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Design for a 400-MHz Passive RFID Prototype System for Long Range Applications

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Abstract

For the purpose of doing a feasibility study of a long range passive radio frequency identification (RFID) system, we designed a prototype system operating at 400 MH. We focused on enlarging the communication distance between the reader and the tag, by using three proposed technologies: a distributed current antenna operating in a balanced circular polarized mode, a full wave rectifier fabricated from the balanced circuit independent from the RFID chip, and a feed forward circuit implanted with a novel carrier leak cancellation circuit called a $\pi/4$ hybrid coupled circulator. With the evaluation results of our new prototype system design implementing these technologies, we predict a service area of more than ten meters is possible for a passive RFID system used in a practical environment.

1. Introduction

Radio frequency identification (RFID) has been used in various applications, for example, in toll gates for motor vehicles, in, commuter pass systems, to check the attendance at exhibitions, and as inventory management systems in libraries, etc. These applications have been operated in stand alone usages because of the limited short range communication capabilities of a tag and a reader, which are hardware components of RFID systems. In recent years, demand for RFID supply chain management (SCM) applications has been increasing. In contrast to stand alone applications, SCM requires longer range communication between a reader and tags. Potential clients seeking such applications, including, shipping traders, logistics managers, and an those involved in electrical/electronics manufacturing, plan to install wireless SCM systems by using the RFID that is capable of achieving communication at distances of several meters. From the viewpoint of wireless system design and the need to take into account fading and shadowing margins, we need to achieve a communication range between a reader and a tag of several tens meters in order to obtain a practical RFID system that enables operation up to several meters. For long range wireless communication, electromagnetic waves in the ultra high frequency (UHF) band is suitable. The United States and the European Union are already studying the use of the UHF band for RFID systems [1]. In the Asian region, China, Japan, Singapore, and other countries are going to discuss this issue [2]. With these considerations in mind RFID systems using UHF are expected to be available within the next two to three years.

To achieve RFID communication that is effective at several tens meters, two realistic scenarios exist that are related to active and passive tag solutions. The typical conventional performance of communication range for active tags and passive tags are reported to be up to one hundred meters [3] and below ten meter [4,5], respectively. If we choose the first scenario, it is not necessary to enhance the communication range, but rather to extend the battery life to up to ten years. However, even though a long battery lifetime was achieved, some clients might not be satisfied with an active tag because they might worry about environmental pollution or direct contamination of the goods they handle, e.g., seafood, poultry, livestock, etc. The key point of the other scenario is how to extend the communication range while maintaining conventional data transfer protocol under International Standardization Organization (ISO) 18000 specifications. To explore the feasibility of the second scenario regarding passive long range tags, we did an experimental study of such a RFID system and we describe the details in this paper.

2. 400 MHz passive RFID prototype system

In the UHF band a lower frequency results in less propagation loss according to the well known Ferris's law as

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

,where λ and R are wavelength and propagation distance, respectively. Previous reports have been published that describe the experimental data of short range passive RFID systems [4-6]. Unfortunately these data are useless for the design of practical applications, whose service areas range up to 10 m. To obtain actual data on propagation performances, we selected 400 MHz as the operation frequency of our prototype system. Because 400 MHz is common in

conventional wireless communication systems, especially public communication, RF components, particularly filters, are easy to procure. In evaluating feasibility by using the prototype system, our main purpose was to find out what determines the physical limitations of the communication range with conventional RFID technologies, and moreover, how to overcome these limitations. With this purpose in mind, we developed a prototype with a very simple function in which a corresponding ID from a tag to a reader. Under ISO 18000 the modulation method of RFID systems is a backscattering method, which is a kind of amplitude modulation. (AM). AM radio waves have three frequencies, of which one is a carrier and the others are modulated signals Information is given by demodulating these signals. The backscattering signal received at the reader is interfered by the transmitting wave from the reader itself. The frequency of the transmitting power is the same as that of the carrier in the receiving wave. Because the longer distance from the tag to the reader causes a large difference in the power between the transmitting wave and the receiving wave, it is very important for the reader to extract this transmitting wave from the receiving .wave. To achieve an efficient substitution for this process, the reader in the developed prototype system was adapted from feed forward technologies.

3. Circular polarized antenna (CPA) for smaller fading margin

In many cases, an SCM system might be operated in an environment that is not "open", e.g., an indoor facility, in container, in livestock breeding area, etc. In such environments, electromagnetic obstacles, e.g., walls, ceilings, floors, and furniture, cause multi-reflection of the electromagnetic waves. These reflected waves are the origin of fading phenomena. In designing the link budget, propagation loss must be taken into account for a worst case scenario, such as when a radio wave at a reader or a tag stays at a lower fading depth. Therefore, the smaller fading amplitude allows us to considerer the lower propagation loss. A wireless system using a CPA is less affected by reflected waves because the CPA is not sensitive enough to detect the different circularly polarized electromagnetic waves created in reflection of odd times.

3.1 Design for single-layer distributed current planar CPA

In almost of all cases, a tag must be tipped on objects. Therefore, an antenna for the tag must have a thin planar shape. One promising candidates for such an antenna is a distributed current antenna [7].A planar CPA can be built by following the using usual design procedures for a distributed current antenna, and by incorporating the following

conditions for two vector induced currents, which are perpendicular to each other and are defined on the small square segments forming the antenna.

$$\frac{1}{\Delta} < \left|\sum_i \vec{I}_i^{\,x}\right| \Big/ \left|\sum_i \vec{I}_i^{\,y}\right| < \Delta,$$

$$\left|\angle \sum_i \vec{I}_i^{\,x} - \angle \sum_i \vec{I}_i^{\,y}\right| < 90° \pm \delta \qquad (2)$$

,where Δ and δ represent the distortion of axial ratio and an error of perpendicular phase difference, respectively. The photograph and data of a manufactured sample are shown in figure 1.

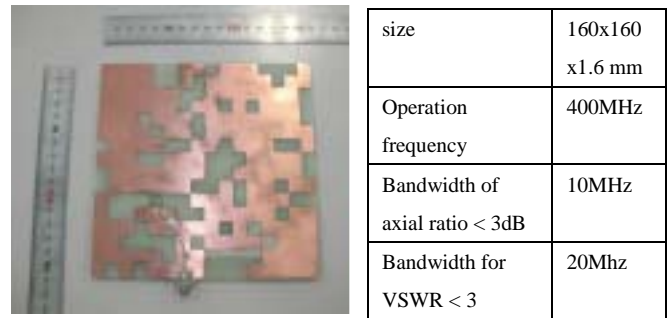| size	160x160 x1.6 mm
Operation frequency	400MHz
Bandwidth of axial ratio < 3dB	10MHz
Bandwidth for VSWR < 3	20Mhz

Figure 1 distributed current CPA

3.2 Experimental evaluation of fading margin for indoor use

Using a sample CPA and a dipole antenna, we measured propagation loss in a vacant factory. This factory had no fixtures or furniture and consisted of a flat concrete floor, wood walls, and a tin roof. A 400 MHz continuous wave was transmitted and received by both of the dipole and CPA. We varied the distance between the transmitting and receiving antennas, and measured the receiving power from a constant signal generator output. The results of this experiment are plotted in figure 2.
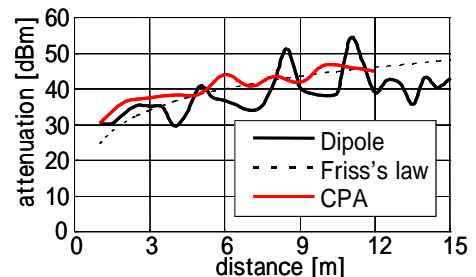

Figure 2 propagation attenuation

Due to suppression of the odd time reflection, the CPA made it possible to reduce the irregular intensity drop of the propagation waves, in contrast to the case of the dipole. For the practical design of the link budge, the results in figure 2 suggest that we should take in to account a fading margin of about in using a CPA. If using a dipole antenna, a margin up to 10 dB may be required.

4. Efficient rectifying circuit

In passive RFID systems, electric power is supplied to a tag through power transmitted from a reader. This is done in order to transfer this power into available power that will activate an RFID chip consisting of analog and digital circuit. Since farther propagation causes less receiving power, the efficiency of the rectifying circuit is very important for long range communication between a tag and a reader.

4.1 Choice of diodes

Rectifying is done by a diode. However, because a practical diode has a threshold voltage, the voltage applied to the diode must exceed the threshold voltage. The applied voltage of diode is determined by the load impedance of the RF circuit of the chip and the resistance value of the diode. Usually RF circuits are usually designed with nominal impedance, i.e., 50 or 75 ohms. If the lower resistance value cannot be reduced to a negligible value compared to this nominal impedance, the receiving power will not be transferred into the RF circuit. For our prototype we chose a Schottky barrier diode having a low threshold voltage and lower resistance in the region where the applied voltage exceeds the threshold voltage.

4.2 Interface design between antenna and balanced rectifier

Rectifier circuits can be categorized into two types that are half wave rectifiers and full-wave ones. Almost of all conventional on-chip rectifiers are half-wave rectifiers because they can be fabricated by using unbalanced circuits on monolithic LSIs. Full-wave rectifies are more efficient n than half-wave rectifiers because they convert RF alternating current into direct current (DC) during the full cycle of the alternating current rather than during half the cycle. However, full-wave rectifiers can not be made using unbalanced circuits they required balanced circuits. Because we are aiming for high rectifying efficiency, we chose a full-wave rectifier. Our method of antenna design in the previous section can be used to design a balanced CPA, hence, no additional interface circuit is required between the antenna and the rectifier. To avoid an increase in the total threshold voltage of the diode, we connected the full-wave rectifier to the RFID chip with an RF transformer and a balun circuit instead of using a diode bridge. The manufactured sample of the two stage full wave rectifier consisting of discrete parts, i.e., a diode, capacitor, resistor, and transformer, achieved a level of efficiency of 38%. The number of stages was chosen in order to apply enough DC voltage to the microprocessor and oscillator in the RFID chip.

5. Carrier leak suppression for back scattering modulation

One of the key issues in backscattering modulation is isolating the transmitting power from the receiving power. The way to achieve this is to use a directional coupler. An ideal directional coupler would perform 100% isolation, however, practical one achieve at the most 30-dB isolation. Based on calculations using Furiss's law of equation 1, this 30- dB isolation is equal to the 3-m distance between a tag and a reader. For long range applications, e.g., up to several tens of meters, this value of isolation is not sufficient. To overcome the problem of lower isolation, we applied feed forward technology to the developed prototype.

5.1 Feed forward technique for carrier leak cancellation

Figure 3 depicts a block diagram of the feed forward circuit used in our reader. We used a circulator as a directional coupler to isolate the receiving power that reflected a tag from the transmitting power of the reader. A leakage of transmitting power was detected by the directional coupler. Moreover, the phase and the amplitude of this detected power were controlled in order to cancel the power leak caused by the circulator's imperfect isolation performance of circulator. Receiving RF power was down converted to an intermediate frequency (IF) of 200 kHz, then a sideband signal was extracted with a filter. The amplitude of this side band signal is continuously monitored. To maximize the monitored signal, the phase and the amplitude of the canceled transmitting power leak was automatically controlled. The developed feed forward section achieved the isolation of 50 dB corresponding to the ideal maximum communication range of 30 m under Furiss's law.
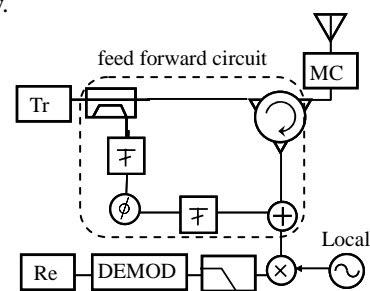

Figure 3 feed forward circuit for carrier cancellation

5.2 π/4 hybrid coupled circulators for higher isolation

Designing the link budget requires taking into account some unpredictable margin-related factors that deteriorate the performance of the transmission path. Two of these factors are fading margin and shadowing margin, which are included in conventional link budget design. If a service range of tens meters is demanded, the communication distance capability should ideally be more than ten times that due to the existence of fading margin and shadowing margins., In other words, we must consider a shadowing margin and fading margin of 10 dB. For a 10 m service area, the required ideal communication

range would be equal to 100 m, which is achieved by 60 dB isolation. For the purpose of extending the isolation value over 60 dB, we proposed the π/4 hybrid coupled circulation circuit shown in figure4.
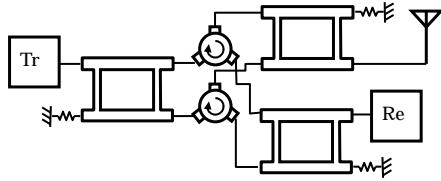

Figure 4 π/4 hybrid coupled circulation circuit

The circuit consists of two circulators and three π/4 hybrids. The power from the transmitting circuit is divided into two paths. These divided powers are combined in co-phase at the input point of the antenna. On the contrary, the power that leaks through the non-ideally performing circulators should be combined in anti-phase at the receiving circuit, therefore, the leaking power cancels itself out. This cancellation ability strongly depends on the bandwidth of the π/4 hybrids. A sample circuit we manufactured achieved the isolation of 70 dB over the bandwidth ratio of 5 %. This bandwidth is wide enough for conventional RFID systems operated under ISO 18000.

6. Link budget for prototype system

To summarize the design for the developed prototype of an RFID system, we show the link budget as follows,

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 the propagation loss, radar cross section, and degree of amplitude modulation made by a tag. From these budgets we can easily determine the following,

1) the enhancement of the antenna gain is effective on both the uplink and downlink,
2) increasing the rectifier efficiency expands the downlink communication,
3) better isolation between transmitting power and receiving power results in a larger uplink communication range

In our continuing efforts to develop a long range passive RFID system, the next stage of development will focus on working within the limitations of transmitting power from the reader to enhance the directional gain of the reader antenna, decrease the on-resistance value of the diode, and improve isolation by using digital filter technology

7. Conclusion

The communication range limitation of passive RFID systems is determined by the degree of isolation between transmitting power of the reader and the receiving power reflected from a tag, as well as on the power consumption of the microprocessor and its related circuits, i.e., clock oscillator, buffer, etc. Conventional RFID technologies achieve a wireless service range of less than a few meters because of unpredictable increases in propagation attenuation caused by fading and shadowing. Adapting a circular polarized antenna is very effective for reducing inevitable design margins from fading. A full-wave rectifying circuit makes it possible to increase the power to supply to the signal processing circuit of the tag. In other words, it enables us to extend the limits of the communication distance from the reader to the tag. Since a full-wave rectifying circuit is unbalanced, the interface between the antenna and the rectifier must be in a balanced mode. The proposed distributed current antenna is very effective for achieving a balanced CPA Feed forward technology is attractive for increasing the isolation required at the reader. Based on our experimental study, we estimate that the feed forward circuit can achieve isolation of about 50 dB. This isolation level corresponds to an ideal communication distance of 30 m, therefore, the practical allowable service area would be up to 3 m. Aiming toward long range passive RFID of the ten meter class, we proposed a novel circuit that make it possible to increase this isolation level. The proposed circuit consisted of two circulators and three π/4 hybrids. We implemented this circuit in a feed forward circuit, and successfully increased the isolation value by 20dB, a level estimated to achieve a service area of more than ten meters in a practical passive RFID system..

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References

[1] R. Glidden, et al. "Design of Ultra-Low-Cost UHF RFID for Supply Chain Applications", IEEE Communication 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] "Hitachi μchip product", 2005, http://www.hitachi-eu.com/mu

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

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

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