Maximization of the Operating Volume using HF RFID Loop Antennas

Kevin D'hoe[1], Nobby Stevens[1], Jean-Pierre Goemaere[1], Lieven De Strycker[1] and Bart Nauwelaers[2]

[1] DraMCo research group, Catholic University College Ghent, Association K. U. Leuven
Gebroeders Desmetstraat 1, 9000 Ghent, Belgium

[2] Department of Electrical Engineering, ESAT, K. U. Leuven
Kasteelpark Arenberg 10, 3001 Leuven, Belgium

Abstract. This article describes how a passive radio frequency identification (RFID) system is optimized. Our attention focuses on the operating volume of a circular loop antenna. Hereby the design of loop antennas is given a new approach to establish a maximum operating volume. Therefore, the off-axis magnetic field is investigated. This is done for a circular loop in free space and in the vicinity of a metal plane. A numerical approach is given towards the maximization of the operating volume. The goal is to provide new insights into the design of a loop antenna and enhance the reliability of the RFID system.

1 Introduction

Within the domain of industrial applications, Radio Frequency Identification (RFID) has become a popular technology. Particularly when it comes to tracking and tracing of objects, passive RFID technologies have been found to provide a suitable solution. This technology is based on the principle of inductive coupling between two loop antennas, namely a reader loop antenna and a transponder loop antenna. Although this technology is well known, many problems occur when it is used in industrial environments. The presence of metals in the vicinity of the RFID loop antenna often causes readout reliability issues. For this reason, the design of the reader loop antenna should be optimal to achieve a maximum volume where a transponder is detected. This volume is called the operating volume. The research is based on previous work where the optimal diameter [1] of a circular loop antenna was examined for ideal and non-ideal conditions, e.g., the presence of a conducting plate in the vicinity of a loop antenna. In that work [1], the magnetic field at the symmetry axis of a circular loop antenna is considered. Within this paper, we will focus on the investigation of the off-axis magnetic field which will finally lead to new insights towards the design of a loop antenna. Two specific cases were handled, namely a loop antenna in free space and a loop antenna near a conducting plate. We will discuss how the operating volume is maximized and which parameters should be taken into account. This approach will lead to the design of reliable RFID systems.

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2 The Off-axis Magnetic Field in Free Space

We consider a quasi-static approach, thus with a constant current distribution over the entire loop antenna. This is plausible for loop antennas whose circumference is much smaller then the wavelength of the applied signal. This implies that the radius r_l can not increase unlimited. We will consider loop antennas with a radius up to $r_l = 0.6\,\mathrm{m}$, which certainly holds the predetermined condition for LF and HF RFID systems.
For lower frequencies, the Biot-Savart law (1) may be applied for the calculation of the magnetic field caused by a current in the loop antenna. A differential magnetic field strength, $\mathrm{d}\mathbf{H}$, results from a differential current element $I\,\mathrm{d}\mathbf{l}$, Fig. 1. The total magnetic field **H(r)** can be written as in equation (2), where L_w is the total length of the loop antenna.

$$\mathrm{d}\mathbf{H}(\mathbf{r},\mathbf{r}') = \frac{\mu_0}{4\pi} I \frac{\mathrm{d}\mathbf{l}(\mathbf{r}') \times (\mathbf{r}-\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^3} \tag{1}$$

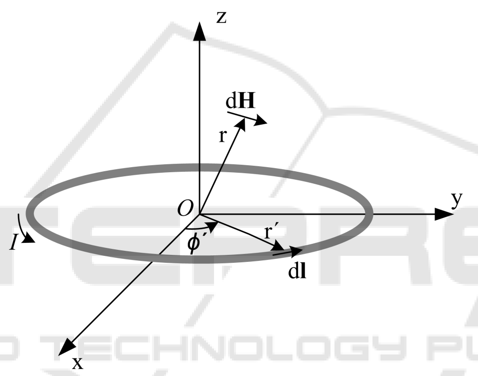

Fig. 1. Circular loop antenna in free space.

$$\mathbf{H}(\mathbf{r}) = \frac{\mu_0}{4\pi} I \int_{L_w} \frac{\mathrm{d}\mathbf{l}(\mathbf{r}') \times (\mathbf{r}-\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^3} \tag{2}$$

Due to symmetry reasons, one can see that knowledge of the magnetic field in the yz-plane is sufficient to know the magnetic field at any other place. After some mathematical manipulations, we obtained the following components of the magnetic field as in equations (3), (4) and (5) in the yz-plane. A mixture of cylindrical and Cartesian coordinates has been applied to handle the configuration of Fig. 1 [2]. The radius of the loop antenna is called r_l.

$$H_x(y,z) = \frac{I r_l z}{4\pi} \int_0^{2\pi} \frac{\cos\phi' \mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2 r_l y \sin\phi' + z^2\right)^{3/2}} \tag{3}$$

$$H_y(y,z) = \frac{I r_l z}{4\pi} \int_0^{2\pi} \frac{\sin\phi' \mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2 r_l y \sin\phi' + z^2\right)^{3/2}} \tag{4}$$

$$H_z(y,z) = \frac{Ir_l}{4\pi}\int_0^{2\pi}\frac{(r_l - y\sin\phi')\,\mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2r_l y\sin\phi' + z^2\right)^{3/2}} \tag{5}$$

After numerical calculation of $H_x(y,z)$ (3), this component seems to be zero for all values of y and z.
These integrals cannot be solved analytically. For this reason, we have evaluated these integrals by use of standard numerical integration methods.

3 Operating Volume in Free Space

The minimum operating field H_{min} of a transponder is defined by the ISO 15693 [3–5] and has a value of 150 mA/m. It is clear that a reader should generate a field of at least H_{min} to activate a transponder. The volume that is delineated by the 150 mA/m-contour of the total magnetic field H_{tot} is called the operating volume. In Fig. 2, the operating volume is presented for different values of r_l. By considering H_{tot}, we assume that the transponder is always oriented perpendicular to the field lines. We have chosen the current I equal to 0.14 A (which corresponds to a power level of 1 W in a 50 Ω impedance reference system).

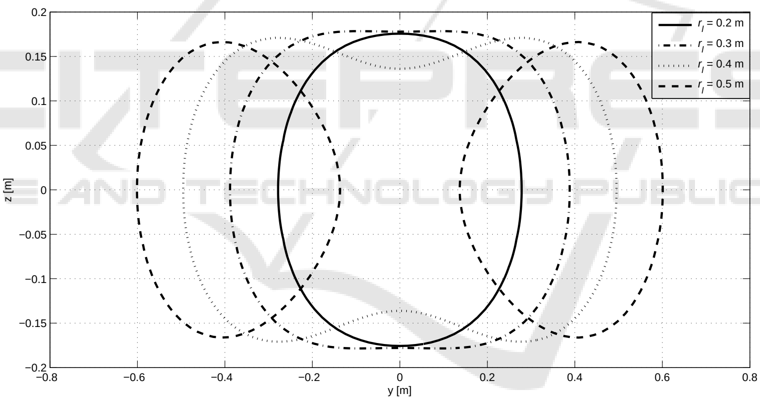

Fig. 2. Operating volume delineated by the H_{min} of a loop antenna.

Considering Fig. 2, one can see that the operating volume is increased as r_l expands within a certain domain. Where r_l is chosen equal to 0.4 m we find the largest operating volume. A disadvantage is the reduction of the magnetic field on the axis of symmetry ($y = 0$). For $r_l = 0.5\,\mathrm{m}$, we can see two separated contour lines which means that a transponder fails to detect in the middle of the loop antenna. It is clear that this is preferably avoided.

In Fig. 3 the operating volume is calculated in function of r_l for different values of I. For each specific current I through the loop antenna there exists a radius r_l where the operating volume is maximized. Considering $I = 0.14\,\mathrm{A}$, it is found that the maximum operating volume is provided at a radius r_l of 0.405 m. For values which our higher then $r_l = 0.405\,\mathrm{m}$ we see a strong decrease of the operating volume which then stabilizes.

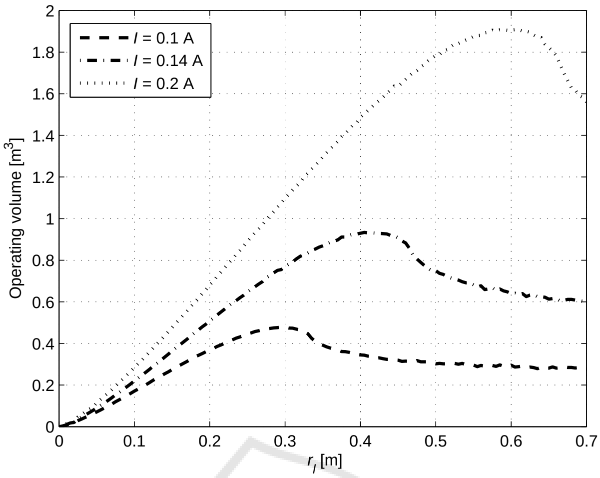

Fig. 3. The operating volume for different values of I.

Fig. 4 gives the optimal radius r_l providing a maximum operating volume for a specific current I through the circular loop antenna. We have found that there is a linear correspondence between the current I and the radius r_l that provides a maximum operating volume:

$$r_l = \alpha I \qquad ([\alpha] = \frac{m}{A}). \tag{6}$$

The value of α is found to be $3\frac{m}{A}$.

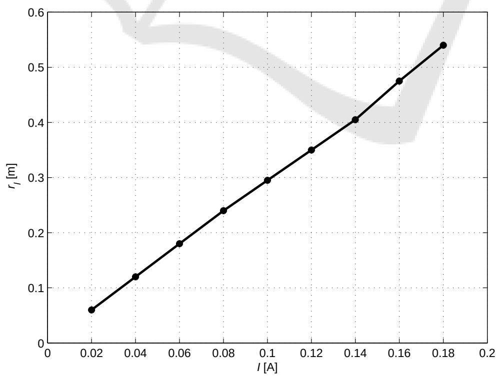

Fig. 4. The optimal radius r_l for a specific current I which provides a maximum operating volume.

4 The Off-axis Magnetic Field Influenced by a Conducting Plate

Fig. 5, shows a perfectly conducting plate of infinite transversal dimensions located at the plane $z = -d$ nearby a circular loop antenna (xy-plane). We know that the magnetic

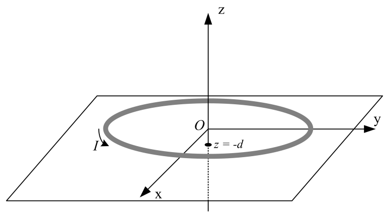

Fig. 5. Circular loop antenna near a perfectly conducting plate.

field at the plane $z = -d$ must be tangential. For $z \geq -d$, the configuration shown on Fig. 6 yields the same solution [6]. As one can see, the loop antenna located at the plane $z = -2d$ has a current opposite to the original loop antenna. Based on superposition,

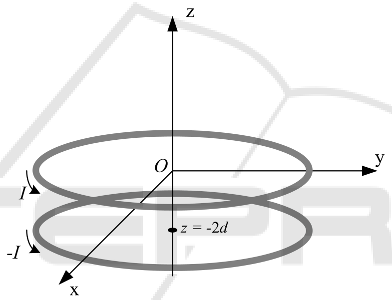

Fig. 6. Introduction of the image current.

we can write that for $z \geq -d$, equations (7), (8) and (9) are valid.

$$H_x(y,z) = 0 \tag{7}$$

$$\begin{aligned} H_y(y,z) =& \frac{I r_l z}{4\pi}\left[\int_0^{2\pi} \frac{\sin\phi' \mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2r_l y \sin\phi' + z^2\right)^{3/2}}\right. \\ &\left. - \int_0^{2\pi} \frac{\sin\phi' \mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2r_l y \sin\phi' + (z+2d)^2\right)^{3/2}}\right] \end{aligned} \tag{8}$$

$$\begin{aligned} H_z(y,z) =& \frac{I r_l}{4\pi}\left[\int_0^{2\pi} \frac{\left(r_l - y\sin\phi'\right)\mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2r_l y \sin\phi' + z^2\right)^{3/2}}\right. \\ &\left. - \int_0^{2\pi} \frac{\left(r_l - y\sin\phi'\right)\mathrm{d}\phi'}{\left(r_l^2 + y^2 - 2r_l y \sin\phi' + (z+2d)^2\right)^{3/2}}\right] \end{aligned} \tag{9}$$

5 Operating Volume Influenced by a Conducting Plate

In section (3), we have shown the importance of choosing an optimal radius depending on the current through a circular loop antenna. Within this section, we will focus on the influence of a conducting plate on the operating volume of a loop antenna. The current I has been chosen equal to 0.14 A. For different distances d, we can calculate the operating volume, using the same numerical procedure as applied for the circular loop in free space, Fig. 7.

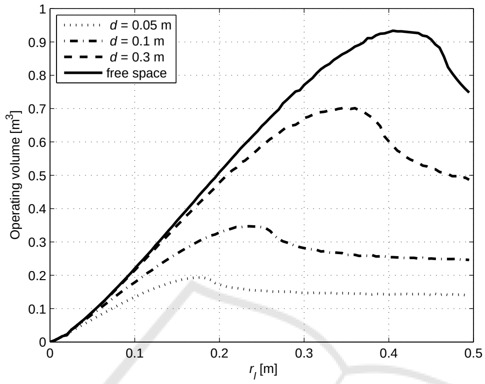

Fig. 7. The operating volume is calculated for different values of d with a current $I = 0.14$ A.

Where the conducting plate is found at a distance d, it is clear that this parameter limits the operating volume. A second issue is the influence on the radius r_l where the highest operating volume is provided. As one can see, the operating volume is increased when the distance d enlarges. The increase of the maximum operating volume depending on parameter d, is shown in Fig. 8. In this figure, the radius r_l is chosen to provide the largest operating volume.

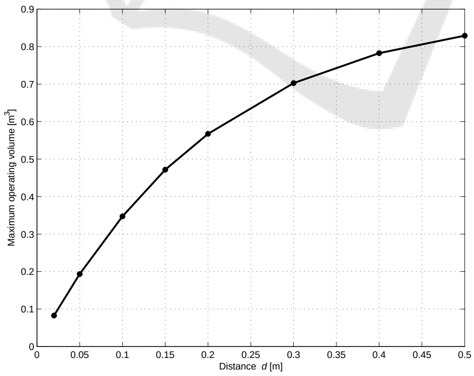

Fig. 8. The maximum operating volume is calculated for different values of d.

Especially when the distance d is small, any increase of this distance implies a significant gain regarding the operating volume.

6 Conclusions

In this paper, a numerical procedure to determine the magnetic field generated by a circular loop in free space or in the vicinity of a metal plane is presented. Based on this procedure, one can generate theoretical models on how the operating volume of circular loop antennas will behave when they are surrounded by conductive objects.
This is especially interesting for the usage of RFID systems in industrial application where metals are ubiquitous and a high reliability is of great importance. We have shown how the magnetic field of an RFID loop antenna is influenced as the distance between the conducting plane and the reader decreases.
Although the operating volume is defined by the ISO/IEC 15693 standard as the 150mA-contour of the total magnetic field, most transponder require an activation field strength much lower then 150mA/m. Typically the required field strength is between 50 mA/m and 80 mA/m. This large difference between the minimum activation field strength specified by the standard and the one needed by the transponders, only enhances the reliability. This ensures that the transponders will also be detected when the orientation differs from the optimal orientation (perpendicular to the field lines).
Within this paper we focused on HF RFID systems but, with minor changes, this method can be extended to the domain of LF RFID, where the operating volume is defined by the 1.5A/m-contour.

References

1. D'hoe K., Stevens N., Goemaere J.P., De Strycker L. and Nauwelaers B., Design of an RFID loop antenna in non-ideal conditions, ECUMICT 2010, Belgium: Ghent, 2010, pp. 405-411.
2. Stevens N., De Strycker L. and Verschelde W., Procedure to Calculate the Inductance of a Circular Loop Near a Metal Plate, EMC Europe 2010, Poland: Wroclaw, 2010, to be published.
3. Identification Cards – Contactless Integrated Circuit(s) Cards – Vicinity Cards – Part 1: Air Interface and Initialization, 1st ed., Int. Std. ISO/IEC 15693-1, ISO/IEC/JTC1 Inf. Technol., 2000.
4. Identification Cards – Contactless Integrated Circuit(s) Cards – Vicinity Cards – Part 2: Physical Characteristics, 2nd ed., Int. Std. ISO/IEC 15693-2, ISO/IEC/JTC1 Inf. Technol., 2006.
5. Identification Cards – Contactless Integrated Circuit(s) Cards – Vicinity Cards – Part 3: Anticollision and Transmission Protocol, 1st ed., Int. Std. ISO/IEC 15693-3, ISO/IEC/JTC1 Inf. Technol., 2001.
6. D. J. Griffiths, Introduction to Electrodynamics, Englewood Cliffs, New Jersey: Prentice Hall, 1981.
7. Finkenzeller K., RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, 2nd ed. New York, NY, USA: John Wiley & Sons, Inc., 2003.