Electromagnetic field exposure of 13.56 MHz RFID loop antenna

Damir Senić, Dragan Poljak, Antonio Šarolić
University of Split
FESB – Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
Ruđera Boškovića bb, 21000 Split
E-mail: *damir.senic@fesb.hr*

Abstract: **The radiation of RFID antitheft gate system has been simulated in FEKO. The obtained numerical results for the electric field and magnetic field have been compared to the exposure limits proposed by the ICNIRP Guidelines. No significant violation of limits, regarding both occupational and public exposure, has been shown.**

1. INTRODUCTION

RFID (*Radio Frequency Identification*) is a term used for wireless description of object by means of radio waves. Possible fields of interest of RFID in the last several years have significantly increased. Due to this fact there are broad areas of applications: *Transport ID through manufacturing processes, Laundry identification, Authentication/verification, Employee ID, Access control, Automated Airline Baggage Systems, Shop anti-theft protection* (figure 1)*, etc* [1]. RFID itself is not quite a new concept, as it dates back to time of the World War II. The first known application of RFID was the aircraft transponder for radar identification [2]. The transponders at that time could be passive (reflects back a signal) and active (broadcasts a signal) and the RFID just implements the same basic concept.

Figure 1 – Anti-theft store protection gate

RFID system mainly consists of transponder (RFID tag) and reader. As mentioned before, there are two types of RFID systems; *passive* and *active*. Passive RFID systems do not have the transmitter; they just reflect the electromagnetic wave coming from reader antenna (backscatter). Active systems do have their own power supply and transmitter which is used for broadcasting the information stored on the microchip. Passive RFID tags consist of microchip and antenna which operates at low (124 kHz, 125 kHz and 135 kHz), high (13.56 MHz) and ultra-high frequencies (860

MHz – 960 MHz and 2.45 GHz) with range up to 10 m. Active RFID tags operate at 455 MHz, 2.45 GHz and 5.8 GHz usually with range from 20 m to 100 m.

This work deals with an analysis of the radiation pattern of an RFID rectangular loop antenna operating at 13.56 MHz, to calculate the EM field values and to compare the results with ICNIRP Guidelines [3]. The antenna insulated in free space, operating at f=13.56 MHz, is simulated in FEKO using Method of Moments (MoM).

2. LOOP ANTENNA

Loop antenna is a closed-circuit type of an antenna that may have different forms, such as rectangle, square, triangle, ellipse, circle etc. Loop antennas can generally be divided in two different classes: antennas with conductor length and loop dimensions small compared to wavelength ($< \lambda/10$), and antennas with conductor length and loop dimensions comparable to wavelength. The loop antenna analyzed in this paper is considered to be the small loop antenna radiating at f=13.56 MHz operating frequency. Small loop antenna behaves as a large coil with constant current distribution (constant amplitude and constant phase).
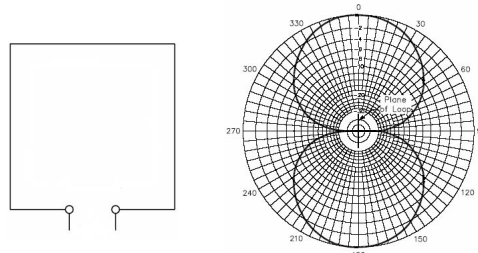

Figure 2 – Example of rectangular loop antenna and corresponding vertical radiation pattern [4]

The maximum of the radiation pattern is achieved in the plane of the loop. The nulls are perpendicular to the loop plane thus forming an eight-figure diagram (figure 2). Small loop is equivalent to the infinitesimal magnetic dipole antenna perpendicular to the plane of the loop, which means that fields radiated by the small loop antenna are the same as those radiated by elementary magnetic dipole antenna [5].

Small loop antennas like other small antennas do not exhibit as good performance (values of electric and magnetic

far fields, gain parameter, etc.) as antennas whose dimension is comparable to wavelength [5,6]. However, due to its sharp nulls and broad maxima small antennas are widely used for different purposes. The gain of the small loop is smaller than half-wavelength dipole gain measured at the same frequency resulting in a with low signal voltage at the output terminals of a receiving antenna. The properties of a small loop antenna can be improved by using a matching element. As already stated, the loop antenna is considered to be a type of coil. Therefore, the whole antenna acts as a large coil and its primary effect is importing the inductive component in impedance. Obviously putting a capacitor as a matching element will annihilate the imaginary part of antenna impedance and result in better characteristics.

3. SIMULATION MODELS

The radiation of the square loop antenna has been simulated by using FEKO software package featuring the Method of Moments (MoM). The dimensions of the loop antenna are 50 cm X 50 cm, with layer thickness of 1 mm and layer width of 35 mm (figure 3). The source is bottom positioned placed in the middle of the lower horizontal part of the loop. The antenna is made of copper.

Two different models were prepared in FEKO, starting with simple matched square loop antenna (figure 4) followed with simulation of gate antenna system (figure 5). All antennas had voltage source excitation with source power of 100 mW matched to the antenna which presents a typical power supply value of common RFID anti-theft gate readers [7,8].
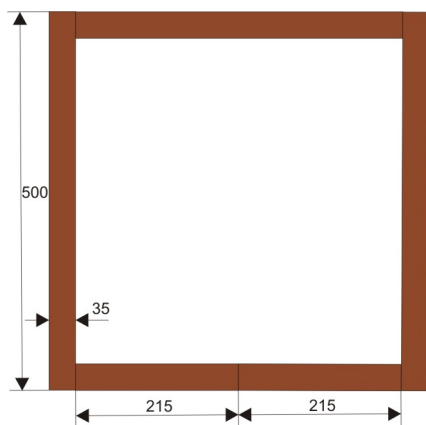
Figure 3 – Square loop antenna with dimensions [9]

Loop antenna has inductive input impedance. As matching element, the parallel RC circuit should be used. Matching in FEKO could also be done with employing the source with no mismatches, what was done in this case. Reason for doing this is much easier way to match the antenna to the source.
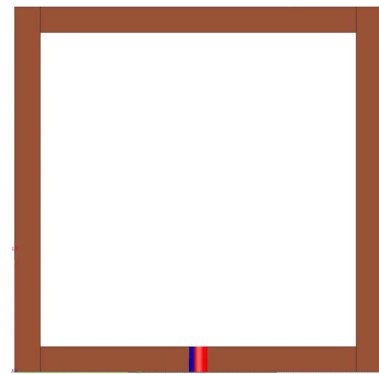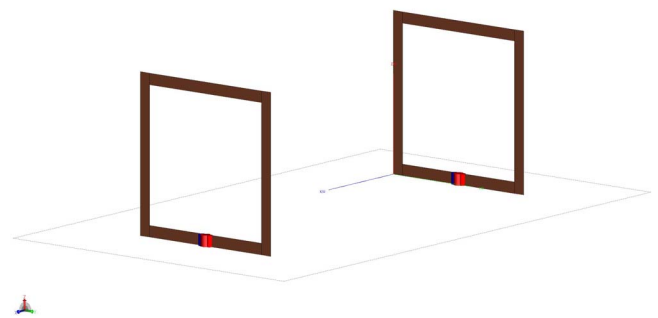
Figure 4 – Single square loop antenna with excitation

Figure 5 – Gate antenna system

4. SIMULATION RESULTS

First, the results of simple matched loop antenna are presented. Antenna is placed in *yz* – plane. According to loop antenna theory, this antenna should have inductive input impedance and eight-figured far field diagram [4].
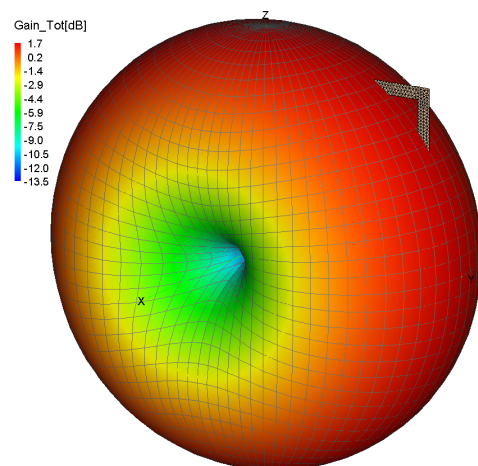
Figure 6 – Single matched loop antenna 3D far field pattern

Total Gain (dB)

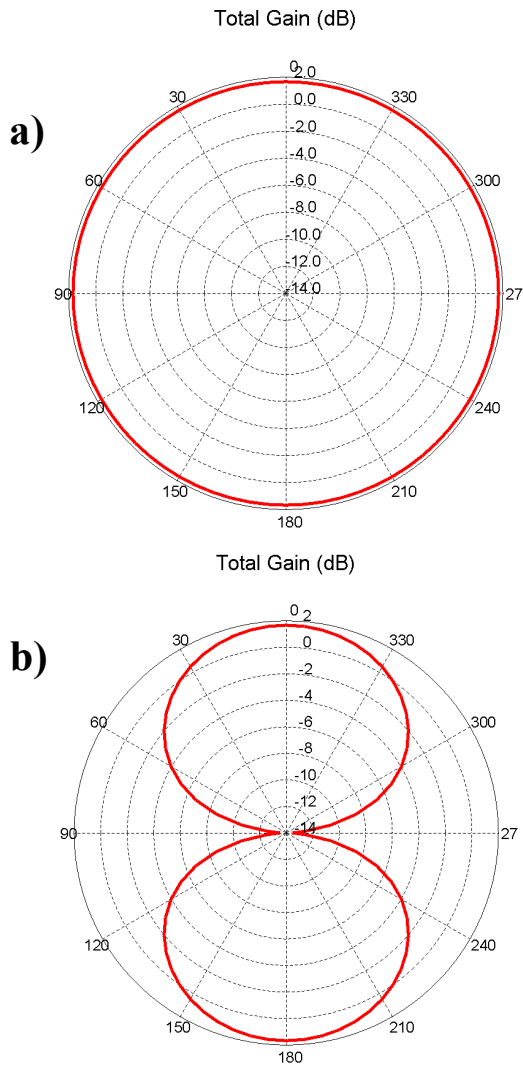**a)**

Total Gain (dB)

b)

Figure 7 – Single matched loop antenna 2D far field pattern: a) yz – plane; b) xz – plane

Simulated antenna had a perfectly shaped eight-figured far field diagram with maximum gain of 1.69 dB. Figures 6 and 7 show the far field patterns in 3D and 2D (*yz* – plane and *xz* – plane respectively). Antennas are working at 13.56 MHz, with wavelength of 22.12 m. The maximum far field level is at boundary between near and far field and, for single matched loop antenna, amounts 265 mV/m calculated at 35.4 m (boundary between near and far field region).

All calculated values of electric fields are well below the reference levels for occupational and general public exposure defined by ICNIRP Guidelines (table 1 and 2). Further development of model toward the real one would be to simulate the EMF exposure of gate antenna system and to compare the results to the guidelines.

Gate antenna system (figure 1) consists of two identical antennas whose dimensions are 150 (height) X 60 (width) X

4 (thickness) cm^3. Minimum width of antenna channel is 60 cm, maximum width is 160 cm and standard width of antenna channel is 120 cm. Simulations of gate antenna system have been undertaken with standard loop separation of 120 cm. The results of radiation pattern obtained for gate antenna system are similar with previously obtained results for matched loop antenna as expected. Only difference is that the maximum value of radiated electric field is now 270 mV/m (figure 8 and 9) due to existence of two same antennas equally driven. Compared to the ICNIRP Guidelines, the calculated values of far field are far below reference levels for both occupational and general public exposure.

Considering all simulated models, it is obvious that maximum values of electric field do not exceed the reference levels noted in ICNIRP Guidelines. Analyzing the electric far field exposure of RFID loop antenna itself is not meaningful because RFID loop antenna is not normally used in far field. However, even for workers and public who are in far field, the field values are negligible with respect to ICNIRP Guidelines reference levels.

Table 1 – Reference levels for occupational exposure for time-varying electric fields [3]

Frequency range	E-field strength (V m^{-1})
up to 1 Hz	—
1–8 Hz	20,000
8–25 Hz	20,000
0.025–0.82 kHz	500/f
0.82–65 kHz	610
0.065–1 MHz	610
1–10 MHz	610/f
10–400 MHz	61
400–2,000 MHz	3$f^{1/2}$
2–300 GHz	137

Table 2 – Reference levels for general public exposure for time-varying electric fields [3]

Frequency range	E-field strength (V m^{-1})
up to 1 Hz	—
1–8 Hz	10,000
8–25 Hz	10,000
0.025–0.8 kHz	250/f
0.8–3 kHz	250/f
3–150 kHz	87
0.15–1 MHz	87
1–10 MHz	87/$f^{1/2}$
10–400 MHz	28
400–2,000 MHz	1.375$f^{1/2}$
2–300 GHz	61
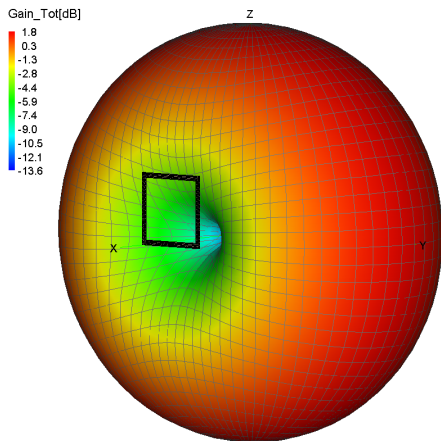
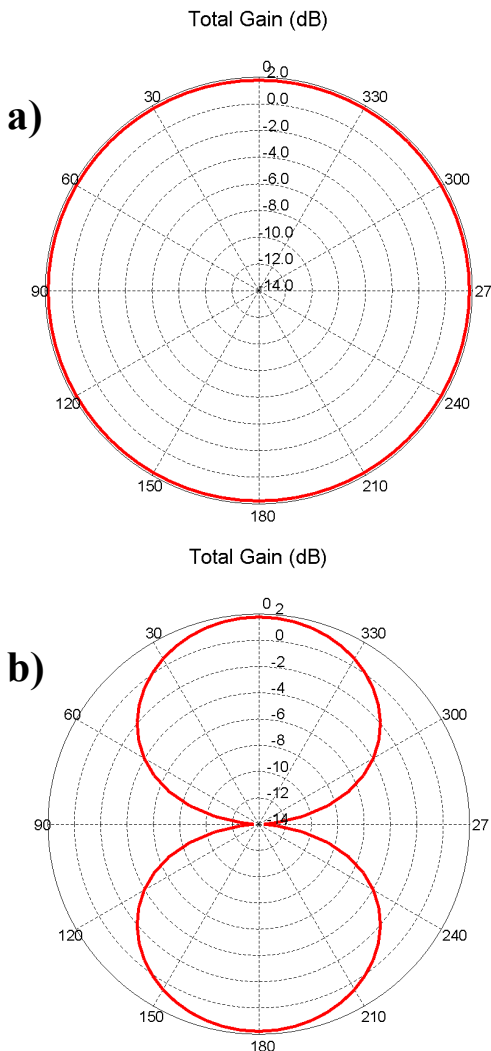*Figure 8 – Gate antenna system 3D far field pattern*

It is very important to emphasize that the purpose of RFID loop antennas requires usage in the near field; RFID tags and antennas are very close to each other compared to the wavelength. The further progress would be to analyze the radiation effects in the near field.

Both antennas are parallel to *yz* plane, separated by 1.2 m along *x* – axis. Furthermore, the electric field between antennas along imaginary line that connects centers of two antennas has been studied. Simulations showed that electric field value close to antenna centre is 118 V/m, which presents the maximum field value, and the minimum value is 13 V/m at 0.6 m away from *yz* – plane along *x* – axis (figure 10). Similar situation is with magnetic near field. Maximum value is close to antenna in *yz* – plane and it amounts 8.6 A/m at the centre of antenna, it decreases along *x* – axis to the central distance between antennas where it has the minimum value of 0.6 A/m and increases toward second antenna to the same maximum value (figure 10).
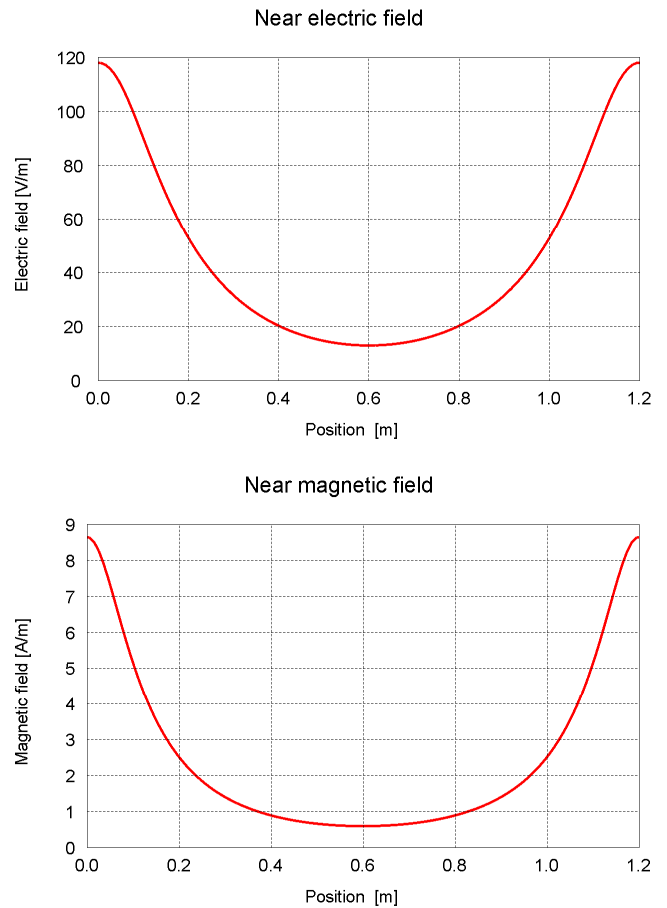

Figure 9 – Gate antenna system 2D far field pattern:

a) yz – plane; b) xz – plane

Figure 10 – Near electric and magnetic field between the antennas along the x – axis

Calculated values of the near electric field close to antennas are above allowed ones defined with ICNIRP Guidelines. However, it is necessary to explain that critical

values defined in ICNIRP Guidelines refer to full body exposure over 6 minutes period. Considering RFID gate system, usual retention in the antenna vicinity, does not last longer than few seconds and presents partial body exposure so it can not be considered as directly violation of ICNIRP Guidelines.

The next step is to calculate the near field distribution along the symmetry axis between the antennas, defined by $x = 0.6$ m and $z = 0.25$ m. This line refers to the pass through the gate, as in theft protection applications. It is expected that the value of electric and magnetic field would increase, approaching the maximum value in the middle point between the antennas and then decreasing again (figure 11).
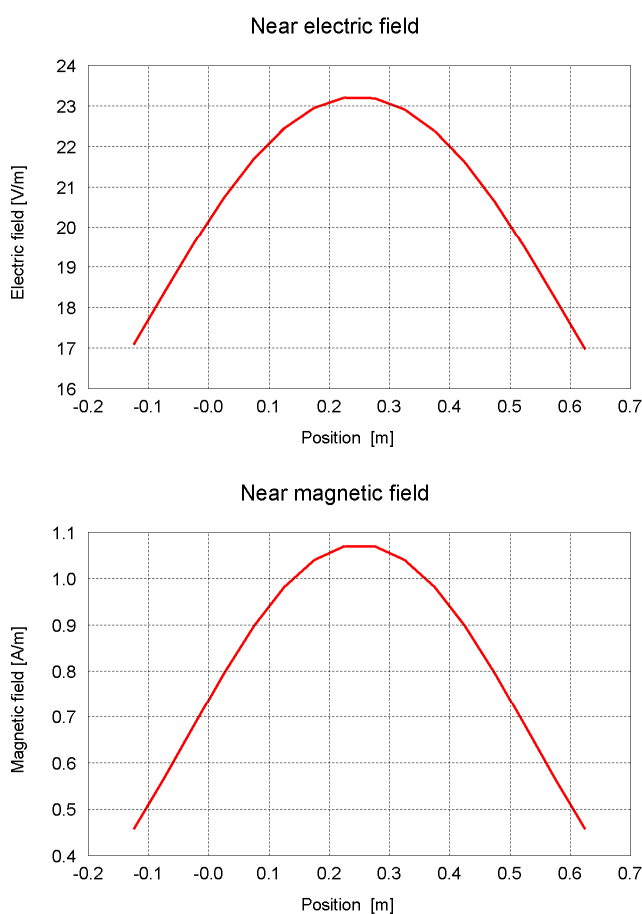
.

Figure 11 – Near electric and magnetic field between the antennas along the y – axis

5. CONCLUSION

In this paper, the analysis of an RFID square loop antenna has been presented. The results of electric and magnetic field calculation have been obtained with FEKO and have found to be below the reference levels defined in ICNIRP Guidelines

for whole body exposure. The electric and magnetic field values have been also calculated between two identical parallel coaxial rectangular loops, thus forming a gate antenna system, commonly used as exit gate for antitheft protection in shops. Field variations have been presented graphically, showing that the human exposure between the antennas would not be uniform. However, since the calculated values were below the ICNIRP reference levels for whole body exposure, the overall conclusion was that this type of RFID antenna, having input power of 100 mW, would not cause a health risk for humans. Possible health effect could be noticed during longer exposures in near field zone where partial body exposure becomes crucial. Eventual health risk due to malfunction of implanted devices (such as pacemakers) is beyond the scope of this paper.

The models and results shown in this paper could be used as an opener to the subject related to more comprehensive analysis of human exposure to RFID loop antennas, using a realistic human model and a model of an implanted device.

REFERENCES

[1] Raza, N., Bradshaw, V., Hague, M., Applications of RFID Thechnology, IEEE publication, London 1999
[2] Skolnik, I. Merrill, Introduction to Radar Systems, 2nd Ed., Singapore 1981
[3] International Commission on Non-Ionizing Radiation Protection, Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz), Health Physics Society, 1998
[4] Straw, R. Dean, The ARRL Antenna Book, 20th Ed., The ARRL Inc., 2003
[5] Balanis, C. A., Antenna Theory Analysis and Design, 2nd Ed., John Wiley & Sons, New York, 1997
[6] Kraus, J. D., Antennas, 2nd Ed., New Delhi, 1997
[7] Finkenzeller, K., RFID handbook, 2nd Ed., John Wiley & Sons, Munich, 2003
[8] Lee, J. G., Byun, J. K., Choi, H. D., Cheon, C. Y., Chung, Y. S., Lee, B., A New Equivalent Antenna Model for Human Body Exposed to 13.56MHz RFID System, Department of Wireless Communications Engineering, Kwangwoon University, Korea, IEEE 2008
[9] Kong, S., Choi, D., Oh, H., Evaluation of Human Exposure to Electromagnetic Fields from RFID Devices at 13.56 MHz, Radio Environment Research Division, Radio Research Agency of Korea Communications Commision, IEEE 2008