A Study on Power Stability Improvement in the Inductive Coupled RFID Transponder System

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***Abstract*—**Transponders of RFID system are classified as active or passive depending on the type of power supply they use. In passive transponders the data carrier has to obtain its power from the induced voltage. The induced voltage is converted into direct current using a low loss bridge rectifier and then smoothed. In practice, the induced voltage in the transponder coil is variable according to the coupling coefficient *k* and the load resistance (R_L). Therefore, the rectified voltage is unstable and the transponder of RFID is unstable sometimes. In this paper, a voltage-dependent shunt resistor (R_S) circuits are designed and inserted in parallel with the load resistance of RFID transponder in order to improve the stability of power.

***Index Terms*—**Rectifier, Transponder, Inductive Coupled Coil.

I. INTRODUCTION

Recently, the automatic identification procedures have become very popular in many service industries, purchasing and distribution logistics, industries, manufacturing companies and material flow systems. The technically optimal solution would be the storage of data in a silicon chip. The most common form of electronic data–carrying device in use in everyday life is the smart card based upon a contact field such as traffic smart card and bank card. However, the mechanical contact used in smart card is often impractical. A contactless transfer of data between the data–carrying device and its reader is far more flexible. In the ideal case, the power required to operate the electronic data–carrying device would also be transferred from the reader using contactless technology. Because of the procedures used for the transfer of power and data, contactless ID systems are called RFID system [1, 2].

Transponders of RFID are classified as active or passive depending on the type of power supply they use. Active transponders incorporate their own battery to provide the power supply to the data carrier. In passive transponders the data carrier has to obtain its power supply from the voltage u_2 induced in the transponder coil.

To achieve this, the voltage u_2 is converted into direct current using a low loss bridge rectifier and then smoothed [2].

However, in practice, the induced voltage u_2 in the transponder coil very rapidly reaches high values due to resonance step-up in resonant circuit. If the coupling coefficient *k* is increase – possibly by reducing the gap between reader and transponder – or the load resistance R_L is increase, then voltage u_2 will reach a level much greater than 100V instantly. Generally the operation of a data carrier requires a constant operating voltage of 3~5 V. The voltage u_2 in the transponder coil is variable according to the coupling coefficient *k* and the load resistance R_L. In this paper, In order to regulate voltage u_2 independently of the coupling coefficient *k* or other parameters, and to hold it constant in practice, we inserted a voltage-dependent shunt resistor R_S in parallel with the load resistance R_L. As induced voltage increases, the value of the shunt resistor R_S falls, thus reducing the quality of the transponder resonant circuit to such a degree that the voltage u_2 remains constant.

II. INDUCTIVE COUPLED TRANSPONDER

An inductively coupled transponder comprises an electronic data-carrying device, usually a single microchip, and a large coil that functions as an antenna. Figure 1 shows a configuration of inductive coupled reader and transponder.

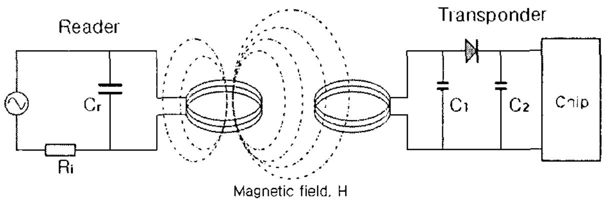

Fig. 1 Inductive Coupled Transponder

Inductively coupled transponders are almost always operated passively. This means that all the energy needed for the operation of the microchip has to be provided by reader. For this purpose, the reader's antenna coil generates a strong, high frequency electromagnetic field, which penetrates the cross-section of the coil area and the area around the coil. Because the wave length of the frequency range used is several times greater than the distance between the reader's antenna and the transponder, the electromagnetic field maybe treated as a simple magnetic alternating field to the distance between transponder and antenna [3]. A small part of the emitted field penetrates the antenna coil of the transponder,

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which is some distance away from the coil of the reader. A voltage u2 is generated in the transponder's antenna coil by inductance.

This voltage is rectified and serves as the power supply for the data-carrying device, microchip. As shown in figure 1, a capacitor C_r is connected in parallel with the reader's antenna's coil, the capacitance of this capacitor being selected such that it works with the coil inductance of the antenna coil to form a parallel resonant circuit with a resonant frequency that corresponds with the transmission frequency of the reader. Very high currents are generated in the antenna coil of the reader by resonance step-up in the parallel resonant circuit, which can be used to generate the required field strengths for the operation of the remote transponder [4].

The antenna coil of the transponder and the capacitor C_l form a resonant circuit tuned to the transmission frequency of the reader. The voltage at the transponder coil reaches a maximum due to resonance step-up in the parallel resonant circuit.

The layout of the two coils can also be interpreted as a transformer, in which there is only a very weak coupling between the two windings. The efficiency of power transfer between the antenna coil of the reader and the transponder is proportional to the operating frequency *f*, the number winding *n*, the area *A* enclosed by the transponder coil, the angle of the two coils relative to each other and the distance between the two coils.

III. FIELD STRENGTH INCONDUCTOR LOOPS

Conductor loops as in figure 2, short cylindrical coil, are used as magnetic antennas to generate the magnetic alternating field in the write/read devices of inductively coupled RFID systems. If the measuring point is moved away from the center of the coil along the coil axis (*z* axis), then the strength of the field H will decrease as the distance *z* is increased. The equation 1 can be used to calculate the path of field strength along the z axis of a conductor loop similar to those employed in the transmitter antennas of inductively coupled RFID systems [3].

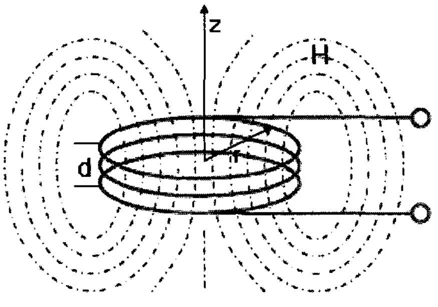


Fig. 2 Magnetic field of short cylinder coils

$$H(z) = \frac{I\ n\ r^2}{2\sqrt{(r^2+z^2)^3}} \tag{1}$$

In equation 1, the parameters as follows: n is the number of windings, r is the radius and z is the distance from the center of coil. Figure 3 shows the result of the magnetic field strength in relation to radius of the coil and distance along the z axis. It shows that the field strength remains constant up to a certain distance and then falls rapidly. In free space, the decay of the field strength is approximately 60dB/decade in the near field of the coil, and flattens out to 20dB/decade in the far field of the electromagnetic wave that generated.

Figure 4 shows the graph of field strength H as the coil radius r is varied. The optimal coil radius for different read ranges is always the maximum point of graph H(r). The relationship between the maximum field strength H and the coil radius r could be found from equation 1. The first derivative H'(r) is driven by differentiating H(r) with respect to r as following:

$$\begin{aligned} H'(r) &= \frac{d}{dr}H(r) \\ &= \frac{2\,I\,n\,r}{\sqrt{(r^2+z^2)^3}} - \frac{3\,I\,n\,r^3}{(r^2+z^2)\sqrt{(r^2+z^2)^3}} \end{aligned} \tag{2}$$

The inflection point, and thus the maximum value of the function H(r), is found from the following zero point of the derivative H'(r). The relationship between the maximum field strength H and the coil radius r could be found as equation 3.

$$r = \sqrt{2}\ z \tag{3}$$

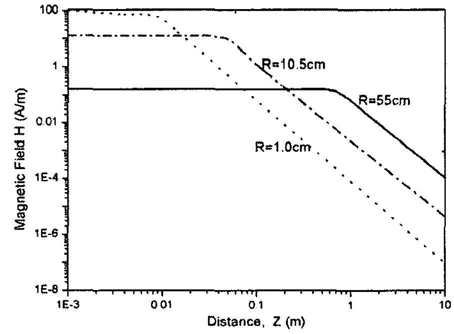


Fig. 3 Magnetic field strength H in the near field of short cylinder coils

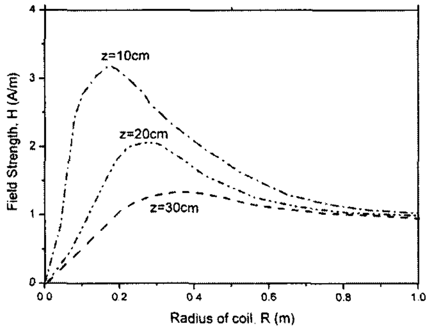


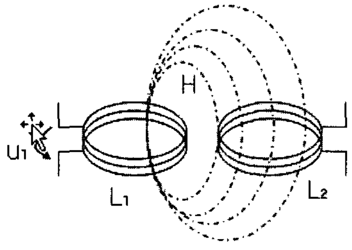
Fig. 4 Field strength H of a transmission antenna given distance z and variable r. (*I=1A, n=1*)

IV. INDUCED VOLTAGE AND RESONANCE

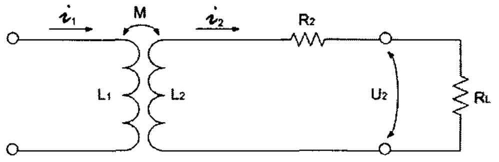
Any change to the magnetic flux generates the electric field strength. This characteristic of the magnetic field is described by Faraday's law. In general form Faraday's law is written as follows:

$$u_i = \oint E_i . ds = -\frac{d\Psi(t)}{dt} \tag{4}$$

Figure 5 shows the equivalent circuit diagram for coupled conductor loops. In an inductively coupled RFID system L_1 would be the transmitter antenna of the reader. L_2 represents the antenna of the transponder, where R_2 is the coil resistance of the transponder antenna. The current consumption of the data memory is symbolized by the load resistor R_L.



(a) Inductive Coupled loops



(b) Equivalent circuit

Fig. 5 Coupled loops and its equivalent circuit

A time varying flux in the conductor loop L_1 induces voltage u_2 in the conductor loop L_2 due to mutual inductance M. The flow of current creates an additional voltage drop across the coil resistance R_2, meaning that the voltage u_2 can be measured at the terminals. Therefore, we can get the equation for load voltage u2 as follows [5]:

$$u_2 = \frac{d\Psi_2}{dt} = M\frac{di_1}{dt} - L_2\frac{di_2}{dt} - i_2 R_2 \tag{5}$$

$$u_2 = j\omega M.i_1 - j\omega L_2.i_2 - i_2 R_2 \tag{6}$$

$$u_2 = \frac{j\omega\, M.i_1}{1 + \dfrac{j\omega\, L_2 + R_2}{R_L}} \tag{7}$$

The voltage u_2 induced in the transponder coil is used to provide the power supply to the microchip. In order to improve the efficiency of the equivalent circuit in Figure 5, an additional capacitor C_2 is connected in parallel with the coil L_2 to form a resonant circuit with a resonant frequency that corresponds with the operating frequency if the RFID system [6, 7].

In practice, C_2 is made up of a parallel capacitor C'_2 and a parasitic capacitance C_p from the real circuit. $C_2=(C'_2+C_p)$. The required capacitance for the parallel capacitor C'_2 is as follows, taking into account the parasitic capacitance C_p [8, 9]:

$$C'_2 = \frac{1}{(2\pi f)^2 L_2} - C_P \tag{8}$$

Figure 6 shows the equivalent of a real transponder. R_2 is the natural resistance of the transponder coil L_2, the current consumption of the microchip is represented by R_L and u_s is induced voltage in coil L_2. The u_p is the voltage at the data carrier load resistor R_L in Figure 6, can be represented as follows [3]:

$$\begin{aligned} u_2 &= \frac{u_S}{1+(j\omega L_2 + R_2)(1/R_L + j\omega C_2)} \\ &= \frac{\omega k\sqrt{L_1 L_2}\, i_1}{\sqrt{(\omega L_2 / R_L + \omega R_2 C_2)^2 + (1-\omega^2 L_2 C_2 + R_2/R_L)^2}} \end{aligned} \tag{9}$$

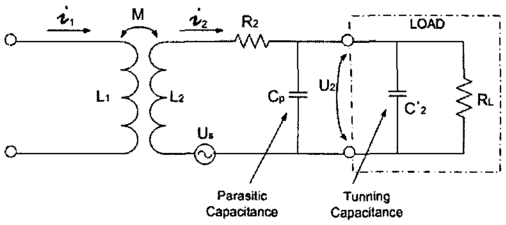


Fig. 6 Equivalent circuit of inductively coupled loops with resonant capacitor.

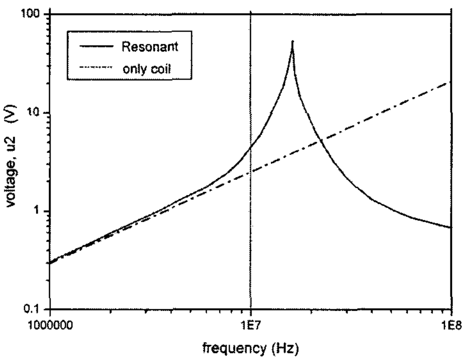


Fig. 7 Resonance characteristics of voltage u_p.

Figure 7 compares voltage u_2 for the circuit with the coil alone shown in Figure 5 and for the circuit with resonance of Figure 6. The graph is almost identical at frequencies below the resonant frequencies of both circuits, but when the resonant is reached, voltage increases by more than a power of ten in the parallel resonant circuit compared to the voltage for coil alone. However, above the resonant frequency voltage u2 falls rapidly in the resonant circuit, even falling below the value for the coil alone.

V. VOLTAGE REGULATION AND RESULTS

In the circuit as figure 6, the induced voltage u_2 in the transponder coil very rapidly reaches high values due to resonance step-up in resonant circuit. If the coupling coefficient k is increase – possibly by reducing the gap between reader and transponder – or the load resistance R_L is increase, then voltage u_2 will reach a level much greater than 100V. Generally the operation of a data carrier requires a constant operating voltage of 3~5 V. The voltage u_2 in the transponder coil is variable according to the coupling coefficient k and the load resistance R_L. In this paper, In order to regulate voltage u_2 independently of the coupling coefficient k or other parameters, and to hold it constant in practice, a voltage-dependent shunt resistor (R_S) regulator is inserted in parallel with the load resistance as shown in Figure 8.

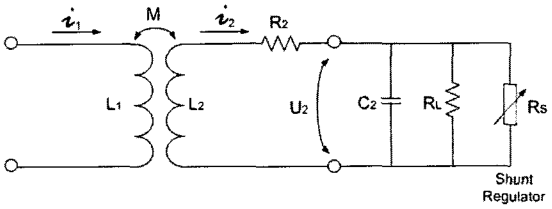


Fig. 8 Voltage regulation in the transponder using a shunt regulator.

As induced voltage increases, the value of the shunt resistor R_S falls, thus reducing the quality of the transponder resonant circuit to such a degree that the voltage u_2 remains constant.

In equation 9, to calculator the value of the shunt resistor for different variables, replace $R_L//R_S$ into the constant R_L. The equation can be solved with respect to R_S. The variable voltage u_2 is replaced by the constant voltage u_{REG} – the desired input voltage of the data carrier – giving the following equation for R_S:

$$R_S = \left| \frac{1}{t_U / (j\omega L_2 + R_2) - j\omega C_2 - 1/R_L} \right| \tag{10}$$

where,

$$t_U = \left(\frac{j\omega k\sqrt{L_1 L_2}\, i_1}{u_{REG}}\right) - 1 \quad \Big| u_{2-unreg} > u_{REG}$$

Figure 9 shows the simulation graph of voltage u_2 when such an ideal shunt regulator is used. Voltage u_2 initially increases in proportion with the coupling coefficient k. When u_2 reaches its desired value, the value of shunt resistor begins to fall in inverse proportion to k, thus maintaining an almost constant value for voltage u_2. This simulation is based on the following parameters: $i_1 = 0.5A$, $L_1 = 1\mu H$, $L_2 = 3.5\mu H$, $R_L = 2k\Omega$, $C_2 = 1/\omega_2 L_2$

Figure 10 shows the variable value of shunt resistor R_S as a function of the coupling coefficient. This can only achieved using a semiconductor circuit. In this paper, we designed the circuit for the shunt resistor R_S as represented in Figure 11. It is configured with the Zener diode, transistor and resistors. The characteristic of the shunt resistor R_S for coupling coefficient is shown in figure 10. The characteristic results of regulator with and without shunt resistor R_S are shown in figure 12.

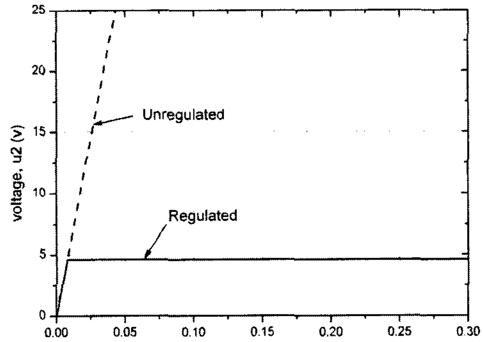


Fig. 9 The graph of voltage u2 with and without shunt regulation in transponder.

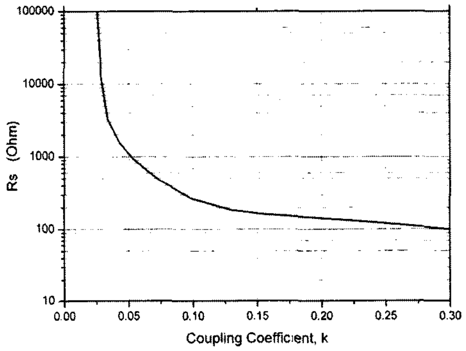


Fig. 10 The shunt resistor R_S as a function of the coupling coefficient k.

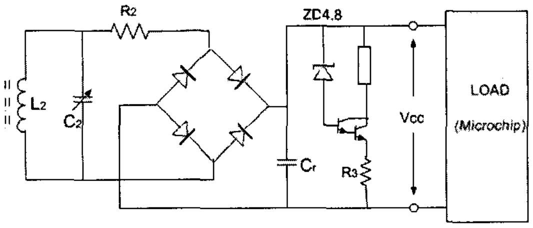


Fig. 11 The designed circuit for a shunt regulator.

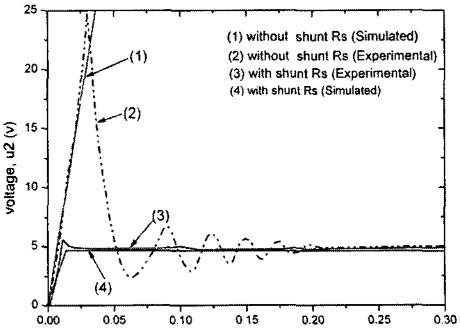


Fig. 12 The characteristics of regulator with and without shunt resistor Rs

VI. CONCLUSIONS

In passive transponders the data carrier has to obtain its power supply from the voltage u_2 induced in the transponder coil. The voltage u_2 is converted into direct current using a low loss bridge rectifier and then smoothed. In practice, the induced voltage u_2 in the transponder coil very rapidly reaches high values due to resonance step-up in resonant circuit. The voltage u_2 in the transponder coil is variable according to the coupling coefficient k and the load resistance R_L. In this paper, In order to regulate voltage u_2 independently of the coupling coefficient k or other parameters, and to hold it constant in practice, we designed and inserted a voltage-dependent shunt resistor (R_S) circuit in parallel with the load resistance R_L. As induced voltage increases, the value of the shunt resistor R_S falls, thus reducing the quality of the transponder resonant circuit to such a degree that the voltage u_2 remains constant as shown in figure 12.

REFERENCES

[1] Steven Shepard, *RFID, Radio Frequency Identification, McGraw-Hill, NY, 2005.*

[2] Youbok Lee, *Antenna circuit Design, AN710, Application Note, micro ID 13.56MHz-RFID system design guide,Microchip,1999.*

[3] K. Finkenzeller, *Fundamentals and Applications in Contactless Smart Cards and Identification, John-Wiley, 2003.*

[4] Berger, Dominik, "*contactless smart card standards and new test methods": Smart card Technologies and applications – second workshop technologies and applications, IEEE Tagungsband, Berlin, 1998.*

[5] Jurianto, Joe and Chia, Michael, *"voltage, efficiency calculation and measurement of low power Rectena rectifying circuit, Sigapore Science Park, Center for wireless Communication.*

[6] Jurianto, Joe and Chia, Michael, *"Zero bias Schottky Diode Model for low power, Moderate current Rectenat, Sigapore Science Park, Center for wireless Communication.*

[7] Muhlberger, Andreas, *"High speed public encryption on contactless smart card", Philips Semiconductors,2001. http://www.semiconductors.philips.com*

[8] Philipp, Stefan, *CISI vs. RISC and a plea for peace. "Enhanced Microcontroller Architecture for Smart Card ICs, Philips Semiconductors,2001.*

[9] Ullerich, S. Mokwa, G. Bogle, *"Micro coils for an advanced system for measuring intraocular pressure, Technical Digest 1st annual International IEEE-EMBS Special Topic Conference on Microelectronics in medicine and biology, France, 2000.*

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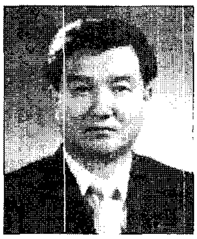

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