Evaluation of Balanced Capacitance Matching Unit for HF RFID Systems in Metallic Environments

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***Abstract*—RFID systems are sensitive to metallic environments in the proximity of the reader antenna. These influences produce shifting of the resonance frequency, causing performances degradation for the entire RFID system. Based on the behavior analysis of an HF RFID antenna circuit in the proximity of metallic environments, in this paper are proposed two tuning methods using a simplistic approach and some mathematical determinations. These solutions can be taken into account when it's necessary to implement a HF RFID system that can offer good performances even if the metallic environments in the proximity of the antenna are constantly changing.**

***Index Terms*—metallic environment, HF antenna, RFID tuning circuit, impedance measurement**

I. INTRODUCTION

RFID systems are increasingly found in a relatively high number in various applications and fields due to the advantages offered [1]. Applicability area of this technology can be extended, but for metallic environments these systems do not provide a high efficiency [2]. Because the magnetic field is the main component in establishing the communication between RFID tags and readers, a metallic environment in the proximity of the antenna will produce a mismatch in the resonance frequency (1) that leads to high performance degradation of the whole system.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

As described by Faraday's law, a current will be induced if a metallic surface is situated in the close proximity of a magnetic field. These so-called eddy currents cause the inducing of a magnetic field that works against the exciting magnetic flux, according to Lenz's law. [3]. As a consequence of this, the magnetic flux Ψ will decrease, thereby bringing decreasing in the antenna inductance (2)

$$L = \frac{\Psi}{I}. \tag{2}$$

Regarding these aspects the resonance frequency of the circuit will increase, causing a decreasing in the transmitted power to the tag. The more this power drops the diminution is the reading distance of the RFID tags, causing a high degradation of the system performances. One of the most approached solutions which partially solve this aspect assumes implementing a "static" antenna pattern with a metal plate as a support on one side [4]. This pattern is tuned to the system resonance frequency once when the system is first implemented, offering some kind of immunity from the metallic environments. Thus if in the range of the antenna appears another metallic environment, this solution doesn't offer satisfactory results in system performance.

II. SYSTEM STRUCTURE

An antenna circuit is taken into account to evaluate the metallic environment effects over the HF RFID system. This antenna circuit consists in a multi-loop antenna (Fig. 1, a) and an impedance matching unit circuit (Fig. 1, b), which provides a 50 Ohm feed line to that antenna. The performances of this antenna pattern are not covered here, being presented in [5].

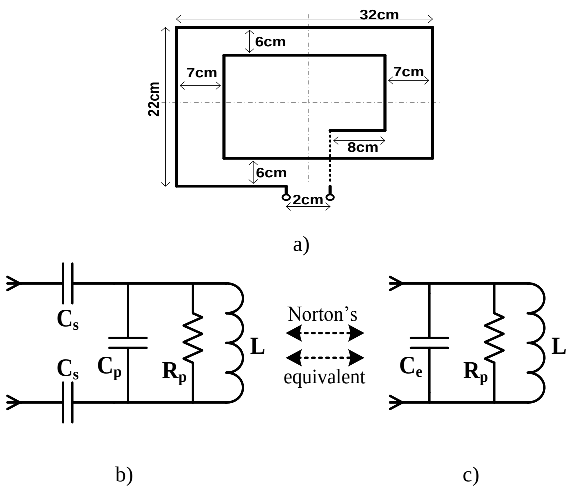

Fig. 1. HF RFID antenna circuit: a – antenna pattern [5]; b – matching unit circuit; c – Norton's equivalent.

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Into a circuit the antenna is considered to be a balanced load, having a symmetrical structure. This aspect reveals that none of the antenna connection points should be connected directly at the feed points, especially to ground. Obtaining such a structure means using two series capacitors C_s connected like in Fig. 1, b. To maintain this structure in balance, both C_s will have the same value.

Another aspect when is implemented a matching unit supposes to analyze the circuit quality factor Q (3). A higher Q factor leads to a higher output power, so more energy is transferred to the tags

$$Q = \frac{R}{2\pi f_0 L}. \quad (3)$$

On the other hand, a higher Q factor leads to a smaller bandwidth (4) and to a higher selectivity in identifying the RFID tags. If the tags are made with high technological dispersion, this aspect regarding the quality factor is very important. So, the quality factor needs to ensure some kind of compromise

$$Q = \frac{f_0}{BW}. \quad (4)$$

III. EXPERIMENTAL SETUP AND PERFORMANCES ANALYSIS

In order always to reach to resonance frequency, the matching unit must satisfy at any time (1). Using Norton's theorem on the circuit from Fig. 1, b, is obtained equivalent circuit from Fig. 1, c, where the equivalent capacitance is calculated using (5)

$$C_e = C_p + \frac{1}{2} C_s. \quad (5)$$

Thus, knowing this equivalent capacitance we can determine the antenna inductance at resonance frequency using (1).

The first set of measurements supposes to match the RFID antenna circuit to 13.56MHz without any metallic environments around it. The circuit capacitors can be determined easily by manually adding different values aiming at each time a 50 Ohm impedance feed line at the resonance frequency (13.56MHz). This impedance at the resonance frequency is monitored constantly with a Network Vector Analyzer (Fig. 2).

Experimental values obtained for these capacitors used for the matching unit are C_s = 47pF and C_p = 53pF. Using (5) is obtained an equivalent capacitance of C_e = 76.5pF. This value is used to calculate the antenna inductance, resulting a value L = 1.8μH. It should be noted that the damping resistor R_p is imposed on to a value of 5.3kΩ to obtain a quality factor Q = 34. This Q involves using a bandwidth wide enough to identify the most commercially available HF RFID tags (~400kHz). This theoretical inductance obtained needs to be checked experimentally. To this end is used a very accurate L Meter which measures with a 10Hz sampling frequency. Performing the measurements is obtained a value of 1.808μH (Fig. 3), which indicates that the results obtained from (5) and the above reasoning is true.

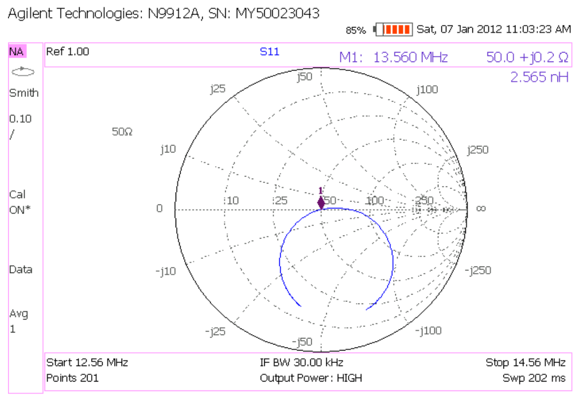

Fig. 2. Smith chart of the HF RFID antenna.

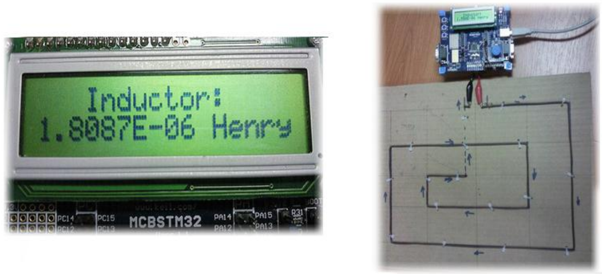

Fig. 3. Measurement of the inductance for the matching unit with an accurate L Meter.

After this step, we need to evaluate the influence of the metallic environments over the antenna circuit. An 80cm x 60cm galvanized steel plate with 0.5mm thickness is used as a disturbing environment. Between the antenna and the metal plate is a distance d that varies from 10mm to 50mm (Table I). The inductance L was measured for each variation of the distance d. Considering the same equivalent capacitance obtained in the absence of any perturbing environment (C_e = 76.5pF) we can calculate the resonance frequency of the circuit. Both values for the measured inductance and the calculated frequency are in Table I.

TABLE I. FREQUENCY SHIFTS OF THE MATCHING UNIT.

d* [mm]	10	20	30	40	50
L measured [μH]	1.31	1.45	1.54	1.6	1.66
f_0 calculated [MHz]	15.89	15.11	14.66	14.38	14.12

*Note: *d represents the distance between antenna and the metal plate*

To check the frequencies obtained with (1), |S11| parameter is picked with a Network Vector Analyzer and plotted in Fig. 4.

The results for the resonance frequency obtained in Table I can be compared with frequencies response plotted in Fig. 4. These similar results show that the proposed calculation method is valid.

In order to provide a good functionality for RFID system in the proximity of metallic environments we need always to adjust the resonance frequency of the antenna circuit to 13.56MHz, with a 50 Ohm feed line. To achieve this goal, below are presented two ways of tuning the antenna circuit, which can be implemented manually or automatically.

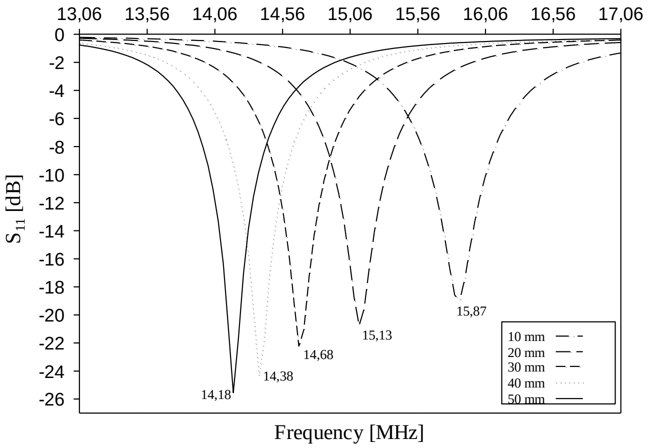

Fig. 4. Frequency shifts with the variation of the RFID antenna – metal plate distance.

A. Tuning method using Cs and C_p

According to Table I, the antenna inductance depends directly by the distance between the antenna and the metal plate. In this case, to ensure a 50 Ohm match at resonance frequency (13.56MHz) for the antenna circuit, we must adjust the equivalent capacitance. Using the same value for the damping resistor (5.3kΩ), the antenna circuit is tuned by adding manually values for C_s and C_p. The values obtained in this case are listed in Table II. Using this method we can achieve a fast automatic tuning of the antenna circuit and is best suited for RFID systems that have always around a changing perturbing environment.

TABLE II. MATCHING UNIT COMPONENTS FOR TUNING METHOD A.

d* [mm]	10	20	30	40	50
C_s [pF]	53	50	50	49	48
C_p [pF]	80	70	65	62	59
C_e [pF]	107	95	90	86.5	83
L [µH]	1.29	1.45	1.53	1.59	1.66
R_p [kΩ]	5.3	5.3	5.3	5.3	5.3

*Note: *d represents the distance between antenna and metal plate*

B. Tuning method using Rp and C_p

From all measurements that were performed is noted that when C_s remains unchanged, in order to maintain a perfect match to the resonance frequency, is necessary to adjust the value of the damping resistor R_p.

In this case, to obtain a 50 Ohm feed line at the resonance frequency of 13.56MHz we need to modify the values for the resistor R_p and for the capacitance C_p. The experimental values obtained are listed in Table III.

TABLE III. MATCHING UNIT COMPONENTS FOR TUNING METHOD B.

d* [mm]	10	20	30	40	50
C_s [pF]	47	47	47	47	47
C_p [pF]	84	71	67	63	60
C_e [pF]	108	94.5	90.5	86.5	83.5
L [µH]	1.28	1.46	1.52	1.59	1.65
R_p [kΩ]	7.4	6.2	5.8	5.7	5.6

*Note: *d represents the distance between antenna and metal plate*

This method is best suited to a manual tuning of the antenna circuit for the RFID system in cases where the configuration of metallic objects in proximity is known and does not change in time.

After a short analysis of the inductance values obtained in the Table II and Table III, we can conclude that these values are approximate identically with the values obtained in Table I.

The differences between the proposed tuning methods can be observed by analyzing Fig. 5 where $|S_{11}|$ parameter is plotted at a distance of 10mm between the antenna and metal plate. This distance is chosen because the influences of metallic environments over the RFID antenna are the most significant.

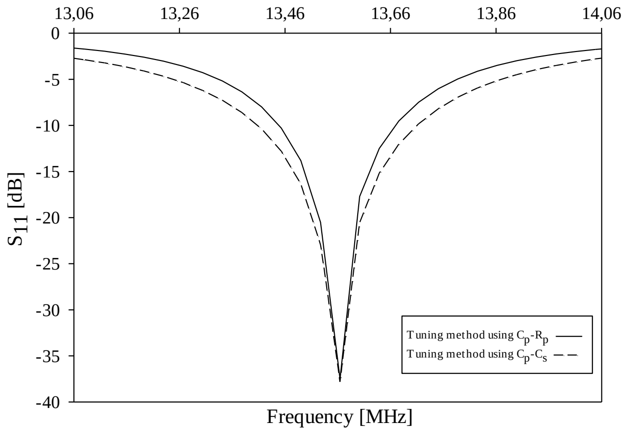

Fig. 5. Comparison of both methods proposed analyzing $|S_{11}|$ parameter.

Although analyzing the $|S_{11}|$ parameter reveals the same frequency response (13.56MHz), changes in value for the damping resistor invokes changes in bandwidth (4), (5). This bandwidth can be calculated with (6)

$$BW = f_2 - f_1, \tag{6}$$

where f_1 and f_2 are the 3dB frequencies and can be obtained with (7) and (8) respectively:

$$f_1 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} - \frac{1}{2RC}, \tag{7}$$

$$f_2 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} + \frac{1}{2RC}. \tag{8}$$

The values for the bandwidth obtained with (6) for both proposed methods are listed in Table IV.

TABLE IV. BW VALUES FOR BOTH TUNING METHODS USED

d* [mm]	10	20	30	40	50
BW (tuning method A) [kHz]	218	316	334	347	362
BW (tuning method B) [kHz]	199	272	303	323	340

Note: **d represents the distance between antenna and metal plate*

A significant change in the bandwidth can be observed when the tuning method *B* is used. This is possible because the method involves changing the value of the damping resistor and the inductance, both important variables in determining *Q* factor. When is used the first tuning method described (method A), only inductance is changing because of the distance between antenna and metal plate, making an insignificant change in the Q factor.

IV. CONCLUSIONS

The analysis of metallic environment influences on the HF RFID antenna circuit reveals that it's possible to make a perfect match on the 13.56MHz resonance frequency using a simplistic approach. Two tuning methods are proposed that can bring benefits regarding the performances improvement of HF RFID systems in the proximity of metallic environments. Based on this study, can be implemented automatic tuning systems that can make an easy and rapid tune of the RFID antenna circuit, even if the environment around is constantly changing, without using human interventions.

REFERENCES

[1] E. Coca, V. Popa, V. G. Găitan, C. O. Turcu, Cr. Turcu, "Speed Measurement of a Moving Object by using a RFID Location System and Active Transponders", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering)*, vol. 88, no. 8, pp. 63–66, 2008.

[2] S. Bovelli, F. Neubauer, C. Heller, "Mount-on-Metal RFID Transponders for Automatic Identification of Containers", in *Proc. of the European Microwave Conference*, pp. 726–728, 2006. [Online]. Available: http://dx.doi.org/10.1109/EUMC.2006.281004

[3] D. Dos Reis, M. Lambert, D. Lesselier, "Eddy-current evaluation of three-dimensional defects in a metal plate", *Inverse problems*, vol. 18, no. 6, pp. 1857–1871, 2002. [Online]. [Online]. Available: http://dx.doi.org/10.1088/0266-5611/18/6/325

[4] K. D'Hoe, A. Van Nieuwenhuyse, G. Ottoy, L. De Strycke, L. De Backer, J. P. Goemaere, B. Nauwelaers, "Influence of Different Types of Metal Plates on a High Frequency RFID Loop Antenna: Study and Design", *Advances in Electrical and Computer Engineering,*vol. 2, no. 9, pp. 3–8, 2009. [Online]. [Online]. Available: http://dx.doi.org/10.4316/aece.2009.02001

[5] A. I. Petrariu, V. Popa, V. G. Gaitan, I. Finis, A. Lavric, "13.56 MHz RFID multi-turn antenna for metallic environments", in *Proc. of the European Conference on the Use of Modern Information and Communication Technologies*, pp. 187–196, 2012.