proximity is an extremely critical point for the antenna performance, since it can significantly degrade the efficiency of on-body devices, and the global performances of the system itself [4-8].

Usually, in order to limit the antenna-body coupling effects, a large metallic ground plane is used for wearable antennas, so as to adequately shield the antenna from the human body itself. This choice is not straightforward for UHF applications (such as Radio Frequency Identification systems), since it often leads to an uncomfortable antenna. In [9-11] the authors proposed a criterion for the choice of the optimal shape and size of the antenna ground plane, able to enhance the robustness of UHF grounded wearable printed antennas with respect to the antenna-body coupling effects, relating the optimal ground plane shape to the position of the maxima of the electric and magnetic energy density distributions in the near field region around the antenna. The degradation of the antenna performance, due to the proximity of the human body, can be reduced if the ground plane is modified aiming to confine the electric energy density in the region far from the antenna border, i.e., the ground plane should be enlarged at the antenna section corresponding to an electric energy density peak.

In this work, the energy-based design criterions exposed in [9-11] have been extended in order to help the designer in the choice of the optimal shape and extension of the ground plane, which maximizes the antenna robustness with respect to the human body, but with the minimum increase on the antenna size. This is necessarily a compromise solution, since it is apparent that the robustness increases as the ground plane becomes larger, but in short range wireless systems for UHF applications the antenna size is a very crucial point for the designer, and must be kept as small as possible. Numerical simulations have been performed using CST Microwave Studio.

2. Numerical simulation results

The criterion for choosing the optimal shape and extension of the antenna ground plane, able to significantly increase the antenna robustness with respect to the proximity with the human body, is applied to an already well known antenna, suitable for wearable tags in the UHF band [11-12]. The geometrical parameters used in the numerical simulations are summarized in Fig. 1c, and the electric and magnetic energy densities are shown in Fig. 1d and Fig. 1e, respectively. The electric energy density shows a single peak, close to the antenna open end, whereas the magnetic energy density shows two peaks, each one close to the antenna lateral edges.

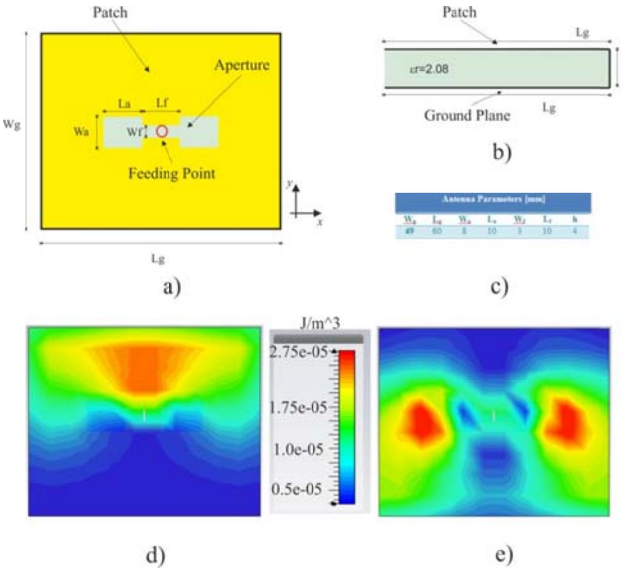


Figure 1. Front view (a), lateral view (b), and main geometrical parameters of the considered antenna (c). For such a structure, the electric (d) and magnetic (e) energy densities are shown close to the ground plane, at the resonant frequency.

To account for the presence of the human body, a simplified three-layer model has been considered in the simulated environment, as shown in [11]. In particular, it is composed of

- skin layer (εr=41.32, σ=0.855 S/m) with a thickness of 1.5mm
- fat layer (εr=5.46, σ=0.05 S/m) with a thickness of 20mm
- muscle layer (εr=54.97, σ=0.934 S/m) with a thickness of 30mm

The parameters which have been evaluated to investigate the antenna performance when varying the antenna distance from the human body phantom, d, are:

- the radiation efficiency η
- the power transmission coefficient τ, expressed as:

$$\tau = 1 - \left| \frac{Z_{IN} - Z_0}{Z_{IN} + Z_0} \right|^2 \qquad (1)$$

wherein Z_{IN} is the antenna input impedance, and Z_0 is a reference impedance.

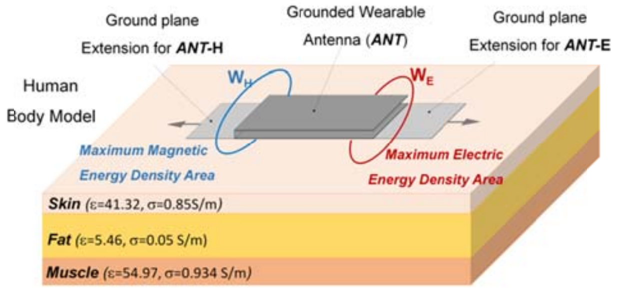
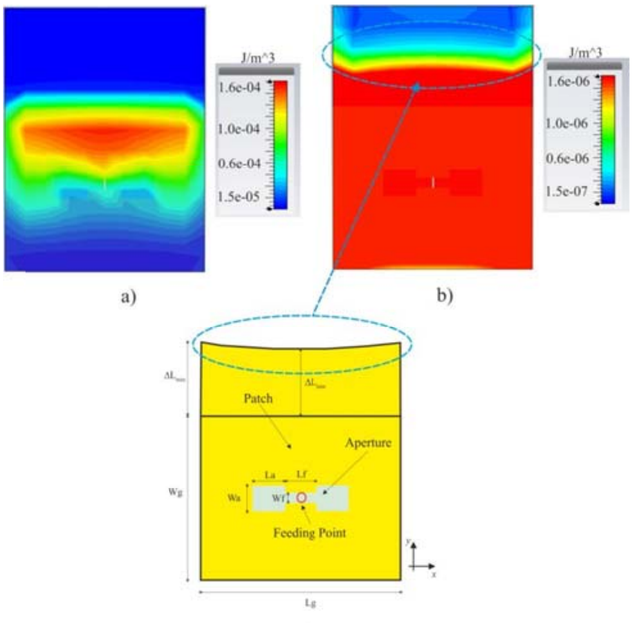


Figure 2. A wearable antenna on the phantom model used to perform the numerical investigation of the antenna robustness to the body proximity (the electrical parameters in the figure are those used at 868 MHz). Antenna ground plane can be extended toward either the region with a peak of electric energy density or the region with a peak of magnetic energy density.

To evaluate the robustness of the considered antenna by varying the body-antenna distance d, the reference impedance Z_0 has been chosen equal to the antenna input impedance at the resonance frequency ($\mathrm{Im}\{Z_{IN}\} = 0\ \Omega$) and when the antenna is adherent to the human body model (d=0mm). The robustness of the proposed configuration has been studied separately for τ and $\tau \times \eta$, and the best ground plane configuration is considered to be the one exhibiting a reasonable value of $\tau \times \eta$, with a τ as great as possible, with both stable with respect to the antenna-body distance, d. It has been shown in [14] that, incrementing the ground plane and the dielectric substrate of the considered antenna shown in Fig.1 toward the direction corresponding to the maximum of the electric energy density of a quantity ΔL varying from 0 mm to 30 mm, the best performance in terms of robustness is obtained for ΔL = 30 mm (i.e., for the larger value of the overall ground plane). We will show here that, if the ground plane is extended following the profile of the electric energy density, it is possible to obtain a very satisfying robustness, but with a considerable reduced size of the antenna.

In order to choose the correct profile for the ground plane extension, the electric energy density is shown for the antenna with ΔL = 30 mm in Fig.3a. In Fig. 3b, the same energy distribution is shown, but with a different scale. In particular, the two energy distributions have different maximum values, and the energy shown in Fig. 3b has a maximum which is lower of a suitable threshold with respect to the distribution shown in Fig. 3a. With this choice, we can cut the ground plane in correspondence of the values of the electric energy density equal to this threshold, as indicated in Fig. 3c. A reasonable choice for this threshold is a value which is a hundred times lower than the absolute maximum of the electric energy density, because the energy density which lies beyond this threshold can be reasonably neglected.



a) b)

c)

Figure 3. (a) Electric energy density on the ground plane for the antenna with ΔL = 30 mm. (b) Electric energy density on the ground plane for the antenna with ΔL = 30 mm with the maximum peak normalized to a threshold 100 times lower than the one shown in (a). (c) Profile of the extended ground plane following the electric energy density shown in (b), with ΔL_{max} = 22 mm, and ΔL_{min} = 20 mm .

In Fig.4 the variation of $\tau\times\eta$ with respect to the distance d from the human body is shown, for different values of the ground plane extension. It is apparent that the robustness of the antenna with respect to the presence of the human body can be significantly increased if the ground plane is extended towards the antenna section corresponding to the location of the maximum of the electric energy density, and this robustness increases for increasing values of the ground plane enlargement. However, the difference between a large ground plane extension (ΔL = 30 mm), and the extension which follows the profile of the electric energy density is not so high, and the results obtained for these two cases for the antenna robustness are rather comparable, while the ratio between the ground plane extensions is considerable. In fact, the extension which follows the profile of the electric energy density is equal to 20 mm at the center, and to 22 mm at the borders, as indicated in Fig. 3c, which corresponds to a ground plane enlargement reduction equal to 35%, and an overall antenna size reduced of about 15%, which is a relatively large value, especially for short range UHF applications, where antenna size is a very critical parameter for the designer.

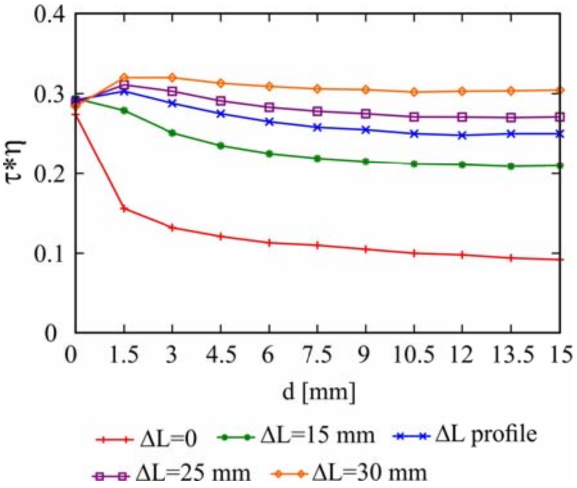


Figure 4. Variation of $\tau\times\eta$ for different ground plane extensions.

3. Conclusions

The robustness of the performance of Antennas for Short Range Near Field UHF RFID Systems with respect to the human body coupling has been numerically investigated, by relating it to the electric and magnetic energy density distributions in the antenna near-field region around the ground plane border, aiming to an appropriate criterion to choose an optimal extension for the ground plane. It has been found that the best compromise solution is to extend the ground plane following the profile of the electric energy density, since with this choice it is possible to obtain a very robust antenna, but, at the same time, reducing its overall size.

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