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A Experiment of 400MHz Passive RFID Prototype System for Long Range Applications

Ken Takei, and Youhei Shirakawa
Cross Technology Development Center. Hitachi Cable Ltd.
880 Isagozawa-cho Hitachi-shi Ibaraki-ken Japan
takei.ken@hitachi-cable.co.jp

Abstract

For the purpose of feasibility study of long range passive RFID system, a prototype system operating 430MHz was developed. Focusing enlargement of communication distance between reader and tag, the reader of the prototype system was applied with feed forward circuit implanting novel carrier leak cancellation circuit named π/4 hybrid coupled circulator. The experimental evaluation of the prototype system indicates that the critical factors limiting communication range existed on down link. Moreover, Improving poor efficiency of manufactured rectifier by using full wave rectifying circuit is very effective to make the prototype system achieve to enable over ten meter distance of communication between reader and tag..

1. Introduction

RFID has been used in various applications, for example toll gate for automobile, commuting pass system, checking of attendance of exhibition, goods management system in library, etc. These applications have been operated in stand along usages because of the limitation of short range communication capability of a tag and a reader, which are hardware components of RFID system. In recent years, demand of supply chain management (SCM) application by RFID has been occurred. Opposing to stand along application, SCM requires longer range communication between a reader and tags. Potential clients seeking such an application, including a shipping trader, logistics manager, and an electric/electronics manufacture, plans to install wireless SCM system by using the RFID achieving several meters communication. From viewpoint of wireless system design, due to taking count in fading and shadowing margin, we have to realize several tens meter communication range between a reader and a tag for the practical RFID system that enables to work up to several meters. For long range wireless communication, electromagnetic wave in Ultra High Frequency (UHF) band is suitable. United States and European Union have already studying the usage of such frequency band for RFID system [1]. In Asian region, China, Japan, Singapore, and other countries are going to discuss this issue [2]. Undertaking above situations, RFID system using UHF is expected to be available within two or three years from now.

To achieve several tens meter communication of RFID, there are two realistic scenarios related to active and passive tag solutions. The typical conventional performance of communication range for active tag and passive tag are reported that are around up to one hundred meter [3] and below ten meter [4, 7], respectively. If we choose first scenario, it is not necessary to enhanced communication range, but to extended life time of battery up to ten years. However, even though long life time battery was realized, some clients are not willing to appreciate an active tag because they are worry about environment pollution or direct pollution onto their treating goods itself, e.g.,. seafood, poultry, fat stock, etc. The key point of another scenario is how to extend communication range keeping conventional data transfer protocol under Inter National Standard (ISO) 18000. In this paper to reveal the feasibility of second scenario about passive long range tag, we made experimental study of such kind of RFID system.

2. 400MHz passive RFID prototype system

In UHF band lower frequency achieve less propagation loss according to well known Ferris's low as

$$Loss = 10\log\left(\lambda/4R\right)^2 [dB] \qquad (1)$$

,where λ and R are wavelength and distance of propagation, respectively. To get actual data about propagation performances, we select 400MHz for operation frequency of prototype system. Another reason of this selection is easiness to procure RF components especially filters constructing the system because 400MHz is widely used conventional wireless communication systems, especially public communication. The main purpose of experimental feasibility by using prototype system is finding out what decides physical limitation of communication range with conventional RFID technologies, moreover, how to overcome this limitation.

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Focusing above purpose, function of prototype to develop is very simple one that is only ID corresponding from tag to reader.

3. Tag

Circuit structure of the prototype tag is shown in figure 1. The structure consisted of five main circuit blocks, i.e. antenna, switch modulator, rectifier, matching circuit, and microprocessor unit (MPU). Former four analog circuits were realized with discrete devices, on the other hand, we chose MPU all-in-one chip of product by TI (MSP430_family). Function of the prototype system was focused on the discrimination of tag by its individual ID. For this usage, software of embedded program was newly developed [8]. The details of this embedded programs is described in the other published article of reference [9].

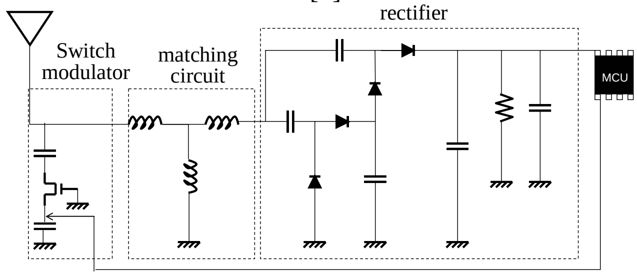


Figure 1 circuit diagram of tag

3.1 Antenna

In many cases SCM system may be operated in not opened environment, e.g., indoor facility, in container, in fat stock breeding area, etc. In such environments, electromagnetic obstacles, i.e. walls, ceiling, floor, and furniture, cause multi reflection of electromagnetic wave. The reflected wave becomes origin of fading phenomena. Wireless system applied CPA is less affected by reflection wave because CPA dose not have sensitivity for the different circularly polarized electromagnetic wave creating in reflection of odd times. Because usual conventional CPA uses half wave resonance phenomena, the size of antenna is about the square of the length of half wave. However serious limitation of tag antenna is its size. To overcome this contradiction, quarter wave length CPA was achieved by using our developing novel design method.

3.2 Switch modulator

The modulation method of prototype system is backscattering modulation, which is one of amplitude modulation (AM). Electromagnetic wave coming from reader is reflected by a tag antenna. When the load impedance of the tag antenna is varied, the reflected power is also varied. Therefore, switching the antenna impedance according to appropriate modulation signal achieves AM signal. The switching circuit in figure made with GaAs FET (SIEMENS_CGY50)., exchanges load impedance of the antenna from 18.4 – j3.0 to 32.3 + j0 ohm. In this case the modulation rate of the AM signal became 38%.

3.3 Matching circuit

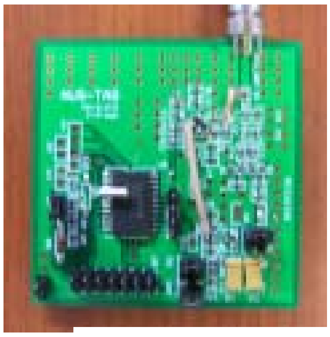
A matching circuit of RFID tag that is adapted backscattering modulation has two important rolls. One is how efficiently transport receiving power from antenna to rectifying circuit. Another is how to realize larger different resistance values of load impedance of the antenna in two cases when the switch of modulator is on and off. Cut and try way achieved T-shape matching circuit consisting of three inductors, which consequently realized the modulation rate of 38%.

3.4 Rectifier

To keep both of enough power and supply voltage for MPU, We chose two stages single wave double voltage rectifying circuit as shown in figure 1. Seeking long range communication, diodes of the rectifying circuit were selected with Schottky barrier diodes. The manufactured rectifier performed the efficiency of 18 %, when incident power from antenna was below to -6dBm.

3.5 Microprocessor unit and surrounding circuit

The microprocessor of developed prototype tag was TI's product of type TI-MSP4301132. The digital parts of this chip consume about 11 μw for data processing bit rate of 4 kHz. This chip includes clock generating circuit except oscillator. The total power consumption of MPU of developed tag was about 20 μw for 4 kbps data transfer. The photograph of manufactured sample is in the following figure.



Specifications
Size: 56 x 56 mm
Frequency: 430 Mhz
η of rectifier: 18 %
power consumption: 43 μW
PCB: double layer FR-4

Figure 2 photo of manufactured sample of tag

4. Reader

One of the serious problems for back scattering modulation is isolation between transmitting power and receiving power. The candidate achieving this isolation is usage of directional coupler. Ideal directional coupler performs 100 % isolation, however, practical one achieve at most 30 dB isolation. Based on calculation by Furiss's law of equation 1, this 30 dB isolation is equal to 3 m distance between a tag and a reader. For long range application, e.g., up to several tens meter, this value of isolation is not sufficient. To overcome the problem of lower isolation, we applied feed forward technology into developed prototype.

4.1 Feed forward circuit for carrier leak cancellation

Figure 3 shows block diagram of feed forward circuit of our reader. We used a circulator as a directional coupler to isolate receiving power reflected a tag from transmitting power of reader. A part of transmitting power is detected by directional coupler, moreover, the phase and the amplitude of this detected power is controlled to cancel practical power leak caused non-perfect isolation performance of circulator. Receiving RF power was down converted by intermediating frequency (IF) of 10 MHz, then sideband signal was extracted with filter. This feed forward circuit includes novel cancellation sub circuit, which consists of two circulators and three π/4 hybrids, for the leak of transmitting power. The power from transmitting circuit is divided into two passes. These divided powers are combined in co-phase at input point of antenna. On the other hand, the leaking powers through non-ideally performing circulators should be combined in anti-phase at receiving circuit, therefore the leaking powers are cancelled each other..

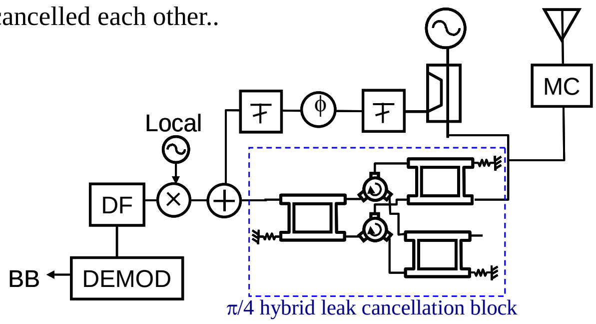


Figure 3 feed forward circuit with π/4 hybrid leak cancellation

4.2 Build-up system for reader of prototype system

We built up the reader with three dimensional passive components, i.e. circulators, π/4 hybrids, filters, attenuators, a directional coupler, and a matching circuit. Some active components of the reader in figure 3 were replaced by appropriate function of conventional measurement equipments, ex., signal generators, a oscilloscope, and a spectrum analyzer. The photograph of developed reader system is shown in figure 4.

This reader system monitors the amplitude of the side band signal at the point just after the mixer in figure 3. To maximize the monitored signal, the phase and the amplitude of canceling transmitting power were manually controlled. Developed feed forward circuit achieved the isolation of 60 dB corresponding to ideal maximum communication range of 100 m under Furiss's law.

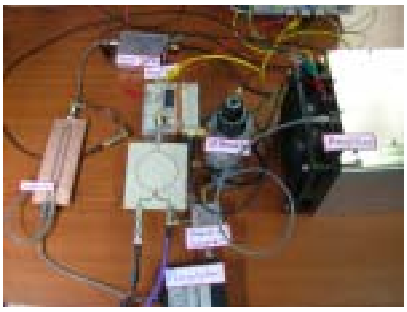


Figure 4 reader system

5. Experimental evaluation for developed prototype system

To evaluate our developing prototype of passive RFID system was done in the discussion room with the sizes of 8 x 14 x 2 m in our Singapore factory. This room had four desks, one round table, and two discussion boards. The function of prototype system is only discrimination of tags by using ID that was initially recorded in each tag. The microprocessor of the tag has ten bit memory. Each tag should be transmit ten digit bit stream corresponding to recorded ID by using backscattering scheme. The transmitting power and frequency of reader were 0.3 mW and 430MHz, respectively. To avoid the collision among the signal transmitting by each tag, the each tag repeated to transmit signals with independently different period. Hence the reader can receive every signal from these tags consuming sufficient long time period.

5.1 Experimental results

We demonstrated the performance of two systems, one has only a tag another has three tags. The results of experiments are shown in the following photograph. These photos include experimental environment and displayed discriminating signal from each tag by reader. The recoded IDs of 2, 4, 8 for each tag were successfully recognized at the distance of 4 m. .

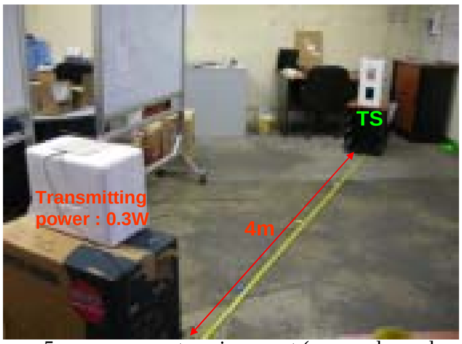


Figure 5a measurement environment (one reader and one tag)

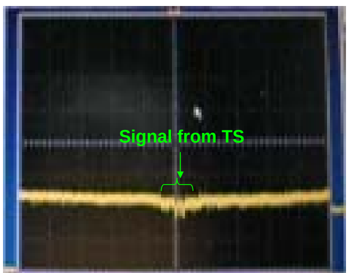


Figure 5b demodulated signal from a tag

Figure 6a measurement environment (one reader and three tags)

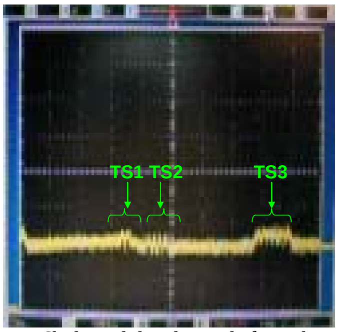


Figure 6b demodulated signals from three tags

6. Discussion about link budget

Link budget of developed prototype system are represented as following equations.

Down Link

$$P_{tag\_proc.} < P_{reader\_Tr} G_{reader\_ant.} L_P(\ell) G_{tag\_ant.} \eta_{rect.}$$

Up Link

$$IS_{reader} < \{G_{reader\_ant.}\}^2 \{L_P(\ell)\}^2 G_{tag\_ant.} Rc_{tag\_ant} M_{tag}$$

,where Lp, Rc,and M are propagation loss, radar cross section, and modulation degree of a tag.

Substituting the given value described in above sections into these equations, and using Furiss's low of equation 1 for Lp, it is apparent that the limitation of communication distance was caused on down link. The formula of up link is still valid for more value of Lp by 4 dB, which is corresponding to the distance of 10 m. For development of the next stage, improving the efficiency of rectifier with full wave rectifying circuit will be firstly required to achieve over 10 m communication between reader and tag.

7. Conclusion

The limitation of communication range of passive RFID system is decided by several factors, i.e. isolation between reader transmitting power and receiving power reflected from tag, an efficiency of rectifying circuit, power consumption of microprocessor with its related circuit, a modulation degree of backscattering modulation of tag, tag. In order to find out critical factors limiting communication range in practical passive RFID system, a prototype system operating at 430 MHz was developed.. The performances of the prototype system were measured by indoor experiment with this system. Experimental results revealed the critical factors degrading communication distance exist in down link. Increasing the efficiency of rectifier is considered hopeful because developed rectifier had the poor performance of 18 %. By using full wave rectifying circuit, its efficiency will become double, therefore, the communication range of developed prototype system is expected to achieve over 10 m. Aiming long range passive RFID of ten meters class, it is necessary to develop novel technologies related antenna, rectifier, switch modulator, and the circuit that increase isolation between transmitting power of reader and receiving power reflecting from tag.

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References

[1] R. Glidden, et al. "Design of Ultra-Low-Cost UHF RFID for Supply Chain Applications", IEEE Communicat. Magazine, pp. 140-151, Aug. 2004

[2] K. Finkenzeller, "RFID Handbook, 2nd Edition", John Wiley & Sons, 2003

[3] S. Lim, K. M K H. Leong, and T. Itoh, "Adaptive power controllable retrodirective array system for wireless sensor server applications", Trans. Microw. Theory tech., Vol 53, no. 12, pp. 3735-3743, Dec. 2005

[4] L. Ukkonen, et al. "Operability of folded microstrip patch-type tag antenna in the UHF RFID bands within 865-928 MHz", IEEE Trans. Antennas and Wireless Propagation Lett., Vol5, pp. 414-417, 2006

[5] J. Mitsugi, and H. Hada, "Experimental study on UHF passive RFID Readability Degradation", Proc. Int. Symp. on Applications and Intemet Workshops (SAINTW'06), 2005

[6] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna design for UHF RFID Tags: a review and a practical application", Trans. Antennas and Propagat., Vol. 53, no. 12, pp. 3870-3876, Dec. 2005

[7] "Hitachi μchip product", 2005, http://www.hitachi-eu.com/mu

[8] K. Takei and T. Ogawa, "Increment-Decrement Algorithm for Compact Circularly Polarized Antenna", in Proc. ICECom, Dubrovnic, 2005, p.p 525-528.

[9] K. Takei, "Auto design tool for multimode antenna using method of moments and genetic algorithm with novel calculation method for matrix equation", in Proc. PIERS, Singapore, 2003, p. 154.

[10] Japanese Patent Application No. 2003-383647.

[11] Y. Tao, Lee Li-Way, in Proc. ISAP, Singapore, 2006.

[12] K. Takei, T. Ogawa, M. Ikegaya, "Compact Algorithm for Making Double Symmetric Inverse Matrix for Planar Antenna Design by Genetic Algorithm and Method of Moment", CJMW, Harbin, 2004, pp. 166-169.

[13] K. Takei and M. Ikegaya "Auto search algorithm for antenna structure by gradient method combined with method of moment", in Proc. INICA 2007, Munich, Germany, Mar. 2007.