EFFICIENCY OF TAG ANTENNA UNIT IN ANTICOLLISION RADIO FREQUENCY IDENTIFICATION SYSTEMS WITH INDUCTIVE COUPLING

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ABSTRACT

The quality factor Q is the measure of tag antenna unit functioning efficiency in areas of energy transfer and communication conditions in anticollision radio frequency identification (RFID) systems with inductive coupling. The problem of homogeneous proper interrogation zone of RFID system, that is mutual overlay of zones that result from conditions of tag supply and the radio communication carried in the system, have been presented in this paper.

Keywords: *RFID system with inductive coupling, system efficiency, interrogation zone, passive tag, tag antenna unit*

1. INTRODUCTION

Passive Radio Frequency IDentification (RFID) systems with inductive coupling are the most widespread [1-3]. These systems can operate in individual and anticollision regime, and the need of designing such systems appears more often nowadays. The typical applications of anticollision RFID systems are concentrated on different economic and public activity in industry, commerce, science, medicine and others.

Their functioning is based on the use of energy, which is stored in magnetic field. The kind of executed operation in individual phases of exchange of data between units of system is essential during communication in anticollision identification process. The basic condition of effective operation of the system is proper supply of each tag in heterogeneous magnetic field created by Read/Write Device (RWD) antenna loop. A minimal value of energy (necessary for proper read/write operation of the tag) is determined by minimal value of magnetic induction B_{min} in each point of its location [4].

Paying attention to the maximum work distance between elements of the RFID system, in particular for systems working in the RFID far field, it is necessary to estimate the simulated and built antenna set RWD-tags in relation to the obligatory normalizations of communication and EMC [5].

Generalizing, the operation of passive anticollision RFID systems with inductive coupling is characterized by the interrogation zone (IZ), which is estimated in any direction of 3D space for group of electronic tags. The elements of algorithm of identification of interrogation zone for inductive coupled anticollision RFID system taking into consideration the field, electrical and communication aspects of operation conditions has been partially presented in this paper.

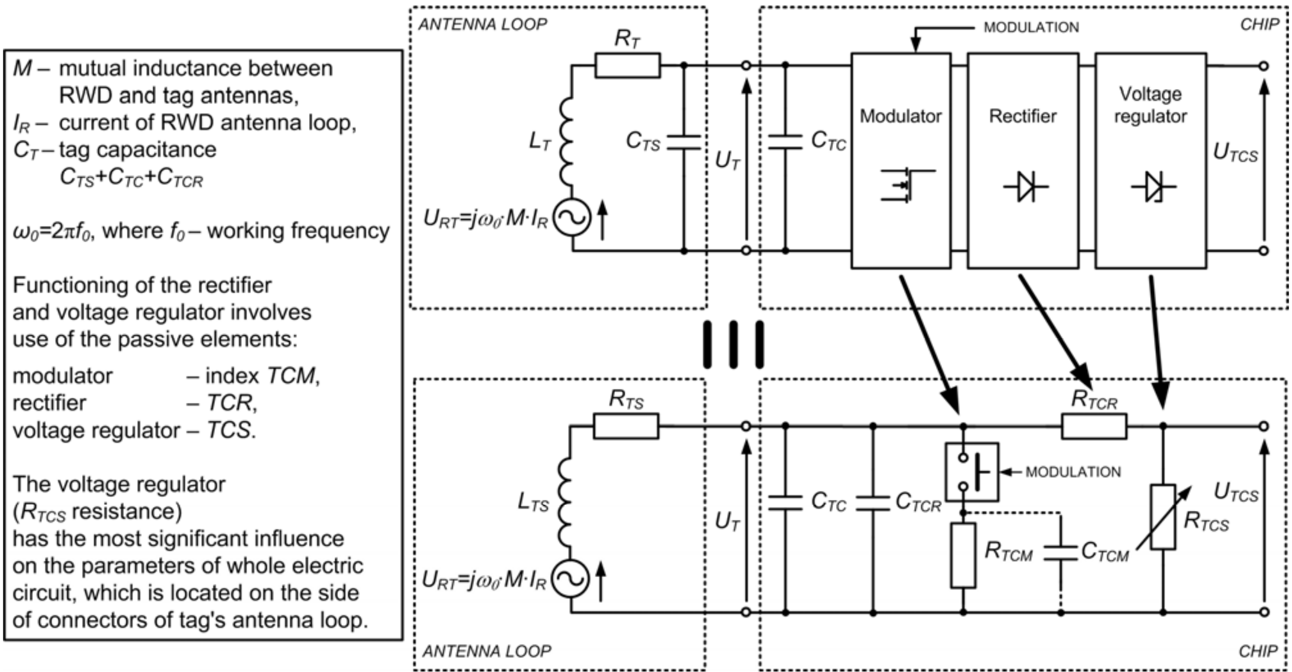

Fig. 1 Equivalent schematic diagram of antenna loop connected to the chip of passive RFID tag which works in anticollision RFID system with inductive coupling

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The mentioned aspects influence on RFID system reliability, which is characterized by the efficiency coefficient and the identification probability of objects on concrete interrogation zone. Presented energetic and communication aspects of efficiency of tag antenna unit are one part of the algorithm of synthesis of RWD and tag antenna set for the system with inductive coupling.

2. EFFICIENCY OF TAG ANTENNA UNIT

The quality factor Q is the measure of tag antenna unit functioning efficiency in areas of energy transfer and communication conditions in anticollision RFID systems with inductive coupling [6-9].

During the synthesis of tag antenna, the changes of this parameter can be made by inductance change (indirectly – by changing the effective resistance of antenna loop), adjusted to requirements of the shape and geometrical sizes of electronic tag. The proper synthesis of interrogation zone of RFID system is closely connected with three aspects which concern the maximum value of Q factor for the operating tag. The first of these aspects relates to correct operating of the tag supply system that is the possibility of radio communication appearing. The second concerns the necessity to obtain the required data transmission bit-rate (and also the bandwidth) in direction: tag-read/write device. The third aspect concerns the impulse and step response of tag circuit in case of reverse data transmission, to provide correct identification of commands sent from the RWD. The two last aspects should directly or indirectly result from the electronic tag chip specification for which the antenna is going to be projected. The first aspect should be considered on the stage of antenna synthesis, and the value of Q factor should contain all mentioned limitations of operating passive tag. There is essential to ensure the homogeneous proper interrogation zone of RFID system that is mutual overlay of zones that result from conditions of tag supply (by absorbing the energy of magnetic field) and the radio communication carried in the system (realized with the suitable value of signal-to-noise).

2.1. Energetic aspects

The effective use of energy of the magnetic field can be interpreted by the maximum value of voltage U_{Tmax}, which is induced on the trimming tag antenna (Fig. 1), and also by the maximum value of quality factor Q_{Tmax} for tag's load antenna. In the structural aspect, there is possibility of deciding only to adjust parameters of tag's antenna loop (by changing the inductance L_{TS}, indirectly by changing the effective resistance R_{TS} and the number of antenna turns N_T). In that case the equation of quality factor Q_T for the operating tag as a function of the series inductance L_{TS} is given by formula:

$$Q_T = \frac{1}{\dfrac{R_{TS}}{\omega_0 L_{TS}} + \dfrac{\omega_0 L_{TS}}{R_{TCR} + R_{TCS}}} = f(L_{TS}) \tag{1}$$

The inductance of tag antenna is the most convenient parameter, which is taken into consideration during the synthesis of antenna loop, adjusted to the structural requirements of every tag (its shape and geometrical sizes). Looking for the maximum value of this parameter brings the practical advantage of obtaining the maximum value of quality factor. In order to calculate the extreme of the function (1), there is a convenient comparison of first derivative with zero:

$$f'(L_{TS}) = \frac{\dfrac{R_{TS}}{\omega_0 L_{TS}^2} - \dfrac{\omega_0}{R_{TCR} + R_{TCS}}}{\left(\dfrac{R_{TS}}{\omega_0 L_{TS}} + \dfrac{\omega_0 L_{TS}}{R_{TCR} + R_{TCS}}\right)^2} = 0 \tag{2}$$

The series inductance of tag's antenna loop, for which the value of quality factor of load antenna is maximal, can be calculated from the (2) equation as follows:

$$L_{TSmax} = \frac{\sqrt{R_{TS} \cdot \left(R_{TCR} + R_{TCS}\right)}}{\omega_0} \tag{3}$$

From the equations (3) and (1) there comes, that the maximum value of quality factor is given by:

$$Q_{Tmax} = \frac{1}{2} \cdot \sqrt{\frac{R_{TCR} + R_{TCS}}{R_{TS}}} \; . \tag{4}$$

The equation (4) expresses the limit value of the energetic aspects of operation conditions of tag and its antenna unit, which can be obtained by the inductance L_{TSmax}. The graphic representation of $Q_T = f(L_{TS})$ and the limit points, which are described by the (3) and (4) equations, have been presented in figure 2.

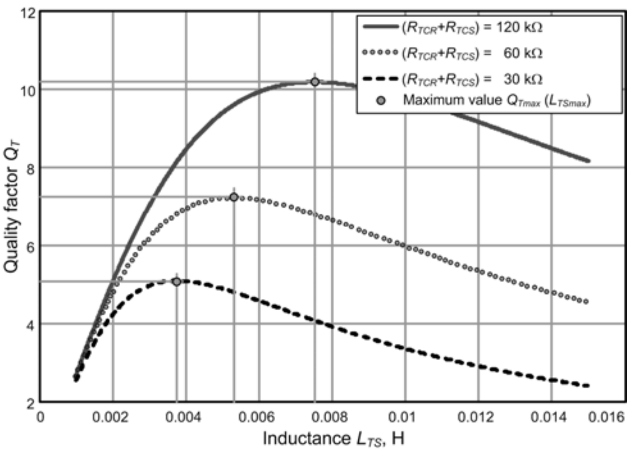

Fig. 2 Total quality factor for example tag with functioning rectifier and voltage regulator (HITAG 1 chip - f_0=125 kHz), as a function of inductance of its antenna loop of R_{TS}=290 Ω

The rectifier and voltage regulator functioning is connected with the variable resistance R_{TCS}, which causes different tag's antenna load in dependence of tag location and its orientation with regard to the RWD antenna loop. In this case the energetically suitable value of the inductance L_{TSmax} depends on tag location in the communication space. If the tags, which are functioning in the anticollision system, were located only in the far RFID field (e.g. on the periphery of interrogation zone), then the choice of the energetic suitable value of the inductance L_{TSmax} would be unambiguous because of the maximum value of antenna load (the solid line in Fig. 2). This situation becomes complicated when tags are located in the near and far RFID field simultaneously. The choice of the energetically suitable value of the inductance L_{TSmax} determines the compromise that should be done because of various antenna load values caused by the functioning internal chip modules. Such case is described by the curves $Q_T=f(L_{TS})$ for the extreme values of $R_{TCR}+R_{TCS}$.

2.2. Communication aspects

The limitations connected with energetic aspects of passive tag and its antenna unit functioning, stay in the contradiction to necessity of assurance of the suitable communication between tag and RWD. On the one hand, the maximum value of tag's quality factor is required for effective use of energy, that is accumulated in RWD magnetic field. On the other hand, the necessity of correct data communication with the suitable bit-rate is connected with assurance of the suitable bandwidth B_{T3dB} for the tag's antenna load:

$$B_{T3dB} = \frac{f_0}{Q_T} \tag{5}$$

In the range of short waves - typically for the frequency f_0=13,56 MHz - during communication in direction: tag-read/write device, the data are sent by amplitude modulation with subcarrier. In this case the side bands, which include transfer data, are strongly attenuated. If the quality factor of tag's load antenna has too large value, then the narrow bandwidth will cause information signal attenuation in the modulated subcarrier.

In the consequence, interrogation zone of the RFID system is going to be reduced because value of the signal-to-noise is insufficient in spite of correct energetic aspects of tag and its antenna unit operation conditions.

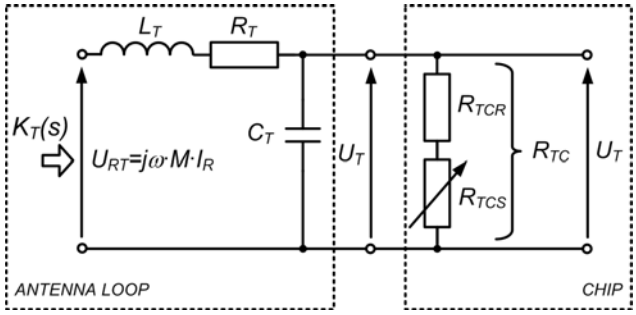

Fig. 3 Equivalent schematic diagram of tuned antenna loop connected to passive RFID tag chip during data transmission in direction RWD-tag

The separate problem of analysis of the communication protocol is assurance of suitable value of the low logical level time t_P (Fig. 4) keeping the required oscillations attenuation level during amplitude shift keying in the tag unit. This problem concerns the impulse response of series resonant circuit in the tag's antenna unit.

The transmittance $K_T(s)$ of the equivalent schematic diagram for operating tag (Fig. 3) is given by equation:

$$K_T(s) = \frac{U_T}{U_{RT}} = \frac{R_{TC}}{R_{TC}+R_T} \cdot \frac{1}{1 + s\cdot\left(\frac{L_T + C_T R_T R_{TC}}{R_{TC}+R_T}\right) + s^2 \cdot \left(\frac{C_T L_T R_{TC}}{R_{TC}+R_T}\right)} \tag{6}$$

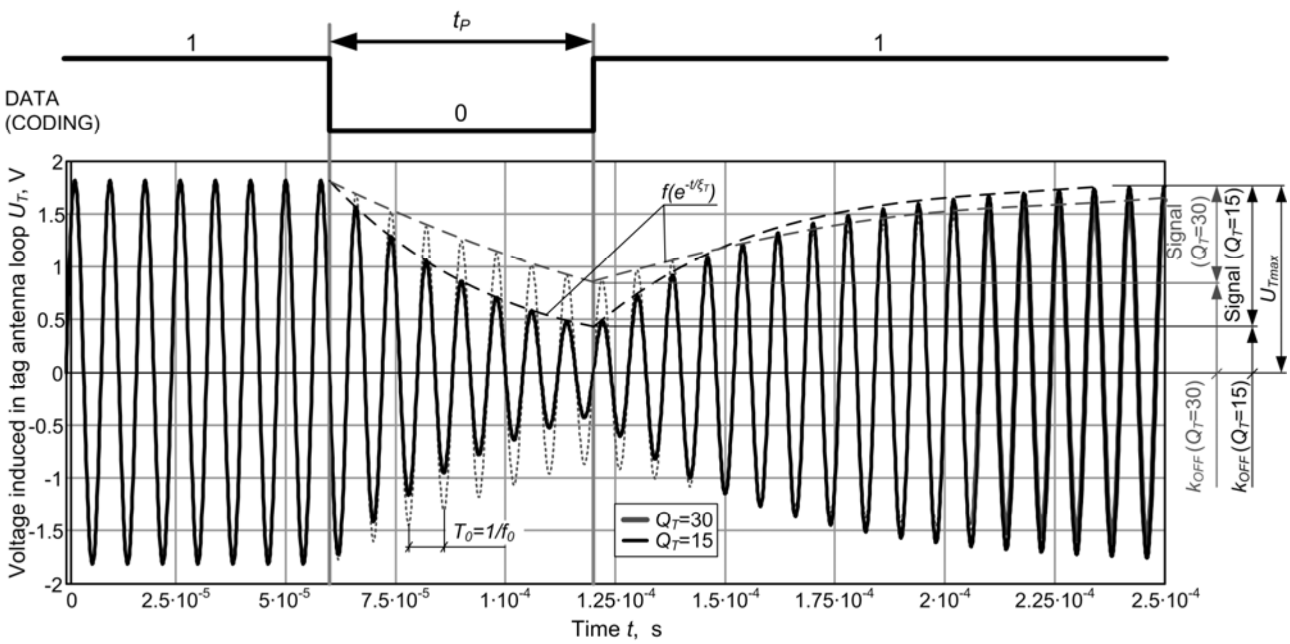

Fig. 4 Transient response of operating tag unit for RWD-tag direction of data transmission

The attenuation coefficient, which describes the oscillations of resonant circuit in result of the impulse response, is given by equation:

$$\xi_T = \frac{Q_T}{\pi \cdot f_0} \tag{7}$$

The maximum value of the attenuation coefficient, for which time t_P is obtained (for suitable value of the no dimensional coefficient of oscillations attenuation k_{OFF}), is given as follows:

$$\xi_{Tmax} = \frac{-t_P}{\ln(k_{OFF})} \tag{8}$$

where $k_{OFF} = X_{\%} U_{Tmax}, \; X_{\%} \in \langle 0\%, 100\%)$

Closure of the set of coefficient $X_{\%}$ from left side when its value equals 0 %, has theoretical meaning, because the oscillations fading and also zero value of the voltage U_{XRSmax} occur after the infinitely long time. From the equations (7) and (8) comes, that the maximum value of quality factor is given by:

$$Q_{Tmax} = \frac{-t_P \cdot \pi \cdot f_0}{\ln(k_{OFF})} \tag{9}$$

Example of the transient response of tag unit (Fig. 3) for RWD-tag direction of data transmission has been presented in figure 4.

Making clear connection between the attenuation coefficient and quality factor of the operating tag – (7) equation, enables to determine the requirements to the maximum value of this parameter for RWD-tag direction of data transmission – (9) equation. Growth of the value of quality factor leads to the elongation of the transient response of tag unit on the impulse and step response from the RWD side. In the consequence, the tag's signal-to-noise ratio decreases, what can make data identification sent from RWD impossible. Similarly as in the case of the data sent from tag to the read/write device, the ideal case is when the maximum value of quality factor for the energetic aspects of operation conditions of tag and its antenna unit is the same as the quality factor on the impulse and step response of antenna unit (required value of the attenuation coefficient).

3. EXPERIMENT

The part of experimental research, which relates to the efficiency of tag antenna unit, has been carried out in RFID laboratory system designed and made in Department of Electronic and Communication Systems, Rzeszów University of Technology. On the present stage, this laboratory system permits carrying out different single and anticollision identification process for all frequencies in RFID systems (LF, HF inductive coupled, UHF). All experimental research have been carried out on the basis of the algorithm of synthesis of RWD and tag antenna set for the anticollision RFID system with inductive coupling. The algorithm has been elaborated on the basis of relations, which allows to determine the interrogation zone of this system. The algorithm contains three stages. In the first and second stages the selection of RWD and tags along with antenna sets is performed. The special procedure of theoretical and experimental investigations, carried out in the third stage, allows to determine the functional efficiency of whole anticollision RFID system [10].

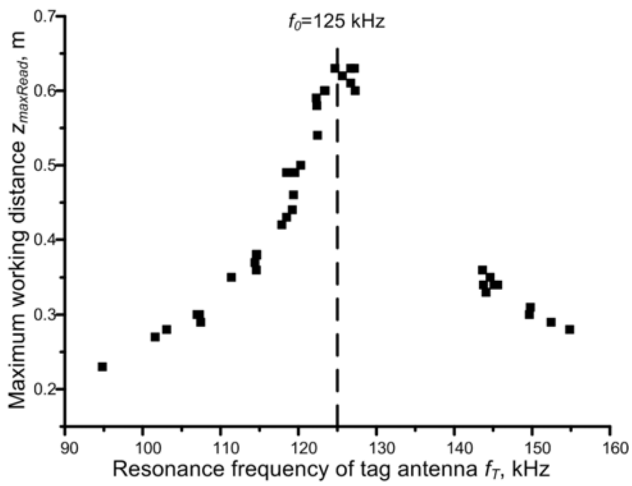

Fig. 5 Measured maximum working distance $z_{maxRead}$ between the RWD and tag antennas from the center on axis of symmetry of RWD antenna loop (for data read from tag memory)

The experimental verification of the tag and its efficient antenna (Fig. 1) model functioning, has been carried out on the basis of tags which were built on HITAG 1 chip and prepared examples of tags' antennas. Conducted measurements and simulations confirmed the correctness of synthesis of the efficiency of tag antenna unit in areas of energy transfer and communication conditions.

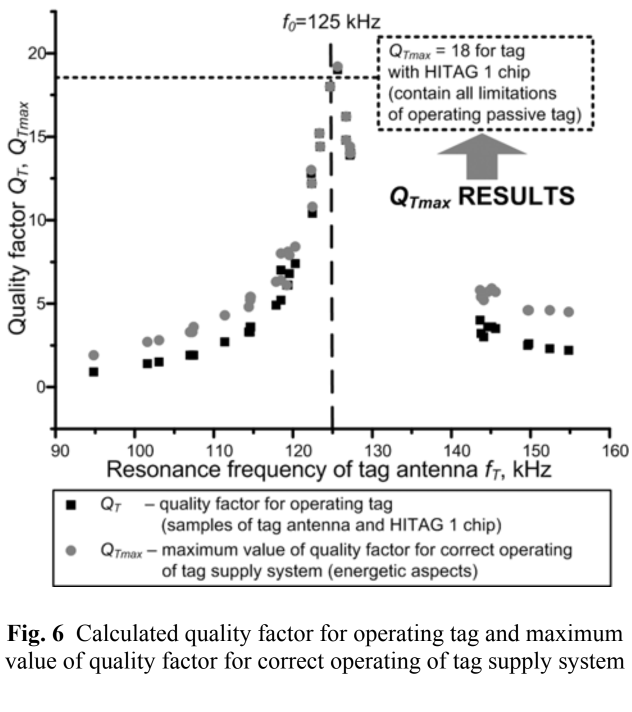

Fig. 6 Calculated quality factor for operating tag and maximum value of quality factor for correct operating of tag supply system

After comparing chosen data as a function of the resonance frequency of tag antenna f_T, it can be noticed that the interrogation zone of the RFID system increases when the frequency f_T approaching to the RFID system's work frequency (Fig. 5). This results from obtainment necessity of the same values of the quality factor for operating tag and the quality factor for correct operating of tag supply system (the round points in Fig. 6). Taking into consideration the fact, that the value of quality factor Q_T for every tag example has not been higher than Q_{Tmax}, in the laboratory RFID system, the mutual overlay of IZ have occurred. Mentioned zones result from conditions of tag supply (by absorbing the energy of magnetic field) and the radio communication carried in the system.

The most important is the fact, that the quality factor for operating tag, maximum quality factor for correct operating of tag supply system and maximum value of quality factor which contain all limitations of passive tag operating, are completely compatible for the frequency f_0. There can be definitely affirmed that for used read/write device, its antenna unit and tags' antennas examples of equal sizes and shapes, the distance between RWD and tag antennas $z_{maxRead} \cong 0{,}63$ m, and is a limit of the interrogation zone of RFID system on axis of symmetry of RWD antenna loop for data read from tag memory.

4. CONCLUSIONS

Conducted simulations and measurements confirmed the correctness of processing method, which describes the tag antenna unit functioning efficiency in areas of energy transfer and communication conditions in anticollision radio frequency identification systems with inductive coupling. This part of the problem of IZ synthesis is the base for practical use of projected identification systems, required for specific anticollision RFID applications in different economic and public activities.

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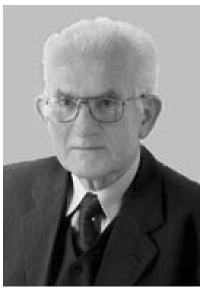
BIOGRAPHIES

Piotr Jankowski-Mihułowicz, Ph.D., was born in 1974. In 1999 he graduated (MSc) at the specialization of electronic devices at the Faculty of Electrical Engineering, Technical University in Rzeszów. He defended his PhD in the field of telecommunications in 2007. His thesis title has been "Creation conditions of antenna array efficiency of anticollision Radio Frequency Identification systems with inductive coupling". Since 1999 he has been working as a PhD, Eng., Assistant Prof. in the Department of Electronic and Communications Systems, Faculty of Electrical and Computer Engineering at the Rzeszów University of Technology. His scientific research is focusing on RFID systems and their practical uses, which are concentrated on different economic and public activity in industry, commerce, science, medicine and others. He co-operates with companies in the country and abroad in order to solving problems from the range of RFID technology.



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