Design and Performance Analysis of Emulator for Standard Conformance Test of Active RFID

Taeseung Song, Wangsang Lee, Taeyeon Kim, and Joon Lyou

An active radio frequency identification (RFID) system has the advantages of a long identification distance and a good identification rate, overcoming passive RFID drawbacks. Therefore, interest in the development of active RFID systems has been gradually increasing in areas of harbor logistics and national defense. However, some identification failures between active RFID systems developed under the same standards have been reported, presumably due to a lack of development of accurate evaluation methods and test equipment. We present a realization of the hardware and software of an emulator to evaluate the standard conformance of an active RFID system in a fully anechoic chamber. The performance levels of the designed emulator are analyzed using Matlab/Simulink simulations, and the applicability of the emulator is verified by evaluating the standard conformance of a real active RFID tag. Finally, we propose a new evaluation method by incorporating a self-running test mode environment into the RFID tags to reduce testing time and increase testing accuracy. The application of the suggested method to actual tags improves measurement uncertainty by 0.56 dB over that obtained using existing methods.

Keywords: Active RFID, emulator, conformance test, self-running test mode, measurement uncertainty, reader, tag.

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I. Introduction

1. Radio Frequency Identification

Radio frequency identification (RFID) uses a smart tag capable of transmitting data by radio. RFID technology has two major areas of application. The first application is handheld non-contact IC cards for pay phones, commuter rail passes, and so on. The second application is in the field of supply-chain management, in which RFID tags are used to manage the flow of products during physical distribution and are attached to containers, pallets, or products. RFID tags may be categorized into two types: passive and active depending on the presence or lack of a battery. A passive tag has the characteristics of a short identification distance, a low price, and semi-permanent usability because it uses an RF signal received from the reader as energy. However, an active tag is expensive and has a limited life because the life span of the power supply section inside the tag is limited. The active tag has been mainly used for identifying and tracking objects from a remote distance, and for managing pallets and containers at airports and harbors [1]-[3]. The United States military has used the tag widely in the transportation of munitions in containers, and it is expected that, given increased security concerns since the September 11 attacks, all containers coming into US ports are being required to be electronically sealed using an active RFID tag [4], [5].

2. Necessity

Unlike passive RFID tags, active RFID tags are RF terminal devices capable of transmitting and receiving radio signals with their own internal batteries and radio transmitters. Active RFID tags are currently used in harbor transportation. They are attached to cargo containers for sea transportation [6]-[8] and designed to be identifiable by RFID readers installed at ports in many countries. Recently, however, many failures have been reported. The biggest problem appears to be that readers cannot respond to the tags because of interoperability problems between readers and tags developed by different manufacturers. The international standard ISO/IEC 18047-7 [9] regarding RFID conformity test methods suggests the use of air interface evaluation between an RFID reader and a tag. However, the test method suggested by the international standard is intended to detect a radio signal over only a very short period. Outcomes were uncertain, making it difficult to evaluate the system accurately.

3. Contribution

In this study, hardware and software used for an emulator to evaluate the conformance of an active RFID tag were designed and implemented. To verify performance levels, a simulation using Matlab was conducted. Our contribution is two-fold.

- We implemented hardware and software of the emulator [10], [11] for active RFID systems using an FPGA module and C-language. Furthermore, the applicability of the emulator was assessed by evaluating the standard conformance of an actual active RFID tag in an anechoic chamber.
- We propose a new evaluation method by incorporating a *self-running test mode* environment into the RFID tags in order to reduce the test time and increase testing accuracy. We found that the application of the suggested method to actual tags improves measurement accuracy over that obtained using existing methods.

4. Organization

This paper is organized as follows. In section II, we present the design of an emulator of an active RFID system and analyze its performance using Matlab/Simulink. In section III, we describe the implementation of an emulator according to the proposed design and verify its performance by evaluating the standard conformance of a real active RFID tag. Section IV describes an air interface protocol and the conformance test methods of an active RFID tag in response to the problems facing existing methods. In section V, we propose a new test method and calculate measurement uncertainty to compare the two methods. Finally, we present our conclusions in section VI.

II. Design Concepts

1. System Structure

An active RFID system has a frequency shift keying (FSK) type direct conversion receiver. As the same frequency is used in transmitting and receiving signals, signals can be separated using a time division duplex method. Figure 1 shows the structure of the transceiver of an active RFID emulator.

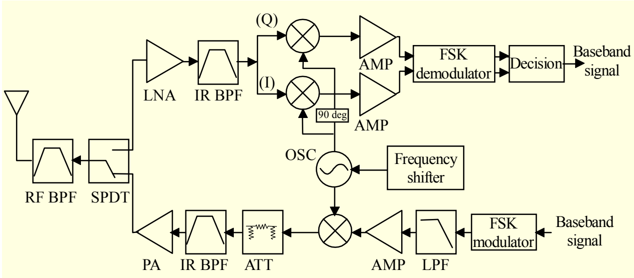


Fig. 1. Architecture of transceiver for active RFID system.

2. System Requirements

Concerning receiving power, a receiver is designed so that it has a maximum 5.6 dBm reduced peak power when the antenna power is 0 dBi. When the effective isotropic radiated power (P_{EIRP}) of an active RFID tag is 5.6 dBm, the receiving power (P_{rec}) of an RFID reader can be calculated using

$$P_{rec} = P_{EIRP} G_{rec} \left(\frac{\lambda}{4\pi d}\right)^2, \quad (1)$$

where G_{rec} is the gain of the receiver, λ is the wavelength of the carrier wave, and d is a distance in free space. The receiving power at various distances is shown in Fig. 2.

When a transmitter has a transmit power of 5.6 dBm the power received at a distance of 100 m is -60 dB. Accordingly, to ensure an identification distance of at least 100 m, a receiving section requires a receiver sensitivity level exceeding -60 dBm.

The receiver sensitivity is the minimum signal input required

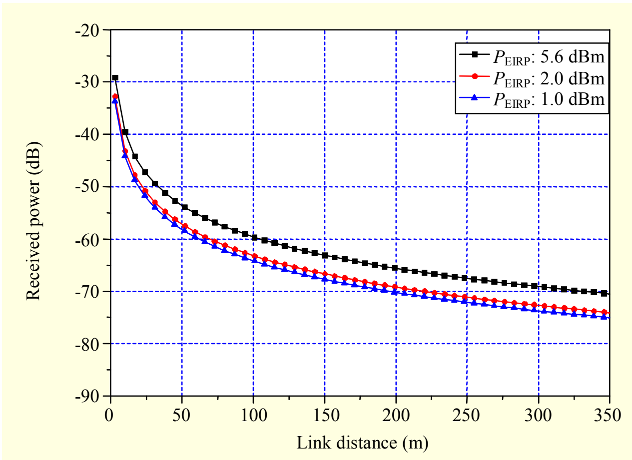


Fig. 2. Receiving power of receiver at various distances.

to generate a signal-to-noise ratio (SNR) or bit error rate (BER) of the receiver output that conforms to the desired value. In other words, it is a characteristic that indicates how faint a signal can be but still be satisfactorily restored by the receiver. Receiver sensitivity is determined by thermal noise power (N_{in}), depending on the receiver input resistance; noise figure (NF), indicating the ratio of internal noise; noise bandwidth (B) of the receiver; and the SNR of the required output.

When the NF of a system is 10 dB, the minimum detectable signal (MDS) becomes -107 dBm, and the receiver sensitivity (P_{min}), representing the carrier-to-noise ratio (CNR) of 3 dB, becomes at least -104 dBm from the following.

$$MDS\,(\text{dBm}) = N_{in}\,(\text{dBm}) + NF\,(\text{dB}) + 10\log B\,(\text{dB}), \quad (2)$$

$$P_{min}\,(\text{dBm}) = MDS\,(\text{dBm}) + CNR\,(\text{dB}), \quad (3)$$

where N_{in} is the thermal noise power composed of Boltzmann's constant (k) and temperature (T), and NF is the overall NF of the receiver with noise factor F such that

$$\begin{aligned} N_{in} &= kT = 1.38\times10^{-23}\text{ J/K}\times 290\text{ K} \\ &= 4.002\times10^{-21}\text{ W/Hz} \\ &= -174\text{ dBm}, \end{aligned} \quad (4)$$

$$NF\,(\text{dB}) = SNR_{in}\,(\text{dB}) - SNR_{out}\,(\text{dB}) = 10\log F. \quad (5)$$

In case of several cascaded multiport devices, the total noise factor (F_{total}) of can be obtained from

$$F_{total} = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \cdots + \frac{F_n-1}{G_1G_2G_3\cdots G_{n-1}}, \quad (6)$$

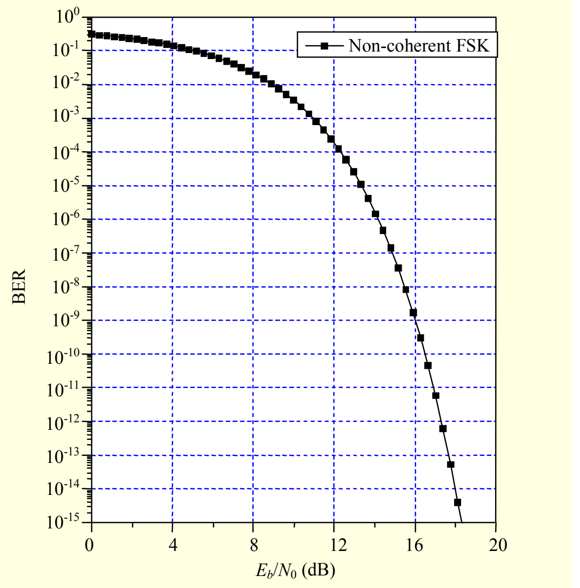


Fig. 3. Graph of BER characteristic for non-coherent FSK.

where F_i (i=1,⋯, n) is the noise factor of the i-th device and G_i (i=1,⋯, n-1) is the power gain (linear, not in dB) of the i-th device.

Finally, the CNR is expressed by the following formula, where E_b/N_0 is the ratio of the signal power per '1' bit of data to noise power, R is the data transfer rate, and B is the bandwidth. Concerning a non-coherent FSK system, the bit error probability (P_E) is calculated as

$$CNR\,(\text{dB}) = 10\log_{10}\left(\frac{R}{B}\right) + 10\log_{10}\left(\frac{E_b}{N_0}\right), \quad (7)$$

$$P_E = \frac{1}{2}e^{-\frac{E_b}{N_0}}. \quad (8)$$

In this study, an emulator for evaluating the standard conformance of active RFID has a 500 kHz bandwidth (B) and a 27.7 kbps data transfer rate (R). When the BER is 10^{-6}, an E_b/N_0 of approximately 14 dB is required as shown in Fig. 3. Accordingly, the required CNR is 1.435 dB [12], [13].

3. Performance Analysis

A performance analysis of the active RFID system proposed in this paper is carried out according to link parameters of ISO/IEC 18000-7 [14] shown in Table 1.

In a transmitting section, a desired signal from the coded data is modulated by an RF carrier and then amplified with minimum distortion levels. Numerous parameters are used to indicate performance, but our attention is focused on output power in consideration of system characteristics. When the peak-to-peak voltage is 200 mV, a signal received from the baseband is around -10 dBm as shown in Fig. 4. The output power after passing through each terminal is as shown in Table 2.

The purpose of using an RF receiving section as shown in Fig. 5 is to convert the received energy into a useful signal with a minimum of distortion. Accordingly, internal circuits and the working environment become the main probabilities of system design when assessing how well the receiving section functions.

Table 1. Link parameters according to ISO/IEC 18000-7.

Link parameters	Value
Carrier frequency	433.92 MHz
Operating frequency accuracy	20 ppm
Modulation type / rate	FSK / 27.7 kHz
Frequency deviation	± 50 kHz
Symbol high / low	Fc ± 50 kHz
Minimum receiver bandwidth	500 kHz

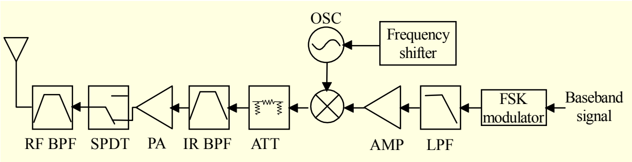


Fig. 4. Structure of transmitter for active RFID emulator.

Table 2. Performance analysis of transmitter.

Signal	In	LPF	Amp	Mixer	ATT	IR BPF	PA	SPDT	RF BPF	Tx Ant	Out
Gain (dB)		-0.01	13.53	-19.12	-6.24	-0.30	28.54	-0.80	-0.01	0.01	
Running gain (dB)		-0.01	13.52	-5.61	-11.85	-12.15	16.40	15.60	15.59	15.60	
Running signal (dBm)	-10	-10.01	3.52	-15.61	-21.85	-22.15	6.40	5.60	5.59	5.60	5.60

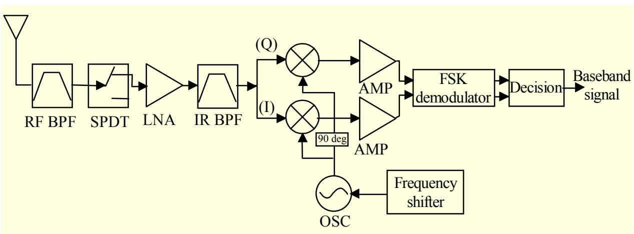


Fig. 5. Structure of receiver for active RFID emulator.

Table 3. Performance analysis of receiver.

Signal	In	RF BPF	SPDT	LNA	IR BPF	Mixer	AMP	Out
Gain (dB)		-0.01	-0.80	20.30	-0.30	-19.12	13.57	
NF (dB)		0.01	0.80	0.90	0.30	14.00	1.80	
Running gain (dB)		-0.01	-0.81	19.49	19.19	0.07	13.64	
Running signal (dBm)	-60.00	-60.01	-60.81	-40.51	-40.81	-59.93	-46.36	-46.36
Running NF (dB)		0.01	0.81	1.71	1.71	2.49	3.58	
MDS (dBm)	-113.43	NF: noise figure CNR: carrier-to-noise ratio MDS: minimum detection signal Sensitivity (dBm) = MDS (dBm) + CNR (dB)						
Required CNR (dB)	1.44							
Sensitivity (dBm)	-112.00							

The performance elements of the receiving section that are most commonly referred to are receiver sensitivity, receiver selectivity, spurious response rejection, and inter-modulation rejection. Receiver sensitivity is considered in our analysis of the performance of this system. Receiver sensitivity indicates how faint a signal can be for a response generated by the receiving section. In analog communications, it corresponds to the minimum RF power at the receiving section input that can guarantee an appropriate SNR at the receiving section output. In terms of digital communication, it corresponds to the minimum RF power at the receiving section input that can guarantee an acceptable maximum BER at the receiving section output. Thermal noise is regarded as the reference of the minimum value.

The receiver sensitivity calculated considering only thermal noise, without considering external noise, is about -112 dBm as shown in Table 3.

$$P_{\min}\,(\text{dBm}) = N_{\text{in}}\,(\text{dBm}) + B\,(\text{dB}) + NF\,(\text{dB}) + CNR\,(\text{dB}) \\ = -174 + 57 + 3.58 + 1.44 = -111.98\,. \quad (9)$$

4. Simulation Results

To analyze the system of the emulator to evaluate a 433 MHz active RFID, a simulator was configured using Matlab. Each communication block substantiated in the simulator was modeled so that it would be similar to the parts of an actually produced evaluating system. Especially for the mixer (an analog device) shown in Fig. 6, its characteristic parameter was directly measured. That measured value was applied to the simulator.

The simulator generates a random signal with the Manchester code. The signal is transmitted after FSK modulation. The transmitted signal is demodulated in consideration of the loss of free space and is then configured so that the error rate can be calculated in comparison to the generated signal. At that time, the data transmission rate is 27.7 kbps. After FSK modulation is conducted so that a frequency shift of 50 kHz can be obtained, the signal to pass through a low-pass filter (LPF) is input to the RF transmission module. Its center frequency becomes 433.92 MHz, and a transmission signal, including a 200 kHz occupied frequency bandwidth, is generated. The generated transmission signal's receiving power should not exceed 5.6 dBm, according to domestic regulations, when the antenna gain is 0 dBi. Figure 7 shows the spectrum of transmission and reception signals generated in the produced simulator.

Demodulation of the received signals is performed using

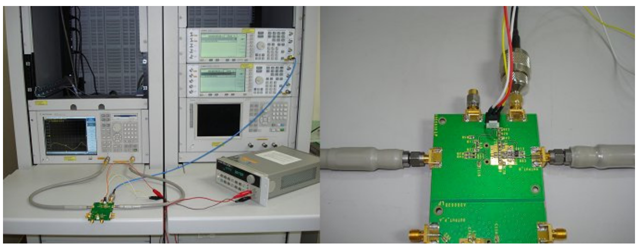
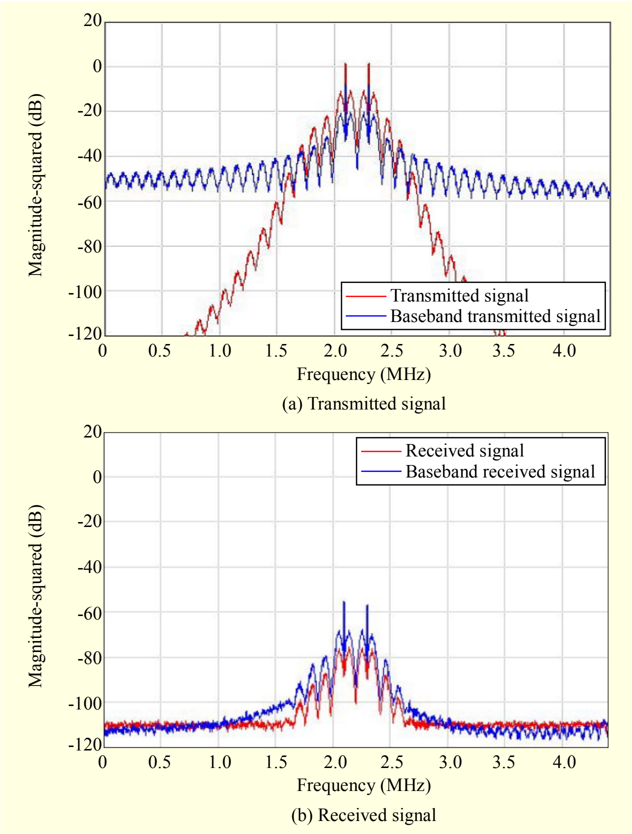


Fig. 6. Measurement of mixer's characteristic parameter.



(a) Transmitted signal

(b) Received signal

Fig. 7. Spectrum of the transmitted and received signals.

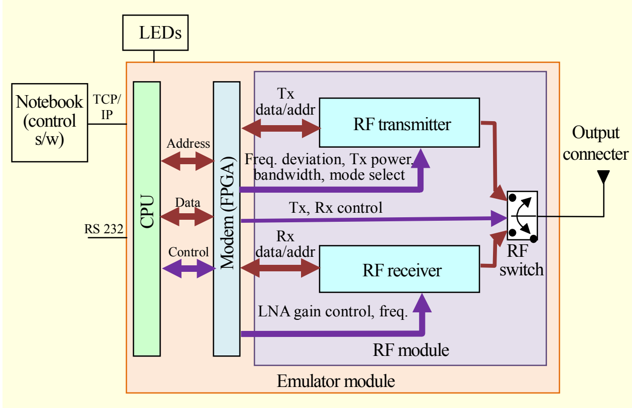


Fig. 8. Data flow of the emulator module.

Fig. 9. View of the manufactured emulator for active RFID.

envelope detection. At that time, path loss in free space is roughly 65 dB at a distance of 100 m at 433.92 MHz. The signals obtained by envelope detection are demodulated after being classified into 0 and 1 using a comparator. The waveform of the demodulated signal is compared with the generated signal to check for errors.

III. Implementation and Evaluation

1. System Implementation

Figure 8 shows a data flow between the RF, FPGA, and CPU modules of the emulator. The emulator for evaluating active RFID comprises an RF module for the transmission of radio signals, an FPGA module for processing measured data, and a CPU module for mounting a management system to an evaluating device.

An RF module comprises a transmission block, a reception block, and a frequency-generating block. In addition, the module has an antenna, a digital section, a power supply section, and an interface. An FPGA module (XCVLX60) distinguishes the control command messages from the CPU, adjusts the RF module (DDSAD9854) to the transmission or reception mode, and conducts data processing. Finally, a CPU module transmits all messages and data completely transmitted or received to a control computer

Figure 9 is a view of the actual manufactured emulator for an active RFID system.

2. Evaluation Results

To evaluate the performance of the active RFID evaluating system designed in this study, the test conditions were set as shown in Fig. 10. In the evaluating system, transmission signals are received by a receiving antenna and measured using RF test equipment. By analyzing the measured signals, the performance of the manufactured emulator can be evaluated.

After evaluating the performance levels of the emulator, transmission output can be checked by delivery of the carrier signal corresponding to 433.92 MHz. A wake-up signal for the tag can be generated. Furthermore, a preamble signal—meaning a preliminary signal before the data for the signal decision between the reader and the tag of an active RFID, which uses the same channel in transmitting and receiving signals—was generated in conformity with standards. The signal modulated by FSK was set to have a frequency shift of ±50 kHz.

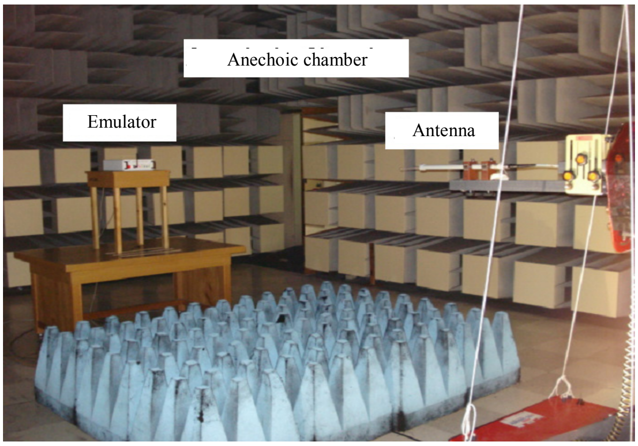


Fig. 10. Test enviroment for evaluating the RFID emulator.

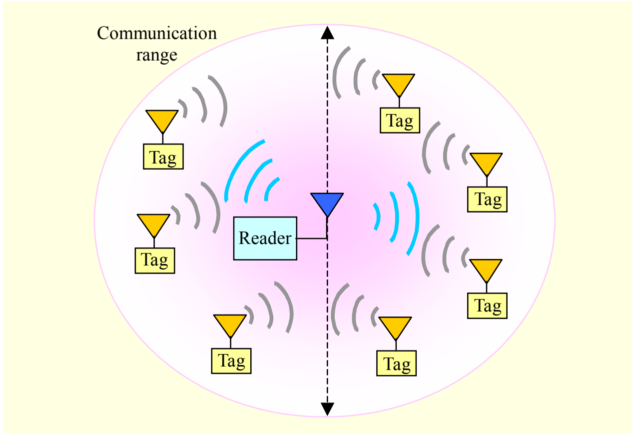


Fig. 11. Configuration of reader and tag in the active RFID.

IV. Active RFID System

The active RFID system can be set up with tags, readers (or interrogators), and hosts. A reader scans more than one tag. These readers are connected to the hosts through an Internet network to provide application services. The active RFID system has a longer interrogating range in general, and it is mainly used in real-time location tracking, container management, and the like. As active RFID tags have their own battery power sources, the benefits are that readers need less power and the range between a reader and tags can be extended remotely. The disadvantages of active RFID tags are their limited life span, because power has to be supplied to them, and their higher cost.

1. Air Interface Protocol

The communication link between the active RFID readers and the tags deployed in harbor logistics applications uses a narrow bandwidth UHF frequency with the characteristics shown in Table 1. The reader sends a wake-up signal with the 30 kHz subcarrier tone for a minimum of 2.5 seconds to wake up all the tags within the interrogating communication range as shown in Fig. 11. Then, all those tags that detect the wake-up signal enter into standby mode to await the commands from the reader. Communication between the readers and tags follows a master-slave type model, whereby the reader always initiates the process and waits for a response from the tags. If multiple tags respond to the reader, then the call algorithm described during the stage of calling tags and intervention to avoid collision determines the order of the tags' communication.

Data between a reader and a tag is transmitted in packet format. A packet is comprised of a preamble, data bytes, and a final logic low period. The end of the preamble and the

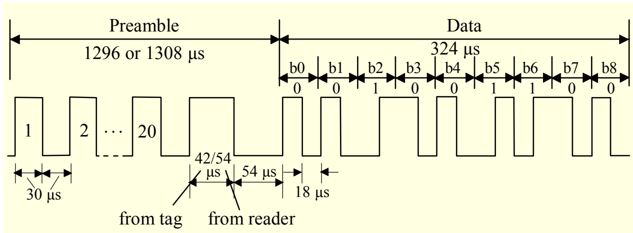


Fig. 12. Data communication timing.

beginning of the first data byte is indicated by the last two pulses of the preamble. The same two pulses of the preamble also indicate the originator of the data packet. Data bytes are sent in Manchester code format. The most significant byte is transmitted first; within a byte, the least significant bit is transmitted first. Figure 12 illustrates the data communication timing of the preamble and the first byte of a packet.

The preamble comprises twenty pulses of 60 µs period, 30 µs high and 30 µs low, followed by a final sync pulse which identifies the communication direction: 42 µs high, 54 µs low (tag to reader) and 54 µs high, 54 µs low (reader to tag). Data bytes are in Manchester code format, comprising eight data bits and one stop bit. The bit period is 36 µs, and the total byte period is 324 µs. A falling edge in the center of the bit-time indicates a 0 bit, while a rising edge indicates a 1 bit. The stop bit is coded as a 0 bit. A CRC checksum is calculated as a 16-bit value initialized with all zeroes (0x0000) over all data bytes excluding the preamble according to the CCITT polynomial ($x^{16} + x^{12} + x^5 + 1$). The CRC is appended to the data as two bytes [15]. A final period of 36 µs of continuous logic low is transmitted for each packet after the CRC bytes.

The packet options field described in Fig. 13 is used to indicate the presence of tag ID and tag manufacturer fields within the current data packet. If a reader wishes to address a single tag by specifying its tag ID, bit 1 of the packet options field needs to be set, indicating point-to-point communication.

Packet options field Packet options field

MSB							LSB
Command (prefix)	Command (type)	Host ID	Tag ID	Reader ID	Command (code)	Parameter	CRC
1 B (0x31)	1 B (8 bit)	3 B	4 B	2 B	1 B	*N* B	2 B

Fig. 13. Reader to tag message format.

If a reader wants to address all the tags within its RF communication range, bit 1 of the packet options field needs to be cleared to indicate the broadcast message. A broadcast message does not use a tag ID field and is omitted from the data packet. Reserved bits are for future use. The default value should be 0.

2. Conformance Test Method

The air interface standard conformance test is required in order to validate whether the RF transmit and receive characteristics and the timing characteristics are compliant to the ISO/IEC 18000-7. In addition, the standard signal generator, which generates the same signal as the emulator, and RF test equipment, such as the spectrum analyzer and oscilloscope, are required to execute the conformance test. The test should be performed in an anechoic chamber. Figure 14 shows the RF standard conformance test environment for active RFID reader and tag.

In the RF standard conformance test for the reader, a spectrum analyzer and an oscilloscope are used to verify the transmit RF characteristics of the device under test. The receiver RF characteristics and the timing of the reader are validated with the tag emulator. A detailed list of test items for the RF standard conformance test for reader and tag is shown in Table 4.

The transmit power measurements and standard conformance test for general wireless communication systems (cellular, wireless LAN, and so on) use the conducted test method whereby the antenna terminal is connected to the test equipment with an RF cable. In the case of an active RFID system, the tags must be specially manufactured by optimal design of the casework and antenna matching in order to execute the conducted test. However, there are some difficulties in installing additional terminals for external connection when making the tags lower and smaller in size. Therefore, the radiated test method using the air propagated RF signal is essential.

The time domain and the frequency domain signals should be able to be measured simultaneously to isolate the FSK modulated tag signal from the reader during the radiated test using the air propagated RF signal. During the measurement of the RF characteristics of the active RFID tag, significant time and effort is required to acquire the backscatter signal from the tag because communication only lasts for a few milliseconds in reference to the reader's signals. Therefore, evaluation by measuring the communication signal in short windows according to the international standard suffers from uncertainty in both measuring time and test results. There have been difficulties in precise testing.

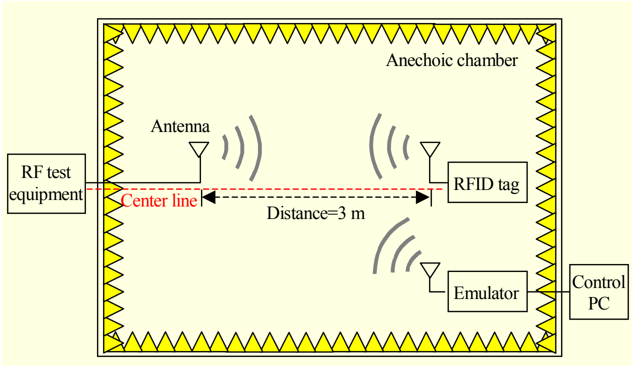


Fig. 14. Environment of RF standard conformance test.

Table 4. Test items for RF standard conformance test.

Item	Contents and limits
Power	Reader or tag : below 5.6 dBm
Operating frequency	Operating frequency: 433.92 MHz Accuracy: ±20 ppm
FSK modulation	Reader: 50 kHz ±5.0 kHz Tag: 40 kHz to 55 kHz
Wake-up signal	Reader: 30 kHz ±1.0 kHz Wake-up signal time: 2.5 s to 2.7 s
Message preamble format and timing	Twenty pulses of 60 µs period (30 µs low, 30 µs high) followed by sync pulse. Sync pulse for - Reader → tag: 54 µs high, 54 µs low - Tag → reader: 42 µs high, 54 µs low
Data coding and reference timing	Manchester code - Logic '1': 18 µs low followed by 18 µs high - Logic '0': 18 µs high followed by 18 µs low

V. Proposed Test Method

1. Self-Running Test Mode

Following the existing standard conformance test of an active RFID system requires a great deal of time and effort to acquire the time domain and frequency domain information of the wake-up signal, preamble signal, and data exchanged once between a reader and a tag. Therefore, this paper defines the command codes, the so-called *self-running test mode*, into the

Command code	Command variable				
Self-running test mode (0x9F)	Signal select (1 B)	Repetition (1 B)	Holding time (1 B)	Interval (1 B)	Tag ID (4 B)

Fig. 15. Message format of self-running test mode.

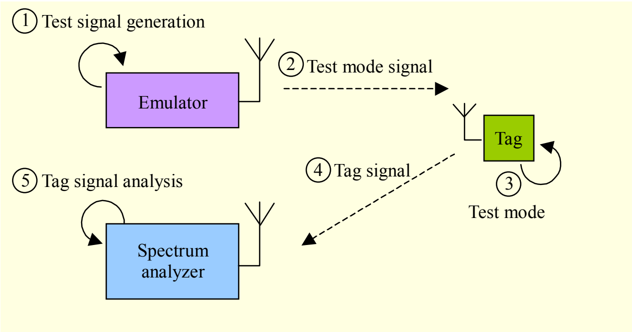


Fig. 16. RF conformance testing procedure according to proposed method.

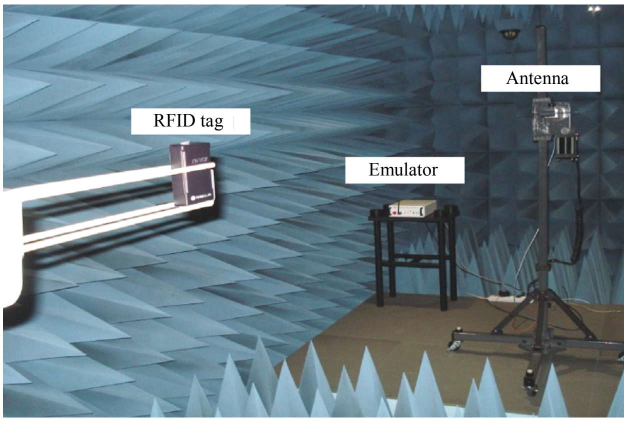


Fig. 17. Standard conformance testing of active RFID tag.

Table 5. Comparison of average time for data acquisition.

Tag	Wake-up signal		Preamble signal		Data signal	
	Normal	Modified	Normal	Modified	Normal	Modified
Average time	56 s	32 s	350 s	31 s	412 s	35 s

message format shown in Fig. 15. This mode applies to the reader and the tag sequentially to repeat the wake-up signal and the preamble signal for a fixed period so that the efficiency and accuracy of the measurement are improved. The basic concept of the measurement is that the emulator acts as a standard signal generator and transmits the wake-up signal to wake up the tag. Then, it transmits the signal that has a self-running test mode command to the tag. In this case, the self-running test mode command uses "0x9F," which is not currently assigned by the international standard ISO/IEC 18000-7. The tag is switched to the self-running test mode and responds with the signal selection, number of repeats, hold time, and intervals specified by the commands from the emulator. The response is analyzed with RF testing equipment, such as a spectrum analyzer and oscilloscope, to test standard conformance. The four-byte tag ID is transmitted only for peer-to-peer communication purposes. Figure 16 shows RF conformance testing procedure proposed in this paper.

2. Measurement Uncertainty

To prove the efficiency of the proposed test method, the self-running test mode commands were implemented for both the actual RFID tag and the emulator, and the conformance tests were performed in an anechoic chamber as shown in Fig. 17. Typical test cases of the conformance test are transmit power, accuracy of the operating frequency, and deviation of the FSK modulation frequency. Those test cases were repeatedly tested 20 times for a normal tag without a self-running test mode. For a tag with a self-running test mode, the acquisition time of the wake-up signal, the preamble signal, and the data signal necessary for the test were recorded. The average acquisition times are summarized in Table 5.

In general, it is not difficult to acquire the wake-up signal with RF testing equipment, such as a spectrum analyzer with both the normal (existing method) tag and the modified (proposed method) tag in the self-running test mode because the signal lasts for at least 2.5 seconds. However, it takes a great deal of time and effort to acquire the preamble signal of a few milliseconds in duration and the data signal of a few hundred microseconds long with the normal tag. On the other hand, it is always possible to acquire all signals with the modified tag after about 30 seconds of operation of a control laptop computer. Figures 18 to 20 present graphs that summarize the results of the conformance test from the 20 repeated measurements with the normal tag and the modified tag. Table 6 shows the results of the conformance test. Note that the modified tag has a lower distribution and a more stable result compared to the normal tag.

Measurement uncertainty is the distribution of a large amount of measurement data acquired by repeated measurement when the measurement value is unknown. It is a useful statistical approach. The reason for using uncertainty is that it is a definite indication of the accuracy of the measurement in a controlled environment. It also reflects the reliability of the test results [16]. This paper presents the uncertainty of the measurement results of the radiated transmit power from the active RFID tag, demonstrating the efficiency of the proposed test method. Figure 21 shows the model of the overall measurement system to verify the uncertainty.

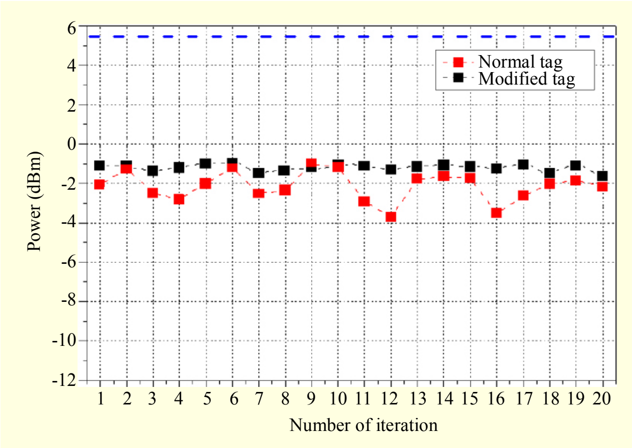


Fig. 18. Test results of transmitting power.

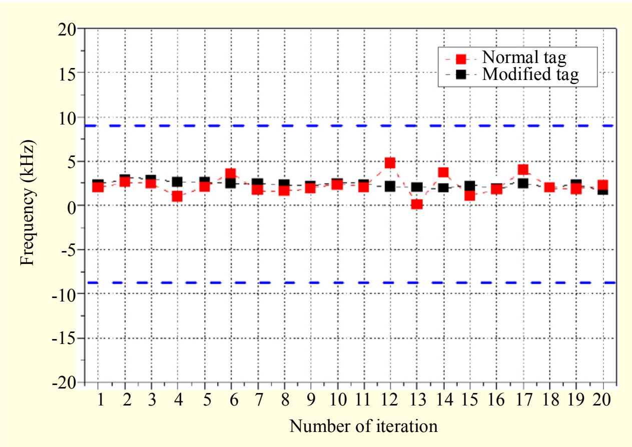


Fig. 19. Test results of operating frequency accuracy.

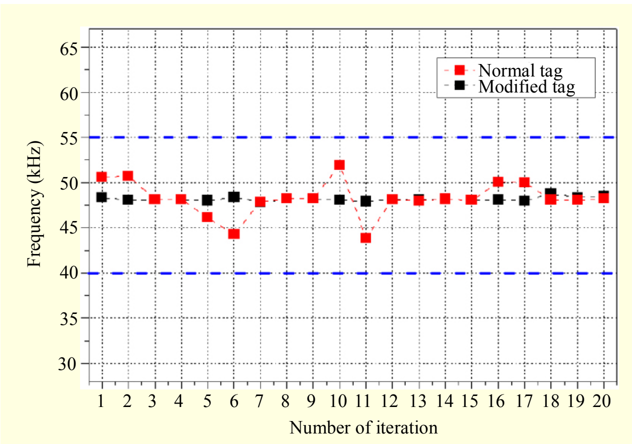


Fig. 20. Test results of frequency deviation.

The modeling equation of measurement uncertainty used to measure the transmit power *P* (dBm) of the active RFID tag is written as

$$P\,(\mathrm{dBm}) = \delta P_{\mathrm{tag}} + \delta F_{\mathrm{loss}} + G_{\mathrm{RXant}} + C_{\mathrm{loss}} + P_{\mathrm{SA}}, \quad (10)$$

Table 6. Results of standard conformance test.

Number of Iteration	Transmitting power (dBm)		Frequency accuracy (kHz)		Frequency deviation (kHz)	
	Normal	Modified	Normal	Modified	Normal	Modified
1	-2.08	-1.32	1.97	2.34	50.62	48.34
2	-1.26	-1.47	2.62	2.90	50.68	48.04
3	-2.48	-1.70	2.41	2.87	48.12	48.11
4	-2.81	-1.59	0.98	2.62	48.15	48.13
5	-2.01	-1.33	2.03	2.63	46.10	48.00
6	-1.20	-1.24	3.59	2.46	44.30	48.36
7	-2.53	-1.75	1.65	2.41	47.84	47.83
8	-2.34	-1.67	1.56	2.34	48.23	48.19
9	-1.06	-1.16	1.87	2.55	48.22	48.21
10	-1.17	-1.09	2.53	2.74	51.89	48.04
11	-2.92	-1.15	2.02	2.64	43.86	47.91
12	-3.71	-1.28	4.76	2.41	48.12	48.12
13	-1.79	-1.10	0.11	2.31	47.98	48.10
14	-1.66	-1.09	3.64	2.78	48.18	48.17
15	-1.74	-1.11	1.06	2.11	48.03	48.01
16	-3.51	-1.18	1.80	2.73	50.06	48.09
17	-2.63	-1.06	3.98	2.45	50.01	47.97
18	-2.02	-1.28	1.93	2.97	48.09	48.73
19	-1.84	-1.05	1.82	2.34	48.03	48.34
20	-2.12	-1.34	2.20	2.55	48.19	48.20
Maximum	-1.06	-1.05	4.76	2.97	51.89	48.73
Minimum	-3.71	-1.75	0.11	2.11	43.86	47.83
Average	-2.14	-1.30	2.23	2.56	48.24	48.14
Standard deviation	0.74	0.22	1.12	0.23	1.99	0.20
Limit	5.6 dBm		± 8.67 kHz		40 kHz to 55 kHz	

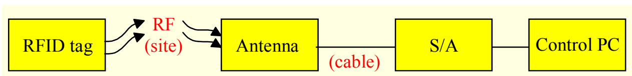


Fig. 21. Configuration of overall measurement system.

where δP_{tag} is the standard deviation of the mismatch from the tag, and δF_{loss} is the compensation of the loss at the measurement site. The gain of a standard antenna (EMCO 3121C) for receiving is G_{RXant}, and the compensation of the cable loss is C_{loss}. Finally, P_{SA} is a calibration of specifications of the spectrum analyzer.

Therefore, we confirmed that measurement using the method we proposed improved the quantitatively calculated uncertainty by 0.56 dB. The measurements in this study were performed with small RF output transmit tags that produce less than -1.0 dBm. This study proved that the conformance test with the self-running test mode improved the reliability of the test results significantly.

VI. Concluding Remarks

In this study, an emulator for the standard conformance test on an active RFID tag was designed and substantiated. The developed evaluating device is a standard signal generator with reproducibility for standard conformance testing. It was designed so that the emulator would give commands or responses to the reader and the tag to be tested and would be able to check for a malfunction of the reader and the tag using a standard signal. Furthermore, some random functional changes, such as transmission output, frequency shift, and bit rate accuracy, were made in the evaluating device to check for various errors and malfunctions arising in the testing sample.

This paper recommends a self-running test mode environment for the conformance test used for active RFID tags and a practical method of applying it sequentially. According to the proposed method, the tags periodically generate a fast response signal, and the measurement system can detect and analyze the signal easily so as to improve measurement efficiency. The proposed algorithm was implemented on actual active RFID tags, and the test results were compared to the existing method through the conformance test. It was confirmed that the acquisition time of average data was improved by 377 seconds. In addition, in the quantitative calculation of uncertainty, the system applied with the proposed method improved uncertainty by 0.56 dB. These results show that the proposed method would be able to improve the measurement time and reliability of the test results in the conformance test of an active RFID tag for harbor logistics, where large numbers of test samples are required.

Further research will be required in the future to determine the optimum location of the tags and antennas in consideration of the type and structure of the attachment materials used with active RFID tags.

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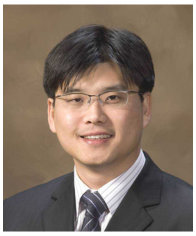

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