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PROTOTYPE IMPLEMENTATION OF AN RF-ID READER SYSTEM

İlker KİRAZ[1] Ali TANGEL[2] Arif DOLMA[3]

[1] Profilo Telra- Dept. of Special Projects Cemala Sahir Sok. No:26-28 Mecidiyekoy, Istanbul/TURKEY
[2,3] Dept. of Electronics and Communication Engineering, Kocaeli University, Izmit/TURKEY

[1] E-mail : ikiraz@profilo-telra.com.tr [2] E-mail : atangel@kou.edu.tr

[3]E-mail : adolma@kou.edu.tr

ABSTRACT

In this study, a prototype RF-ID reader system working at 125 KHz frequency was designed and succesfully implemented. Fundemantals of designing a reader systems has also been addressed. For the Radio Frequency interface, EM4095 (Marine Electronics product) has been choosen. In the software side, the reader MCU was programmed using C Programming Language. It is believed that this study will give a systematic approach to design an RF-ID technology based reader device.

Keywords: *RF-ID Systems, Reader/Transponder, Magnetic coupling.*

1. INTRODUCTION

Radio Frequency Identification (RF-ID) is a technology that gives a chance to transmit identification information of a person or a substance using radio waves. It has various similar properties with contact smart cards except one thing. It is capable of working contactless. Although, RF-ID is a new technology, it has been widely used and finds new application areas due to having many advantages. In recent years, RF-ID technology has been used especially for logistics, trading, and business areas. It has been considered that RF-ID technology will also find new application areas and becomes more popular in the near future. Different applications of RFID technology are addressed in the literature, such as [1,2,3,4]. Some examples of RF-ID systems are compared in Table 1 according to working frequency and corresponding application areas.

Table 1 *– Comparison of RF-ID systems under different working frequencies*

Frequency Range	LF 125 KHz	HF 13.56 MHz	UHF 868 - 915 MHz	Micro-wave 2.45 GHz to 5.8 GHz
Typical maximum reading distance	Shortest 1" -12"	Short 2"-24"	Medium 1'-10'	Long 1'-15'
Transponder feeding	Passive	Passive	Active / Passive	Active / Passive
Data Speed	Slow	Medium	Fast	Fastest
Interaction between metals and water	Good	Medium	Worse	Worst
Typical Applications	Gate cont. and safety	Library, Laundry, gate control	Higways, Bridges toll otom.	Highways Bridges toll otom.

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between transponder and reader [1]. In a typical communication sequence, the reader emits a continuous radio frequency (RF) carrier sine wave [5]. When a transponder (tag) enters the RF field of the reader, the transponder receives energy from the field. After the transponder has received sufficient energy, it modulates the carrier signal according to the data stored on the transponder. This modulated signal is resonated from the transponder to the reader. The reader detects and decodes the modulated signal. Finally, information is transferred to a computer [5].

2. FUNDEMENTALS OF RF-ID SYSTEMS

Most of the RF-ID systems are based on the principles of inductive coupling in electromagnetic theory. Therefore, some of the basics in electromagnetic theory should be recalled to understand better how the energy and data are transferred as wireless. The following sub-sections briefly addresses these basics.

2.1. Magnetic Field Intensity

Charges in motion produce a current, that in turn, creates a magnetic field(B) [6]. The magnetic field intensity (H) is vector quantity of magnetic field. The magnetic field intensity due to the current flow along with a wire for a radial distance (r) from the wire is expressed as [6]:

$$H = \frac{I}{2\pi r}$$

The magnetic field intensity along the normal axis of the coil is given by [7]:

$$H = \frac{I.N.R^2}{2\sqrt{(R^2+x^2)^3}} \quad \text{where;}$$

I : current through the coil
N : number of turns of the coil
R : coil radius
x : perpendicular distance from the center of the coil

If the coil is rectangular shape with the edge lenghts of a and b, the magnetic field intensity is given by [1]:

$$H = \frac{N.I.a.b}{4\pi.\sqrt{\left(\frac{a}{2}\right)^2+\left(\frac{b}{2}\right)^2+x^2}}.\left(\frac{1}{\left(\frac{a}{2}\right)^2+x^2}+\frac{1}{\left(\frac{b}{2}\right)^2+x^2}\right)$$

2.2. Magnetic Flux, Magnetic Field and Mutual Inductance

Passive RF-ID tags receive power for operation through an induced antenna coil voltage. The reader antenna is the primary coil that transfers voltage to the transponder antenna that acts as the secondary coil just like in a typical transformer operation [5]. The induced voltage in the coil is:

$$V = -N\frac{d\Phi}{dt} \quad \text{where;}$$

N= Number of turns in transponder antenna coil
Φ = Total magnetic flux through the surface of transponder antenna coil which can be calculated as:

$$\Phi = \int B.dS \quad \text{where;}$$

B : Magnetic field
S : Surface area

Combination of the above equations for H, V and Φ yields the maximum induced voltage in the transponder antenna coil fort he circle shape antenna coil as [5]:

$$V = -\frac{\mu_o N_1.N_2 a.^2(\pi b^2)di}{2(a^2+r^2)^{3/2}dt} = -M\frac{di}{dt}$$

where M is the mutual inductance between transponder and the reader coils. Also recall that:

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad , \quad 0 \le k \le 1$$

where k is the coupling coefficient, and L_1, L_2 represents the coil inductances.

2.3. Resonance Frequency

When a capacitor and inductor are placed in paralel, such a circuit resonates at a frequency given by [5,6]:

$$f = \frac{1}{2\pi\sqrt{L.C}}$$

Upon some of the basics of the electromagnetic theory summarized above, one can find more detailed information about the optimum antenna designs for RFID transponder/reader implementations from the literature. Some earlier examples from the literature are [5,7,8]. Moreover, ASIC design and simulation examples of an RFID reader and transponder can be reached as well, such as [9,10]. This work, however, presents a prototype implementation of a low frequency range RFID reader system. The following sections summarize the design, implementation steps and measured test results of this study.

3. HARDWARE IMPLEMENTATION OF A 125 KHz RF-ID READER

RF_ID systems working on the frequencies around 125 KHz offer more suitable solutions because the radio waves in this range of the spectrum can be transmitted more easily in the case of passing through or close to metal or water environments. Moreover, the hardware implementation costs are also reduced in this frequency range.

The block diagram of the reader system designed in this study is depicted in Fig. 1. In the reader system, EM4095 IC chip, which is a product of *EM Marine SA*. has been chosen [11,12]. Also, for the transponder unit, EM4102 which is a read-only transponder device has been choosen from the same company [12].

For the central control unit, PIC 18F2320 is preferred from *Microchip*. RS232 standard has been employed for the outside world data communication of the control unit. The software flow-chart that has been written for the system is given in Fig. 2.

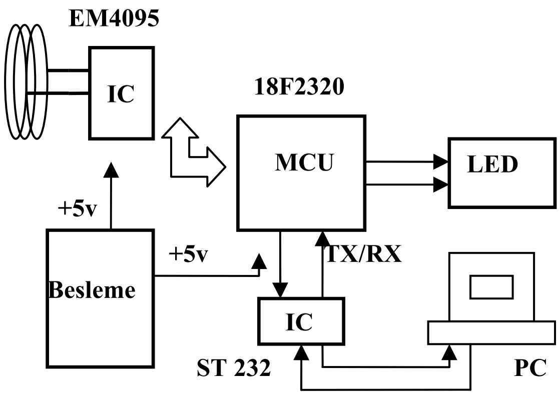

Fig. 1. *Hardware components of the prototype reader*

3.1. Calculation of the Critical Design Parameters

When designing an RF-ID reader, one of the critical design issues is to design the antenna unit. Choosing appropriate L,C values for the specific resonance frequency is main task sor the antenna design process. In our case, before designing the antenna circuit, one must care about the current and voltage critical limits for EM 4095. Otherwise, the induced high voltage or current across the antenna might be harmful for the chip.

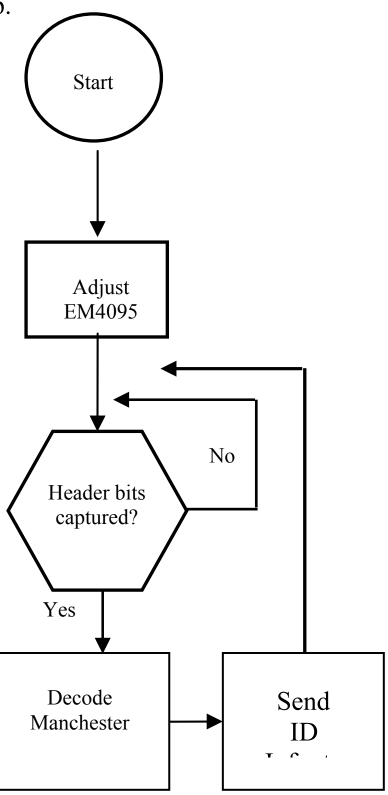

Fig. 2. *Software Flow-chart*

Fig. 3 shows a conceptual circuit of an RF-ID reader system. Here, L_1 is used to produce electromagnetic field needed for the system operation. The serial resistor, R_1 represents the corresponding ohmic resistance, and L_1 represents the inductance of the antenna coil. A serial capacitor, C_1 is used to obtain maximum current passing through the L_1 at the reader working frequency. Resulting circuit is a simple RLC resonance circuit, where $f_{RES} = f_{TX}$. The resonance frequency can be calculated using the Thompson equation as:

$$f_{TX} = f_{RES} = \frac{1}{2\pi\sqrt{L_1.C_1}}$$

Since the working frequency in our case is 125 KHz, the calculation will go through as follows:
In this work, C = 2.2 nF is arbitrarily chosen as a standard capacitor value. In this case:

$$L_1 = \frac{1}{(2\pi f_{RES})^2.C_1} \approx 736\mu H$$ is obtained.

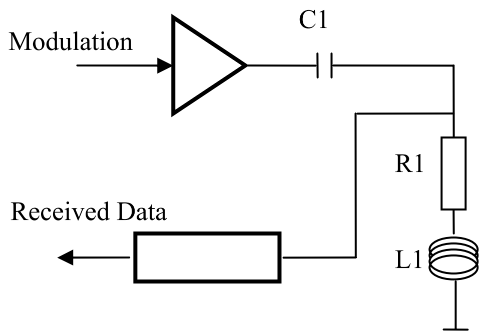

Fig. 3. *Conceptual circuit of an RF-ID Reader*

To obtain this inductance value, An antenna coil using 0.3mm diameter isolated copper wire with 3cm diameter plastic core is formed as was seen in Fig. 7. The resulting inductance value was measured as 714 μH, which was close to the calculated value above. The antenna ohmic resistance is measured as $R_{ANT} \approx 2.5\Omega$.

At this point, the limit current and voltage values of EM4095 was taken into account just in case whether or not a limiter circuit is necessary. From the data sheet of EM4095, I_{ANT}max=300mA is obtained for AC signals [12]. Additionaly, antenna driver resistor values is given as R_{AD} = 3Ω. In this circumstances, the antenna current will be:

$$I_{ANT(PEAK)} = \frac{4}{\pi}\frac{V_{dd} - V_{ss}}{R_{ANT} + 2R_{AD}}$$

$$I_{ANT(PEAK)} = \frac{4}{\pi}.\frac{5}{2{,}5 + 2*3} \approx 749mA.$$

This result has shown that a current limitation resistance, R_{SER}, is inevitable since the maximum current limit for the IC would be exceeded otherwise. By taking into account of the antenna driver limits, , $I_{ANT(PEAK)}$ =150mA is choosen in this implementation process. In this case, the total resistance value to be handled is calculated as:

$$R_{TOT} = \frac{4}{\pi}\frac{V_{dd} - V_{ss}}{I_{ANT(PEAK)}}$$

$$R_{TOT} = \frac{4}{\pi}.\frac{5}{150x10^{-3}} \approx 42\Omega$$

As a result,

$$R_{TOT} = R_{ANT} + R_{SER} + 2R_{AD}$$

$$R_{SER} = R_{TOT} - (R_{ANT} + 2R_{AD})$$

$$R_{SER} = 42 - (2{,}5 + 2x3) \approx 33\Omega$$

is obtained. For $I_{ANT} = 150mA$, the ac peak value of the induced voltage accross the antenna is calculated as:

$$V_{ANT(PEAK)} = I_{ANT(PEAK)} x 2\pi f_0 L_{RES}$$

$$V_{ANT(PEAK)} = 150x10^{-6} x 2\pi 125x10^3 x 714 x10^{-6}$$

$$V_{ANT(PEAK)} \approx 85V$$

3.2. EM4095 Transcevier IC

The EM4095 chip is a CMOS integrated transceiver circuit intended for use in an RFID base station to perform the following functions [12]:

- antenna driving with carrier frequency
- AM modulation of the field for writable transponder
- AM demodulation of the antenna signal modulation induced by the transponder
- communicate with a microprocessor via simple interface.

It is compatible with EM4102 transponder IC device, which was the selected product and the information processing protocol basis for the software written in this study. As an example, Fig. 4 shows the configuration of EM 4095 for read-only transponders [12].

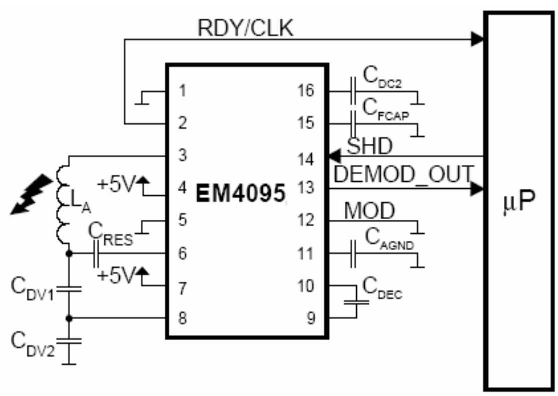

Fig. 4 *Configuration of EM 4095 for read-only transponders.*

3.3. EM4102 Read-Only Transponder IC

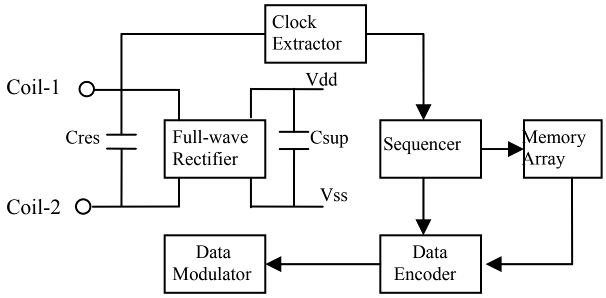

Fig. 5. *EM 4102 Block Diagram [12]*

The block diagram of EM4102 is given in Fig. 5. EM4102 is supplied by means of an electromagnetic field induced on the attached coil The AC voltage is rectified in order to provide a DC internal supply voltage. When the last bit is sent, the chip will continue with the first bit until the power goes off [12]. Full explanation of the data processing protocols and memory array structure can be reached on the company web site [12].

4. EXPERIMENTAL SETUP AND MEASUREMENTS

Fig. 6 and Fig. 7 show the photo of the experimental set up, and closer view of the implemented circuit PCB with antenna coil, respectively.

Figures 8-9-10 show oscilloscope waveforms observed at the critical outputs during the test.

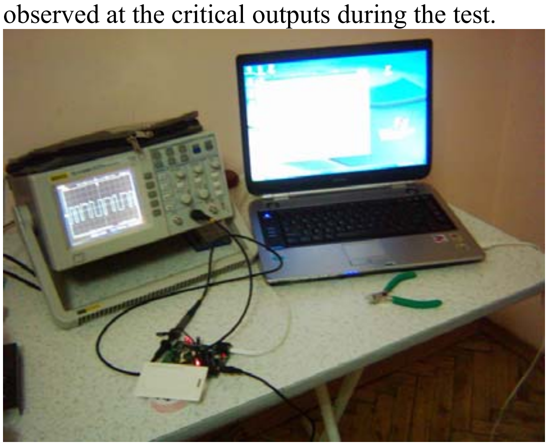

Fig. 6. *Experimental setup*

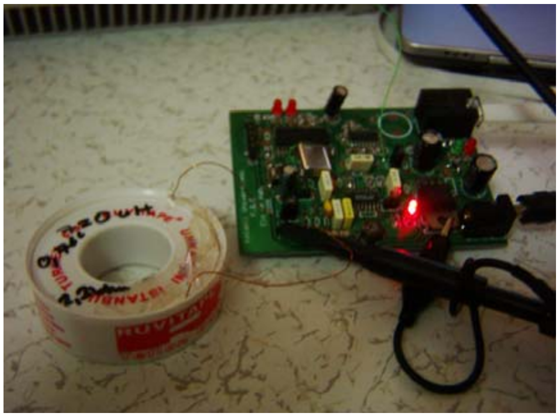

Fig. 7. *The PCB photo of the reader circuit and antenna coil*

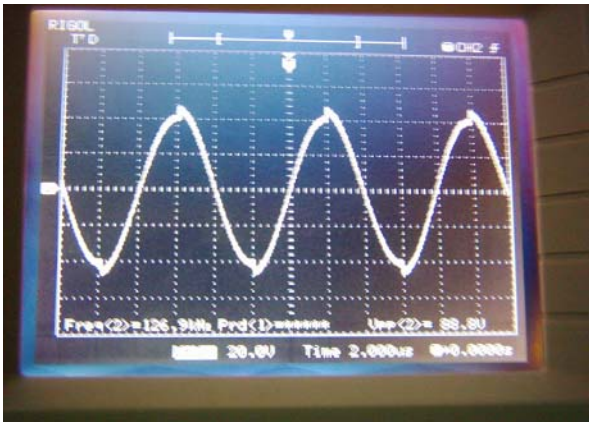

Fig. 8. *125KHz (Vpp=98V) sinusoidal signal obtained accross the reader antenna*

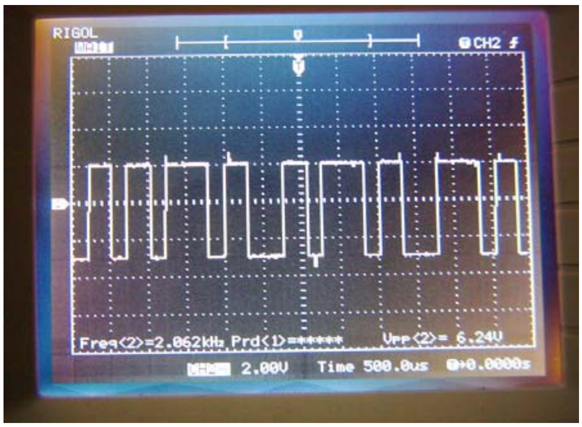

Fig. 9. *Data stream observed at the data pin of the reader*

This data seen on Fig. 9 belongs to the unique ID number of a specific transponder. The received ID numbers are outputted in Manchester Coding format by EM4095 [12]. This data stream is then decoded by the Micro Control Unit (MCU).

Fig. 10 shows the amplitude modulated signal observed across the antenna.

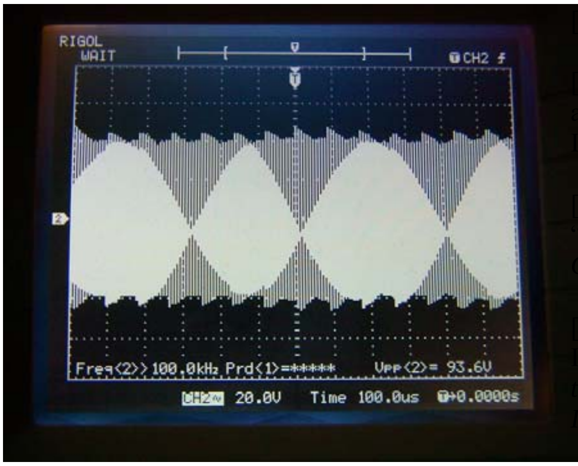

***Fig. 10.** The amplitude-modulated signal observed accross the antenna coil*

5. CONCLUSIONS

In this study, implementation and testing of a prototype 125 KHz RF-ID reader system compatible with a passive type of transponder, was targeted. The circuit has been succesfully implemented. During the design phase, it was figured out that the antenna design process has important role on the overall system performance. Optimum reading distance has been reached by taking into account of the reader/transponder ICs' current and voltage safe limits. For this purpose, an optimum value serial resistance has been calculated and added to the antenna coil circuitry. It was observed that the resulting prototype reader circuit has fairly stable working performance. In addition, it was proved that the selected IC chips, EM4095 and EM 4102, were correct decision for the purpose of this study. Althogh it was designed only for read-only transponder systems, several parts of this study can be expanded or applicable to other applications such as readable/writable transponders or higher frequency RF-ID systems. Finally, It was believed that this work will be serving as a case study example for the junior researchers in this field.

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