A Performance Enhanced UHF RFID System with Modified *I/Q* Diversity Receiver

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ABSTRACT

In this paper, we propose a modified *I/Q* diversity scheme receiver of UHF RFID reader system. The modified *I/Q* diversity receiver is more robust than the conventional homodyne receiver in the wireless noisy, fading channel and phase noise environments by making use of additional axes. In particular, it is shown that the closer the phase difference $\theta(t)$ between the reader and the tag to π/4, the larger performance improvement we can get. The performance of the proposed receiver is verified by equations and is demonstrated by the computer simulation for various difference $\theta(t)$ cases.

Key Words : RFID, Diversity, Receiver, Modified I/Q

Ⅰ. Introduction

UHF radio frequency identification (RFID) system consists of two components; passive RFID tags and a RFID reader. A RFID reader can detect tags within the range of 5~10 meters to getthe unique identification (UID) number contained in the internal memory of tags.

When a reader receives the response of the tags in identification process, there can be the phase difference between received sub-carrier signal and local oscillator (LO) signal. This phase difference mainly comes from 3 factors. The first is the distance between a reader and a tag which can be changed seriously when a reader or a tag is moving. The second is the multi-path fading which can be occur in obstacle indoor environment. The third comes from the phase noise of local oscillator.

The phase difference of LO and received sub-carrier signal makes received baseband signal weak in some case which make reading performance degraded. Therefore for overcoming this phenomenon, Li-cheng Zai and Treiu C. Chieu present *I/Q* diversity receiver scheme which use an additional phase mixer to generate different phase baseband signal[1]. This method maintains the tag response signal strength enough to decode in the reader. Therefore most of RFID readers in the market adopt this scheme.

But the signal strength can be still small in some phase environment. It can be the degradation factor to obtain correct received data and also make identification range decreased. Therefore we propose modified *I/Q* diversity scheme which add up different diversity using additional mixer. This scheme improves received signal quality which is neglected in conventional *I/Q* diversity scheme.

In section 2, we explain the conventional *I/Q* diversity scheme. In section 3, we present a new method; modified *I/Q* diversity scheme for demodulating tag response is described. We proved our algorithm outperforms the conventional one with theoretical equations in this section. In section 4, there is a description about the simulation environmentsand the RFID system construction parameters. After that, the simulation results are presented. We make a conclusion in section 5.

※ 본 연구는 대학 IT 연구센터 육성지원사업의 연구결과로써 HY-SDR연구센터의 연구비 지원으로 수행되었음.
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논문번호 : KICS2007-12-547, 접수일자 : 2007년 12월 7일, 최종논문접수일자 : 2008년 6월 11일

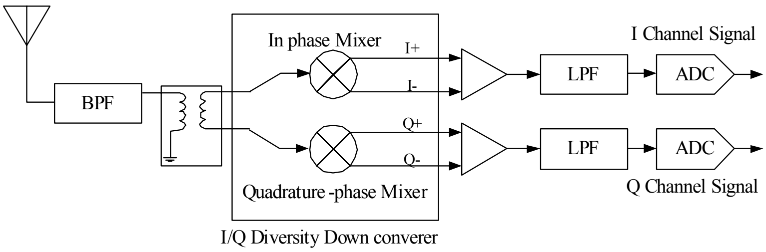

Fig. 1. Conventional homodyne receiver structure

Ⅱ. Conventional homodyne receiver scheme

The conventional homodyne receiver structure of the RFID reader is shown in Fig. 1. During the down conversion process, the backscattered tag response is demodulated by using a mixer's inbuilt amplitude demodulator and then generated into *I*/*Q* channel baseband signals. This receiver is mainly composed of an in-phase mixer and a quadrature-phase mixer which have a phase difference of $\pi/2$[2]. Therefore the each signal paths can be modeled as

$$S_I = s(t)\cos(\theta(t)) \quad (1)$$
$$S_Q = s(t)\cos(\theta(t))$$

where $\theta(t)$ denotes phase difference between tag and reader. S_I, $S_Q$denotes signal power of *I*, *Q* channels. *s(t)* denotes transmitted signal.

By the equation (1), the output of *I* mixer is in proportion to $\cos(\theta(t))$ while the output of *Q* mixer is in proportion to $\sin(\theta(t))$. Because the two channels are in proportion to $\cos(\theta(t))$ or $\sin(\theta(t))$ separately, when the magnitude of the output signal in *I*channel is 0, then the magnitude of the output in *Q* channel will reach maximum and vice versa. In the receiver, the *I*/*Q* mismatch will cause the signal constellation such as the QPSK. In this condition, AWGN will be added in equation (1). Then if we use conventional receiver scheme, $\theta = \pi/4$ is the most unfavorable phase from the viewpoint of signal power. Even though $\theta = \pi/6$, our simulation shows we need about 1.2 dB more signal power at the 10-3 BER compared with the case $\theta = 0$ in the AWGN wireless channel.

Ⅲ. Modified *I*/*Q* diversity scheme

In Fig. 2 and 3, the modified *I*/*Q* diversity scheme applied on the receiver and its signal constellation diagram are shown. According to signal space of Fig. 3, the demodulated tag response in one axis (*I* or *Q*) gets stronger signal than that in other space. And, as we already mentioned, $\theta = \pi/4$ is the most unfavorable phase from the viewpoint of signal power. So we proposed the modified *I*/*Q* diversity method. In an environment where the phase changes variously, if we add $\pi/4$-axes

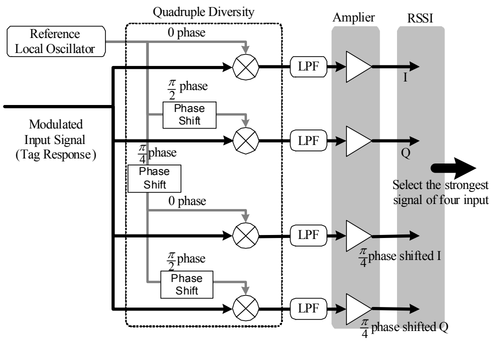

Fig. 2. Modified *I*/*Q* diversity scheme

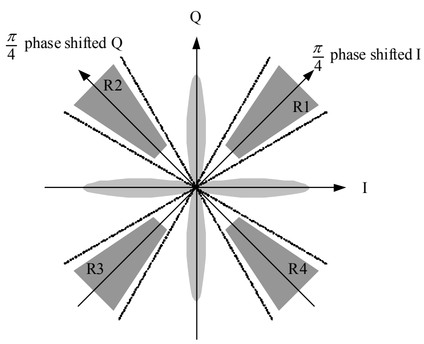

Fig. 3. Signal space of modified *I*/*Q* diversity

to the conventional receiver, the performance of the receiver could be improved.

In order to detect signals more clearly which are distributed near the $\pi/4$ axis in the signal space in Fig. 3, we add a $\pi/4$-phase shifter to the reference LO signal as shown in the structure of Fig. 2. Therefore we add one more mixer using $\pi/4$-phase shifted LO signal and down-convert the same received tag response signal with the mixer. Finally, there are four signals (I, Q, $\pi/4$-phase shifted I, $\pi/4$-phase shifted Q) available to be demodulated at the end of the amplifier. By using the received signal strength indicator (RSSI) based on tag response signal, we detect the strongest signal channel among four outputs and perform the next digital signal processing operations.

Comparing with the conventional receiver structure[2], our scheme is not complex because we just need one more demodulator and a phase shifter. Since the number of axis is increased to 4, the signal-to-axis minimum distance is much closer comparing with that in the 2 axes case. Therefore, if the received signal is located in the region such as R1, R2, R3 or R4 in Fig. 3, we can obtain larger signals comparing with those in the 2 axes case.

A signal whose phase is θ is shown in Fig. 4. In this case the power obtained in I axis and $\pi/4$ -phase shifted I axis, S_I and $S_{I'}$, are

$$S_I = A\cos\theta \qquad (2)$$
$$S_{I'} = A\cos\left(\frac{\Pi}{4} - \theta\right)$$

We compare S_I and $S_{I'}$ value in Fig. 4 given

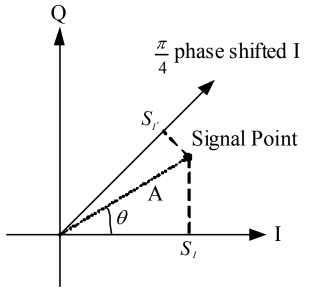

Fig. 4. Comparison of received tag response signal power

by equation (2). If θ is larger than $\pi/8$, then $S_{I'}$ is getting larger than S_I. When θ is $\pi/4$, then S_I = 0.7071A and $S_{I'}$ = 1.0A. So our proposed system achieves 3 dB gains over the previous one. The result is verified further by measuring the BER with various phase θ in the simulation.

For verifying the performance of proposed modified I/Q diversity scheme, we calculate error probability P_e and compare BER of the conventional and the proposed scheme. In assumption, a tag and a reader are located on fixed position. A tag sends response signals to the reader and which are influenced by AWGN noise. The phase difference between the LO signal and received sub-carrier is $\pi/4$ which is the worst performance point in conventional scheme. The encoding type of received signal is FM0 and the decoder use non-coherent decoding method. In decoding process, each level of the signal is decided low or high and consequent two signals are combined to one data. The received signal constellation is illustrated in Fig. 5.

In Fig. 5, the A indicates the strength of RF signal. The points s_1 and s_2 indicate the position where reader can receive the signal in condition of noise free. Then error probability of the system can be described as

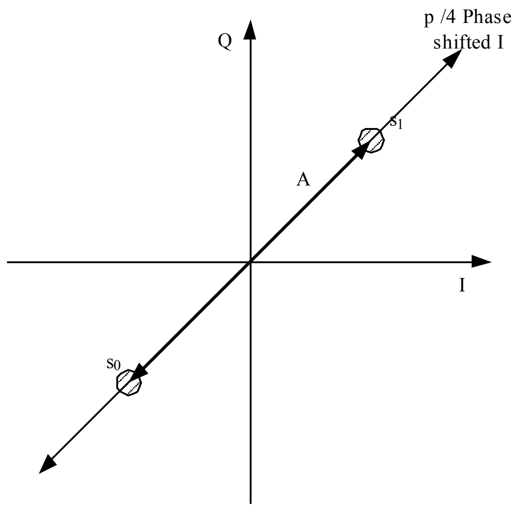

Fig. 5. Received signal constellation

$$P_B = Q\left(\sqrt{\frac{E_d}{2N_0}}\right) \quad (3)$$

, where E_d of *I/Q* diversity and modified *I/Q* diversity can be obtained from

$$(E_d)_{IQ} = 2A^2T \quad (4)$$
$$(E_d)_{mIQ} = 4A^2T$$

, where T indicates the symbol period. Therefore, by using equation (3),(4) we can get

$$(P_B)_{IQ} = Q\left(\sqrt{\frac{A^2T}{N_0}}\right) \quad (5)$$
$$(P_B)_{mIQ} = Q\left(\sqrt{\frac{2A^2T}{N_0}}\right)$$

In RFID system standard, the encoding method of the tag is FM0code. In the FM0 coding, we can get the correct data only when each two sequential signals are correct. Therefore we can calculate the BER of *I/Q* diversity and modified *I/Q* diversity schemes by

$$BER_{IQ} = 1 - Q\left(-\sqrt{\frac{A^2T}{N_0}}\right)^2 \quad (6)$$
$$BER_{mIQ} = 1 - Q\left(-\sqrt{\frac{2A^2T}{N_0}}\right)^2$$

The E_b of FM0 encoded signal can be obtained from

$$E_b = 2A^2T \quad (7)$$

The symbol time for calculating the bit energy is doubled. As a result we can get equation (8) by using equation (6) and (7).

$$BER_{IQ} = 1 - Q\left(-\sqrt{\frac{E_b}{2N_0}}\right) \quad (8)$$
$$BER_{mIQ} = 1 - Q\left(-\sqrt{\frac{E_b}{N_0}}\right)$$

And we can get the result as shown in the Fig. 6.

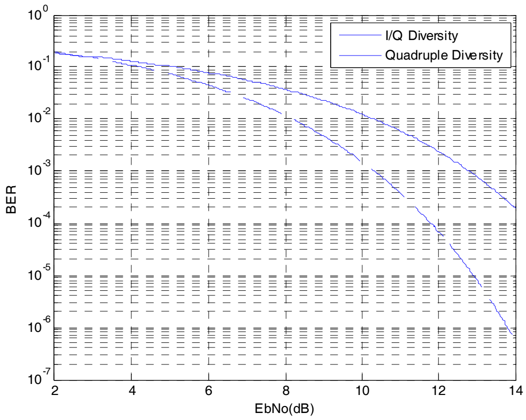

Fig. 6. Theoretical BER performance b/w conventional & proposed system

In the Fig. 6, the proposed modified *I/Q* diversity scheme outperforms the conventional *I/Q* diversity scheme with 3 dB gain at 10^{-3} BER.

Ⅳ. Simulation

By using the theoretical calculation, we simulated the modified *I/Q* diversity scheme in three cases. In the first case, we simulated our modified *I/Q* diversity and conventional diversity scheme in wireless AWGN environment with phase $\theta = 0$. In the second case, phase θ is $\pi/6$. In the third case, phase θ is $\pi/4$. In Fig. 7, the simulation environment for the RFID system is shown. It can be divided into two parts, a reader receiver and a tag. We will not consider the forward link because the signal power of the forward link is about 30dBm[3].

In the tag, FM0 code is used as a data encoding format[4][5]. In the return link, the tag response signal is generated by the amplitude shift keying (ASK) modulation method[6][7] defined in EPC class1 Gen 2[8] and ISO standards. In the wireless channel, we added AWGN with a tag response and we modeled the phase shift caused by the reflection and the distance between the tag

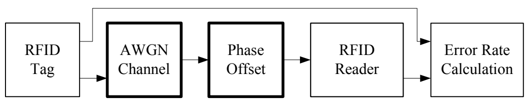

Fig. 7. Simulation environments for the RFID reader system

and reader as phase θ. In the receiver of the reader, we modeled conventional receiver structure and modified *I/Q* diversity receiver structure individually. Finally, the recovered signals are compared to the original data to get the BER result. The whole simulation process is designed by using MATLAB SIMULINK.

The BER performance can be seen by comparing the down-converted signals in the modified *I/Q* diversity and the conventional diversity. In Fig. 8, the simulation result in wireless AWGN environment with phase $\theta = 0$ is shown. When $\theta = 0$, our recommended scheme shows the same performance with the conventional diversity. But,

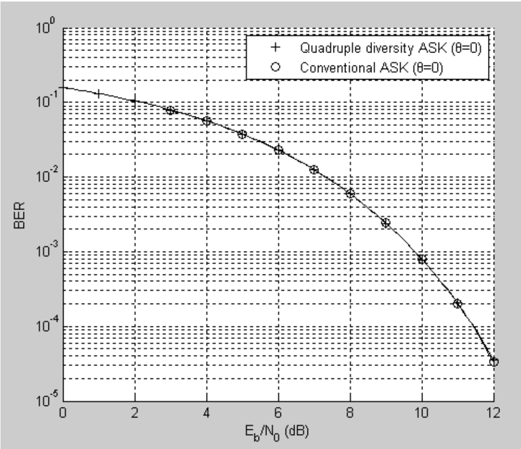

Fig. 8. The BER performance in an AWGN channel with $\theta = 0$

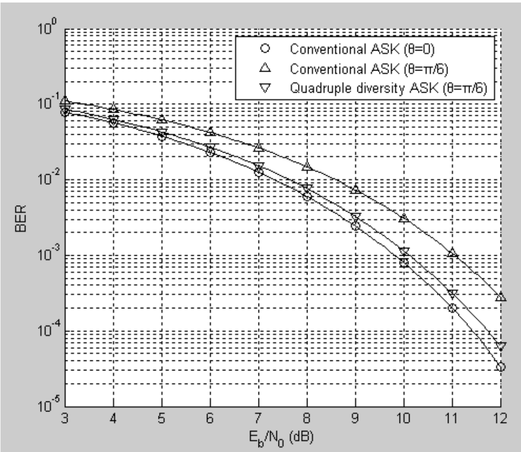

Fig. 9. BER performance in AWGN channel with $\theta = \pi/6$

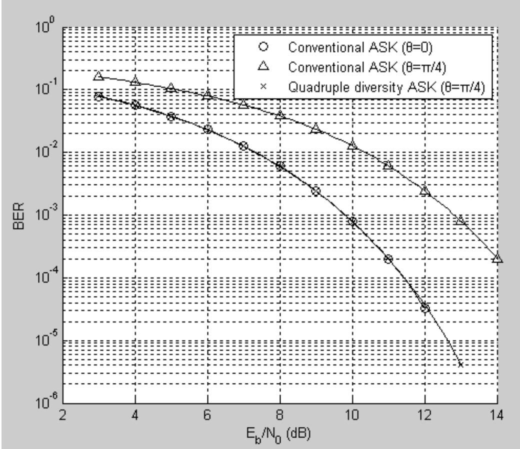

Fig. 10. BER performance in AWGN channel with $\theta = \pi/4$ (Same with theoretical curve)

when phase θ is larger than $\pi/8$, our scheme shows better performance than the conventional one. Our simulation shows when phase $\theta = \pi/6$, our scheme shows about 1 dB gain at the 10^{-3} BER in Fig. 9. When phase θ is $\pi/4$, our scheme achieves more significant performance improvement than the conventional one. In Fig. 10, the performance difference is about 3 dB gain at the 10^{-3} BER. This is the same result comparing to theoretical verification and we find the BER curve in Fig. 6 is same as the BER curve in Fig. 10.

V. Conclusion

In this paper, we have proposed a modified *I/Q* diversity scheme to improve the BER performance in the UHF RFID reader receiver in wireless AWGN environments. We modeled environments which include the effect of multi-path, reflection and distance as phase θ. Our recommended scheme showed same performance with conventional one when phase $\theta = 0$. But when the phase is considered in the wireless AWGN channel, our system shows significant performance improvement comparing with the conventional one. When we consider phase θ is $\pi/6$, our simulation shows about 1 dB performance gain at 10^{-3} BER. The proposed method in this paper may increase the complexity and the cost when makingthe hardware. However, it is still a feasible method under the requirement of high quality, reliability and robustness to a noise, multi-path fading and phase noise. As our main focus was on the reader's receiver performance, more discussions will be needed for more specified environments, such as the indoor and industrial wireless channel, which will be settled in further studies.

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