Influence of Different Types of Metal Plates on a High Frequency RFID Loop Antenna: Study and Design

Kevin D'HOE[1], Anneleen Van NIEUWENHUYSE[1], Geoffrey OTTOY[1], Lieven De STRYCKER[1], Luc De BACKER[1], Jean-Pierre GOEMAERE[1], Bart NAUWELAERS[2]
[1]*Department of Electronics Engineering, Catholic University College Ghent, Belgium*
[2] *Department of Electrical Engineering, Catholic University of Leuven, Leuven, Belgium*
dramco@kahosl.be

***Abstract*—This paper presents our research on the influence of metal plates on a radio frequency identification (RFID) loop antenna operating at 13.56MHz. More specific we have tested different types of metal plates near a loop antenna in terms of resonance frequency. The performance of an RFID system strongly depends on the configuration of the antenna. The study shows that the resonance frequency will shift up in a metallic environment, resulting in a failing performance. A solution is presented to avoid the influence of a changing environment around a loop antenna. As an example a loop antenna is designed to prove the increase of stability.**

***Index Terms*—loop antenna, metallic environment, radio frequency identification (RFID), resonance frequency**

I. Introduction

Knowing the location of objects can be of great additional value for many applications. RFID is a popular technology used to track objects among others in an industrial process. This technology is also used to make an automatic inventory of objects without the need of human interaction.

Still, there are some problems using RFID systems in metallic environments. Using the ISO15963 standard, operating at 13.56 MHz, we will give a detailed overview of the influence of metal parts in the environment of a typical loop antenna, used in a RFID system, in terms of resonance frequency and the success of reading out tags in a metallic environment.

This technology uses passive tags. These passive tags will draw their energy from the output power of the loop antenna. Therefore, an optimal transfer of energy towards the passive tags is necessary. Issues occur when there are metal parts in the vicinity of the loop antenna. The most important problem is the shifting of the resonance frequency. Because of this frequency shift, there is no optimal energy coupling between the RFID tag and the loop antenna, resulting in a weak performance and low reliability.

Tuning the antenna in a static metal environment could be a solution. These so called "static" environments are mostly not achievable in an industrial process. An example is given, using a metal cupboard with drawers, reading out present objects in a drawer. Opening one of the drawers will change the environment and consequentially the influence of metal on the loop antenna.

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In this paper we will give an overview of the influences of different types of metal plates on a loop antenna. A new antenna concept, used in a dynamic metallic environment, is also presented and tested. This antenna provides a high reliability in the use of object inventory without the need of human interaction.

The influence of metallic environments has already been studied but few of these studies focused on an RFID system, operating at 13.56 MHz [1]-[11].

II. Experimental setup

A. Antenna configuration

The antenna used for the experiments is shown in Figure 1. The dimensions of the loop antenna are 360 mm x 360 mm and the width of the copper trace is 40 mm.

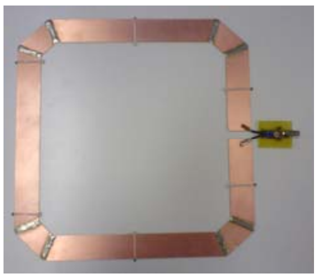

Figure 1. Antenna design.

A capacitor matching circuit is used, matching the antenna to a 50 Ω feed line and tuning the antenna to a resonance frequency of 13.56 MHz (Figure 2) .

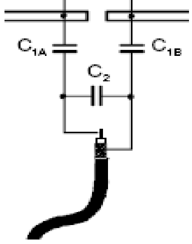

Figure 2. Capacitance matching circuit [19].

($C_{1A} = C_{1B}$ = 82 pF , C_2 = 680 pF , R_1 = 0Ω– 5 kΩ, C_{PAR} = 47 pF – 94 pF)

B. Measurement setup

To test the influence of a metal plate near the antenna, we have used a self-made rack, completely constructed in wood (Figure 3). The influence of wood is negligible compared to the influence of a metal. Using this rack we could make an accurate measurement. There was no influence of other metallic objects in the surroundings of the antenna.

Figure 3. Measurement setup.

As mentioned before, we have recorded the resonance frequency, in order to proof the influence of metal plates on a loop antenna. We plotted the $|S_{11}|$ – parameter, using an Advantest TR4172 Vector Network Analyzer with transmission reflection test set TR14501A.

C. Types of metal plates

An important issue in this paper is the comparison of different types of metal plates. Out of other papers, we know a frequency shift will occur caused by the presence of the eddy current, [15], [16]. These tests mostly took place using a massive metal plate, as in [1], [2].

In this paper we will demonstrate the differences between a massive metal plate and different types of perforated plates, especially depending on the degree of perforation. This could lead to less influence on the antenna, reducing the eddy current.

We have used 4 types of metal plates. The dimensions of all metal plates are the same, with a size of 500 mm x 500 mm. In TABLE I you will find the properties of the different metal plates used for the measurements.

In a future stage we will use one of these perforated steel sheets to design an antenna useable in a dynamic environment.

TABLE I. DIFFERENT TYPES OF METAL PLATES

Distance	Resonance frequency	Percentage of frequency shift
Free space	13.56 MHz	0%
40 mm	15.99 MHz	17.92%
20 mm	17.65 MHz	30.16%
10 mm	19.42 MHz	43.21%
5 mm	21.68 MHz	59.88%

D. Types of measurements

We have done 2 types of measurements. First, we have measured the S_{11}-parameter, representing the shift of the resonance frequency. A second type of measurement is done by recording the percentage of successful reading out tags with a metal plate near the antenna. This last measurement shows the importance of tuning the antenna to the correct resonance frequency in practical situations.

III. MEASUREMENTS

All measurements were done, using the same configuration, as shown in Figure 4. A metal plate is placed at the back of the antenna. Varying the distance "d" between the metal plate and the antenna, we plotted the $|S_{11|}$ – parameter. First, we have done this measurement using a massive metal plate (type I). Later on we compared the results of the different types of perforated metal plates with the massive plate measurements.

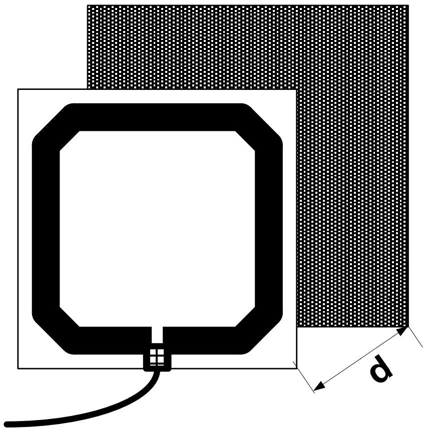

Figure 4. Measurement configuration.

A. Measurement of the resonance frequency shift in the presence of a massive plate

In Figure 5 we plotted the return loss of the antenna. In TABLE II you will find a detailed overview of the frequency shift compared to the resonance frequency of 13.56 MHz in free space. As one can see, a metal plate at a distance of 5 mm, will cause a frequency shift of 59.88%. In this situation there is a total mismatch of energy transfer between tag and antenna, resulting in failures of reading the tag. We even get a frequency shift of 17.92% with a massive metal plate at a distance of 40 mm.

TABLE II. OVERVIEW OF RESONANCE FREQUENCY WITH MASSIVE PLATE MEASUREMENTS

Metal plate	Material	Open Area	Hole Diameter	Hole shape	Thickness
type I	galvanized steel	0%	-	-	0.7 mm
type II	galvanized steel	33%	3 mm	round	0.7 mm
type III	galvanized steel	50%	4.8 mm	round	0.7 mm
type IV	galvanized steel	79%	6 mm	hexagonal	0.7 mm

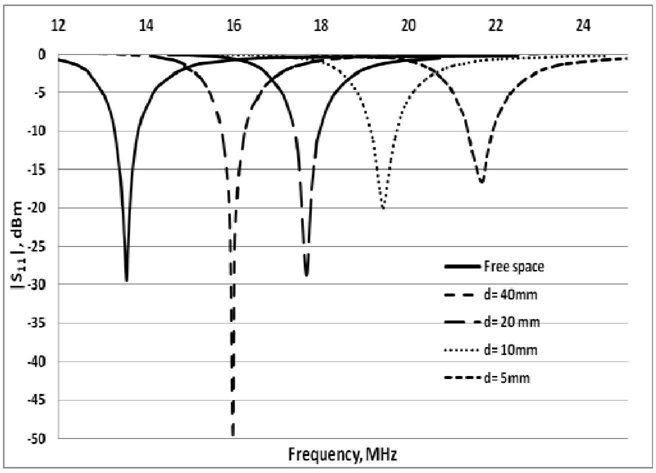

Figure 5. Return loss of the antenna with massive plate parallel to antenna.

B. Measurement of the resonance frequency shift with different types of metal plates

As other papers pointed out, using different types of materials (i.e. copper, aluminum, etc.) will not cause a big difference with respect to the influence on a loop antenna in terms of frequency shift, as in [1].

This section gives an overview of the influence on a loop antenna using different types of metal plates. This could lead us to less influence at the same distance. Figure 6, shows the return loss of the antenna with different types of metal plates near the antenna. The distance between the metal plates and the antenna is 5mm.

The same measurements have been done for the distances of 10 mm, 20 mm, and 40 mm.

TABLE III gives an overview of the resonance frequency shift. As expected, only a small difference in the shift of the resonance frequency is measured, using different types of metal plates at the same distance. Even when the metal plates are very close (5mm – 10 mm) the difference is very limited, smaller than 4%.

We could expect this, the wavelength of the signal is much larger than de perforations in the metal plates. Nonetheless it is important in view of the fact that the frequency shift has an important influence on reading out tags, see also 0.

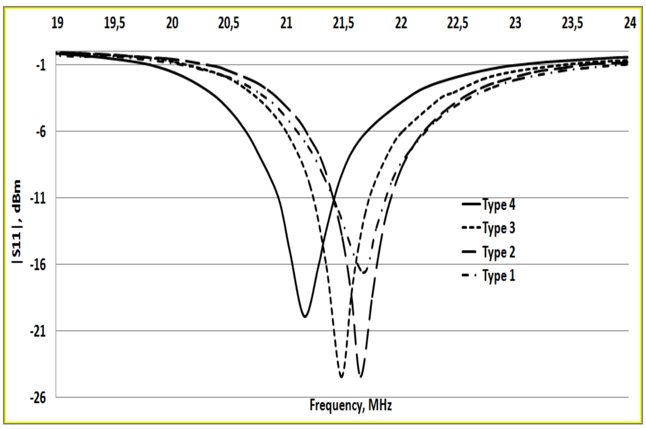

Figure 6. Return loss of the antenna using different types of metal plates at a distance of 5 mm.

TABLE III. OVERVIEW OF INFLUENCE OF DIFFERENT TYPES OF METAL PLATES

Distance	Metal plate	Resonance frequency	Difference between type I and type IV	Percentage of frequency shift
5 mm	type I	21.68 MHz	0.51 MHz	59.88%
	type II	21.66 MHz		59.73%
	type III	21.49 MHz	3.76%	58.48%
	type IV	21.17 MHz		56.12%
10 mm	type I	19.42 MHz	0.50 MHz	43.21%
	type II	19.22 MHz		41.74%
	type III	19.24 MHz	3.68%	41.88%
	type IV	18.92 MHz		39.53%
20 mm	type I	17.65 MHz	0.29 MHz	30.16%
	type II	17.60 MHz		29.79%
	type III	17.61 MHz	2.04%	29.86%
	type IV	17.36 MHz		28.02%
40 mm	type I	15.99 MHz	0.16 MHz	17.92%
	type II	15.90 MHz		17.26%
	type III	15.93 MHz	1.18%	17.48%
	type IV	15.83 MHz		16.74%

C. Reading out a tag in metal environment

To check the shift of the resonance frequency for a practical situation, we tried reading out a tag placed in front of the loop antenna. This tag is placed at a fixed distance in relation to the loop antenna, as shown in

Figure **7**. Varying the distance "d" of the metal plate towards the antenna we have measured the success rate of correct reading out a tag in front of the antenna. Measurements were done sending 2000 inventory requests to the RFID tag. The success of reading is clarified in Figure 8, using 2 different types of metal plates described in TABLE I. Measurements have been done, using type I and type IV of metal plates.

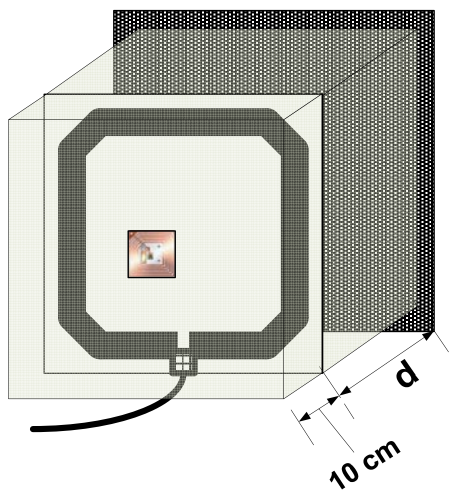

Figure 7. Measurement configuration reading tag.

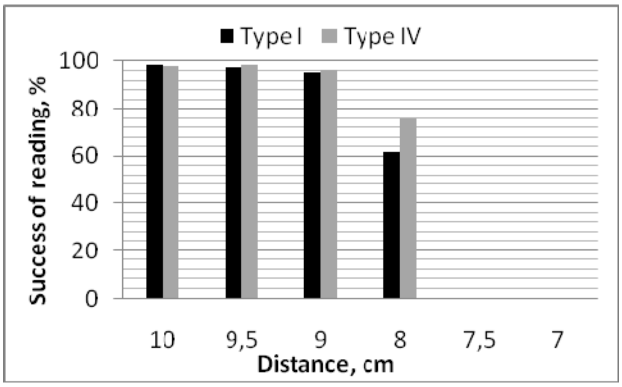

Figure 8. Success of reading out tags with different types of metal plates in the environment of the loop antenna.

One can see that the tag in front of the loop antenna will not be read out when the distance “d” is less than 7.5 cm. This will occur for both types of metal plates. As we mentioned earlier there will be no big difference between the two types of metal plates. Especially not when the distance between the loop antenna and metal plate increases.

TABLE IV shows that the success rate of reading decreases enormously when the percentage of frequency shift becomes higher than 9%. At this stage the energy field has already lost a significant amount of power at the resonance frequency of the tag.

Even when measuring in free space, we will not be 100% successful in reading the tag. Because of noise, some failures will occur.

IV. NEW ANTENNA CONCEPT

A solution can be, tuning the antenna at its resonance frequency when a static environment is achieved. The problem raises again working in changing environments, repeatedly tuning the loop antenna to its resonance frequency is needed to reach a high percentage of successful reading tags.

Another way of taking care of this issue is to install a permanent metal plate at the back of the loop antenna and retuning the loop antenna to its resonance frequency. Using this configuration a stable loop antenna is created.

A disadvantage of this construction is the decrease of reading range. Another disadvantage could be the direction dependence of reading a tag with the loop antenna. The metal plate placed at the back of the loop antenna, will prevent reading tags situated at the backside of the loop antenna. This issue can also be used as an advantage, knowing the tag can only be read in a certain area (cf. drawers in metallic cupboard).

We have chosen to use a metal plate of type IV, placed at the back of the antenna with an open area of 79%. The main reason for this configuration was its weight, especially knowing there is no big difference of influence, using different types of metal plates. We wanted to make an antenna, easy to use in all environments. The permanent metal plate was placed at a distance of 10 mm from the loop antenna, as shown in **Figure 9**.

TABLE IV. SUCCESS OF READING A TAG COMPARED TO THE FREQUENCY SHIFT

Metal plate	Distance	Resonance frequency	Percentage of frequency shift	Success of reading
Type I	Free space	13.56 MHz	0%	98.3%
	10 cm	14.34 MHz	5.73%	98.1%
	9.5 cm	14.50 MHz	6.95%	97.3%
	9 cm	14.64 MHz	7.96%	95.2%
	8 cm	14.78 MHz	8.96%	61.6%
	7.5 cm	14.91 MHz	9.95%	0%
	7 cm	15.14 MHz	11.64%	0%
Type IV	Free space	13.56 MHz	0%	98.3%
	10 cm	14.32 MHz	5.64%	97.9%
	9.5 cm	14.50 MHz	6.97%	98.3%
	9 cm	14.62 MHz	7.81%	96.1%
	8 cm	14.80 MHz	9.14%	75.6%
	7.5 cm	14.86 MHz	9.65%	0%
	7 cm	15.08 MHz	11.26%	0%

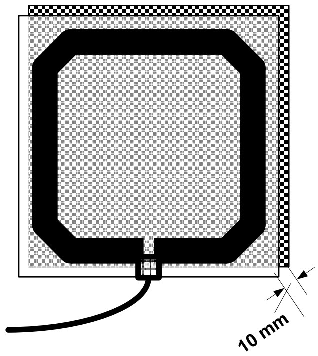

Figure 9. Loop antenna with permanent metal plate.

Using this configuration with an input power of 1W, we still have a reading range of 26 cm in free space. A comparable test was done using a standard loop antenna, resulting in a reading distance of 39 cm in free space. This means a decrease of 13 cm in terms of reading range.

For most applications, the reduction of reading range will not cause a problem compared to the increase of stability in a dynamic environment. In the next section the increase of stability using the new antenna concept will be illustrated.

A. Measurement results using the new antenna concept

First, the influence of a metal plate approaching the back of the antenna was measured. In this case we used the new antenna concept with a permanent metal plate positioned at the back of the loop antenna, evaluating the influence of a second metal plate, Figure 10.

Secondly, because of the presence of an asymmetric field around the loop antenna, the influences of a metal plate in front of the antenna needed to be measured, Figure 11.

1) Metal plate at the back of the antenna

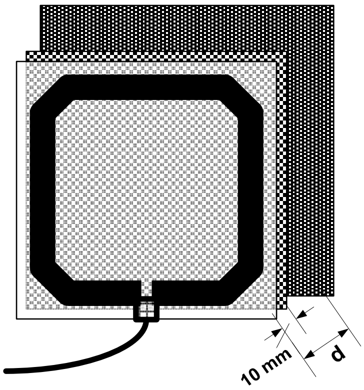

Figure 10. Configuration of a metal plate at the back using the new concept.

We measured the influence of a second metal plate at a distance "d" of 20 mm. In TABLE V one can see the comparison of a standard loop antenna and our new antenna concept.

Evidently, it is seen that the influence of a second metal plate at the back of our new antenna concept is negligible. The percentage of the frequency shift remains small, only 0.29%. Knowing this was an important aspect. Considering the results of TABLE IV, we know that the success rate of reading out tags remain stable when the frequency shift is smaller than 8%. This frequency shift will not cause any problems reading tags in front of the antenna.

TABLE V. INFLUENCE OF METAL PLATE AT THE BACK USING NEW CONCEPT OF ANTENNA

Distance	Antenna type	Metal plate	Resonance frequency	Percentage of frequency shift	Difference between antennas
20 mm	Standard	Type IV	17.65 MHz	30.16%	4.05 MHz
	New concept		13.60 MHz	0.29%	

2) Metal plate in front of the antenna

Using the configuration seen in Figure 11, measurements have been done using a massive plate. These measurements are compared to a standard loop antenna in TABLE VI.

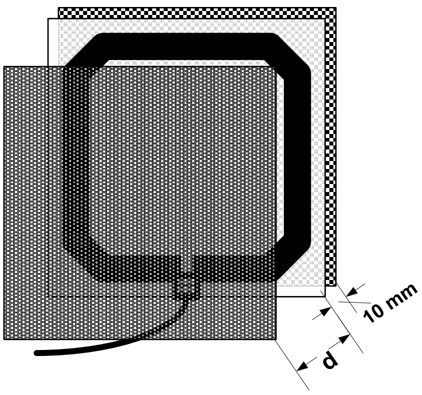

Figure 11. Configuration of a metal plate in front using the new concept.

As one can see, the percentage of frequency shift is significantly lower as compared with a standard loop antenna. At a distance of 40 mm there is only a frequency shift of 5.16%. With the results of TABLE IV in mind, we can conclude, it will not cause any problems reading out a tag.

Even in practice, we usually will not have this situation. Reading out a tag placed between a metal plate and a loop antenna separated by a distance of 40 mm, will cause a bigger frequency shift of the resonance frequency of the tag antenna. Even though, this situation was not measured in practice.

TABLE VI. INFLUENCE OF METAL PLATE IN FRONT USING NEW CONCEPT OF ANTENNA

Distance	Antenna type	Resonance frequency	Percentage of frequency shift	Difference between antennas
5 mm	Standard	21.68 MHz	59.88%	2.14 MHz 15.78%
	New concept	19.54 MHz	44.10%	
10 mm	Standard	19.42 MHz	43.21%	2.29 MHz 16.88%
	New concept	17.13 MHz	26.33%	
20 mm	Standard	17.65 MHz	30.16%	2.7 MHz 19.91%
	New concept	14.95 MHz	10.25%	
40 mm	Standard	15.99 MHz	17.92%	1.73 MHz 12.76%
	New concept	14.26 MHz	5.16%	

V. CONCLUSION

First, this paper presented an overview of the influence of a metal plate in terms of resonance frequency. Using different types of metal plates, we compared the differences in frequency shift of a standard loop antenna at several distances of a metal plate.

Using different types of metal plates in terms of open area will not result in a significant difference in the shift of resonance frequencies.

Secondly, we studied the influences of a metal plate when reading a tag, using a standard loop antenna. Having an output power of 1 W and a tag placed at 10 cm away from the loop antenna, a high performance reading the tag was achieved when the frequency shift was less than 8%.

Finally, a new antenna concept was presented and tested, using a permanent metal plate at the back of the loop antenna. Out of the measurements we can conclude that the stability of the loop antenna was increased. The influence of a metal plate at the back of the new antenna concept is almost nil. The influence of a metal plate in front of the new antenna concept is significant lower compared to a standard loop antenna.

This way we created a new antenna concept resulting in a higher stability compared to a standard loop antenna. This antenna can be used in a dynamic environment without retuning the loop antenna, respecting a minimum distance of 40 mm placing a metal plate in front of the antenna.

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