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Analysis of Receiving Strength according to the Attachment Location of RFID tag in Palletized Unit-load of Agricultural Products

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Abstract This study was conducted as a basic study for the selection of tags suitable for logistics management in the palletized unit-load unit and the development of various technologies to activate the palletized unit-load shipment of agricultural products through local APCs. Three types of passive RFID tags of UHF 900 MHz and one type of active RFID tag of 2.4 GHz band designed and manufactured through this study were used to analyze the receiving strength according to the tag's attachment location and distance of the palletized unit-load of agricultural products. In the passive RFID tag, there was a large difference in receiving strength by the tag's attachment location and a large amount of data loss depending on the distance within 30 m, whereas, in the active RFID tag, it was superior to the passive tags in terms of both receiving strength and data loss. Therefore, active tags are desirable from the perspective of multiple identification of warehouses with large spaces in relation to the application of RFID tags for palletized unit-loads of agricultural products, but the development of low-power technologies such as software wakeup power management as well as hardware to minimize battery power consumption is necessary.

Keywords UHF, RFID, Active Tag, Passive Tag, RSSI, Palletized unit-load

Introduction

RFID (radio frequency identification) technology, along with ISO/IEC JTC 1 and ITU-T, international organization for standardization, and the industrial EPC Global, has developed as a representative wireless identification technology for identifying objects in the fields of transportation cards, access management, animal management, and inventory management for technical practical use since the late 1990s. In addition, RFID technology spread to livestock, smart homes, and factory automation industries in the mid-2000s, and the identification rate of the RFID tag and the reader has improved significantly since 2010 due to continuous technological development. Since 2020, it has been widely used by incorporating smart ICT sensor technology into logistics location tracking that combines mobile devices.[1)]

The existing barcode system had limitations in application due to the limitation of the identification distance when identifying the logistics code, the inability to identify products on the move, and the inability to identify multiple loaded goods. In order to compensate for the limitations of identifying the logistics code of this barcode system, an UHF RFID reader based on radio identification in the ultra high frequency (UHF) band was required. As for the identification technology of UHF RFID readers, the passive tag of the protocol ISO/IEC 18000-6 and the active tag of the protocol ISO/IEC 18000-4[2)] are mainly used in ISM (Industrial Scientific Medical) band.

In the internal operation method of a general passive RFID tag, the tag receives power wirelessly transmitted from the reader, operates the internal circuit of the tag, and sends the unique tag ID and EPC (Electronic Product Code) stored in the internal memory back to the reader. Therefore, in the case of passive tag, there is a very close relationship between the power intensity transmitted from the reader and the transmission and reception rate of data that the tag responds to because the battery is not built into the tag. In addition, if there is an obstacle in wireless power transmission, the reception identification rate due to radio interference is significantly lowered, and the identification distance of passive tags in the 860 to 960 MHz band is usually within 10 m if the protocol ISO 18000-6C and EPC Class 1 Gen 2[2-4)] are satisfied, and the identification distance varies depending on the external structure and output of the antenna. On the other hand, in the case of an active RFID tag, its own battery is built into the tag,

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so it does not respond to the reader's power and signals, but responds to its own unique information with its own built-in battery power. Therefore, it has a longer identification distance than passive tags and has less impact on obstacles, so it is very useful for logistics on the move. However, since the active tag mainly uses small lithium coin cell batteries, it must be designed to consume very low power while waiting for tag operation, and because power is always provided to identify signals with the reader, standby power consumption occurs. Therefore, internal battery power management technology is required separately in software along with the low power design of the hardware, which has a higher initial cost burden than passive tags. In Korea, the UHF radio frequency band used by passive tags is 917 to 923.5 MHz, and the frequency band used by active tags is 2.4 GHz.[5)]

When RFID technology is applied to agricultural logistics, it is expected to be effective in various areas, such as stabilizing agricultural prices, in addition to improving logistics efficiency and reducing logistics costs. In Korea, RFID technology before 2006 was mainly used for the production history system centered on livestock products, and it began to be used in more diverse fields as a leading IT technology project in rural areas that began in 2007. However, it was mainly introduced in limited areas such as simple import and export management of agricultural products, and its application in terms of nationwide logistics management was insufficient.[6,7)]

In the future, the application of active RFID tag to logistics management is expected to become common. Currently, domestic production of passive RFID tags is carried out through several small and medium-sized enterprises, but active tags are not produced in Korea, so technology development is necessary for stable domestic supply and demand.[8-11)]

This study was carried out by obtaining basic data for selecting tags suitable for logistics management in the palletized unit-load unit, and developing various technologies to activate the palletized unit-load shipment of agricultural products through local APCs. More specific research objectives are as follows.

1) Design and manufacture of 2.4 GHz active RFID tag and reader suitable for logistics management in palletized unit-load unit of fresh agricultural products

2) To develop the dedicated receiving program for collecting RFID data

3) Analysis of receiving strength according to tag's attachment location and travel distance of palletized unit-load of agricultural products

Experimental Design and Methods

1. Measurement environment of UHF RFID system

The measurement environment of RFID tags in this study is shown in a block diagram as shown in Fig. 1. The dedicated program for collecting RFID data resides in the inventory, and the EPC information values received from the tag are also stored here. The process for receiving and storing the data of the tag first sends a command from a dedicated program to the reader, and the reader sends a request signal to the tag to read

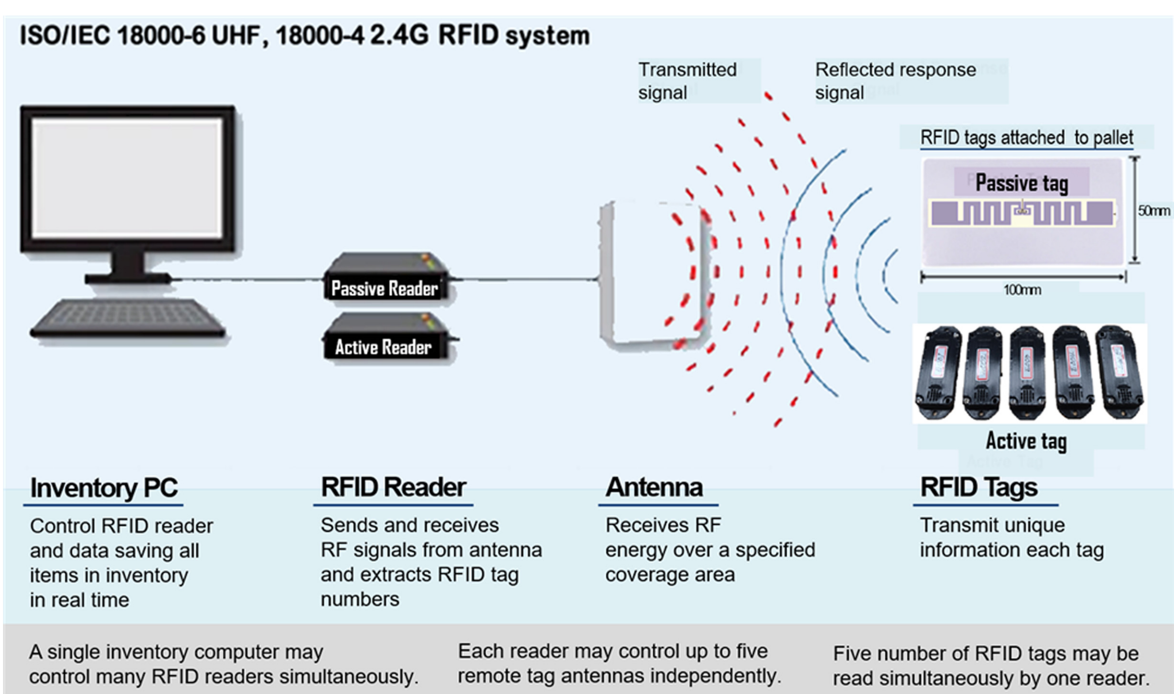


Fig. 1. RSSI measurement environment of UHF RFID tag in ISM band.

- Antenna : UHF 6 dBi & 12 dBi, Impedance 50 Ω
- Tag : (see Table 1 for more information)
  - Passive Tag (ISO18000-6C, EPC-GEN2) : three types
  - Active Tag (ISO18000-4, EPC-GEN2) : one type (manufactured)
- Frequency : 860~960 MHz (KOREA, Center Frequency 920 MHz) and 2.4 GHz
- Reader : (Passive) CF-MU904, RA1202, (Active) manufactured
- Measurement : HP-PAVILION Core i7 Processor
- Timer triggered data : 20 msec ~ 1000 msec
- RSSI (Received signal strength indication) : -70 dBm $\leq$ R (RSSI) $\leq$ +0 dBm
- Distance for measurement :
  - 0 m≤D (6 dBi)≤25 m (Passive Tag)
  - 0 m≤D (6 dBi)≤30 m (Active Tag)

the information value of the tag. The tag decodes the reader's request signal and responds to the information value with the reader, and the reader stores the received information value in the inventory of the dedicated program. Information data received and stored from tags are measurement time, RSSI, EPC, etc.

The RSSI measurement environment of RFID tag adopted in this study is summarized as follows.

2. Active RFID tag and reader design

2.1. Design considerations

A test active RFID tag and reader suitable for logistics management in palletized unit-load unit of agricultural products units were designed. ISO/IEC 18000-4[2)] was the protocol applied to design the active RFID tag, and the frequency measurement band for communication between the tag and the RFID reader was 2.4 GHz.

2.2. Performance verification

Prior to the field evaluation of the designed and manufactured active tag, a basic performance test was conducted on the transmission and reception function that collects RFID operating status and basic tag information in the LAB environment. An internal test environment was established to collect tag information for this test, and basic data for correction were obtained by checking the antenna transmission output lost at 1 m, which is the unit of measurement, and the RF loss output value between the reader and the tag.

3. Field test for receiving strength of RFID tag

3.1. Pallet attachment method of RFID tag and configuration of palletized unit-load

There were three types of passive RFID tags (A, B, C) and one type of active RFID tag (designed and manufactured through this study) applied to the field measurement of the

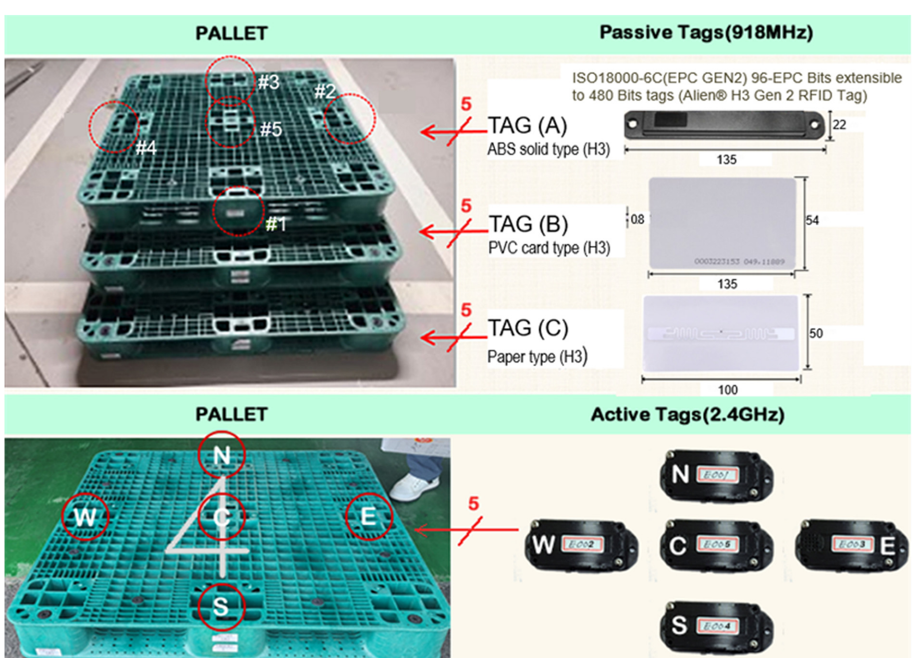


Fig. 2. Tag's attachment locations in pallet.

(a) Passive RFID tag (b) Active RFID tag

Fig. 3. Configuration of palletized unit-load for field measurement of receiving strength of RFID tag: (a) pallet_1100 × 1100 mm, Box_440 × 330 × 204 mm, apple 10 kg_48 box, (b) pallet_1100 × 1100 mm, Box_450 × 305 × 195 mm, korean melon 10 kg_56 box).

Table 1. Detailed specifications of RFID tag and reader applied to field measurement

Classifications	Passive reader	Passive tag	Active reader	Active tag
DC power	5 V	Wireless power	5 V	3.3 V
Model	CF-MU904, RA1202	Tag-A: Alien ABS Tag-B: Alien PVC Tag-C: Alien 9662	Manufactured	Manufactured
Frequency	902~928 MHz		2.4 GHz	
Antenna	SMA(IPEX)	PCB Ant.	SMA (IPEX)	PCB Ant.
Gain	6 dBi/12 dBi	N.A	6 dBi	6 dBi
Impedance	50 Ω	N.A	50 Ω	N.A
Size	580×172×60 mm	Tag-A: 135×21×12 mm Tag-B: 135×54×0.8 mm Tag-C: 100×50×0.8 mm	150×210×50 mm	91×34×25 mm
Weight	2.8 kg	Tag A: 20 g, Tag B: 1.1 g, Tag C: 0.5 g	1.2 kg	70 g
Temperature	−40 ~ 80°C (Industrial standard)			
Protocol	ISO18000-6B/6C (EPC GEN2)		ISO18000-4 (EPC GEN2)	
RF power	17 dBm (ADJ)	-	19.5 dBm (ADJ)	-

receiving strength according to the tag's attachment location and distance of the palletized unit-load of agricultural products. Five for each type of teg were attached to the lower empty space of the pallet in four directions and at the center position, respectively (numbering counterclockwise based on the front of the forklift truck) (Fig. 2). Five repetitive tests were conducted for each combination of the applied RFID tag and reader. Table 1 shows the detailed specifications of each tag and reader applied to the field test.

For the configuration of palletized unit-load for measuring the receiving strength of passive and active RFID tag, double-deck four-way plastic pallets were used as shown in Fig. 3, and a pinwheel pallet pattern was applied to 48 apple packaging boxes (packaging weight, 10 kg) for the passive tag test and 56 melon packaging boxes (packaging weight, 10 kg) for the active tag test. However, it was difficult to apply the same agricultural product because the reception strength measurements of the two tegs were conducted at different times, but all other conditions, such as the box size, package weight, pallet, and stacking pattern, were the same as possible.

3.2. Test method

The receiving strength (RSSI) was continuously measured as the forklift truck lifting a palletized unit-load attached RFID tags moved from a certain distance (30 m) to the APC storage entry gate (average speed, 5 km/h). At this time, the reader was located at the top of the gate (Fig. 3). Here, the maximum measurement distance was set to 30 m in consideration of the distance between the local APC workshop and the cold warehouse and the space size in the cold warehouse.

Table 2. Received value parameters for measurement data

Tag type	Receive items	Units	Setting up a data range	Note
Passive RFID tag	Time	msec	20~1000 msec	Time series data
	RSSI	dBm	0~50 dBm	Receiving strength
	Gain	dBi	6	Compensation value
	Distance	m	25	Distance
Active RFID tag	Time	msec	20~1000 msec	Time series data
	RSSI	dBm	0~80 dBm	Receiving strength
	Gain	dBi	6	Compensation value
	Distance	m	30	Distance

4. Data acquisition parameters and analysis

4.1. Data acquisition parameters

Table 2 shows the measurement parameters in the field measurement of the receiving strength according to the tag location and travel distance of the palletized unit-load.

The RSSI transform formula of the UHF RFID tag is shown in Equation (1).[12)]

$$RSSI_{tag(i)} = 10\log_{10}\left[\frac{\sum_{n=1}^{10}\{rawData_{(i)}\}}{n}\right](0 < i \leq n) \tag{1}$$

In order to implement the transmission and reception equivalent equation for the identification distance between the reader and the tag, the transmission output must be obtained (Fig. 4). Usually, the gain of the reader antenna is defined as 6 dBi and the gain of the tag antenna is defined as -1 dBi. The output of the reader and tag can be obtained by Equation (2).

$$P_r = P_t \times G_t \times G_r \times \left(\frac{\lambda}{4\pi r}\right)^2 \tag{2}$$

Here, P_r is the output power of the reader, P_t is the minimum power for the tag to operate, G_t is the gain of the tag antenna, G_r is the gain of the reader antenna, λ is the center frequency, and r is the identification distance between the reader and the tag.[13)]

The power transmission coefficient, τ, of the tag can be expressed by Equation (3), where R_c and R_a are tag chip resistance and antenna resistance, respectively, and Z_c and Z_a are tag chip and antenna impedance, respectively.

$$\tau = \frac{4R_c \cdot R_a}{|Z_c + Z_a|^2} \tag{3}$$

Therefore, the identification distance, r, is expressed by the following Equation (4) from the above equations.

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_r \cdot G_r \cdot G_a \cdot \tau}{P_{th}}} \tag{4}$$

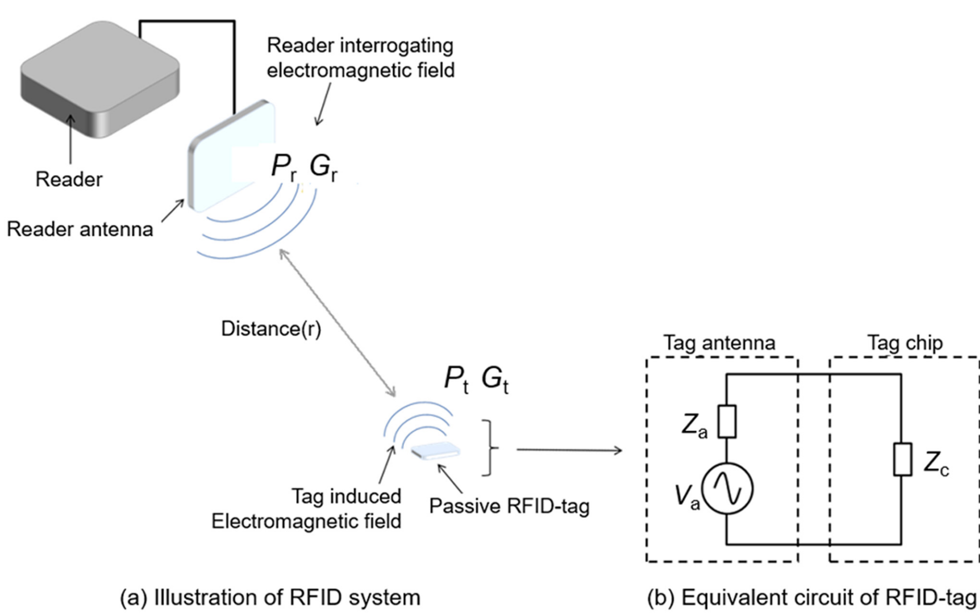


Fig. 4. The output of the reader and the identification distance between the reader and the tag

Here, λ is the wavelength, P_r is the power transmitted by the reader, G_r is the reader antenna gain, G_a is the gain of the receiving tag antenna, and P_{th} is the minimum threshold power.

The peak read range, r, across a frequency range can be referred to as the tag's resonance and will coincide with the maximum power transmission coefficient, τ. In addition, in the numerical model presented in Equation (3), the complex impedance, Z_a, of the antenna can be determined by performing the electromagnetic field and frequency domain analysis of the chip and antenna design combined with the tag. The reading range in which the reader and the tag system including the gain, G_a, and the power transfer coefficient, τ, are combined is expressed as r of Equation (4), and the distance can be determined from this.

4.2. Data analysis

A dedicated receiving program for collecting RFID data was developed as shown in Fig. 5 to enable transmission and reception with the reader in both active and passive tag. The following is a summary of the program's considerations and operational procedures.

- First, it is possible to select a serial COM port for communication connection with the reader to set the environment for serial communication connection on the program before testing.
- Accessing the basic communication setting protocol values (115200 bps, 8 bits, None, Parity 1), the version of the reader is output and the data is ready to be received.
- Subsequently, it is necessary to select the frequency band for measurement, which is set to 918 MHz for the passive tag and 2.4 GHz for the active Tag. It also selects the type of chart for screen visualization.
- Set the maximum distance of the reader on the program and set the data receiving period below 1000 msec (default, 20 msec). The received value is then stored in the local storage in csv or txt file format (raw data) with the measurement start click.

Fig. 6 shows an internal flowchart of software developed to measure RSSI receiving strength of active and passive tags, and Fig. 7 shows an example of a file format stored in the inventory.

Results and Discussion

1. Performance tests on active RFID tag and reader designed and manufactured

Fig. 8 shows the reader circuit diagram of the 2.4 GHz active RFID tag designed and manufactured through this study. An ESP32 32 bit RISC-V Processor with a dedicated 2.4 G RF function was adopted, and a serial UART (Universal Asynchronous Receiver and Transmitter) was configured for

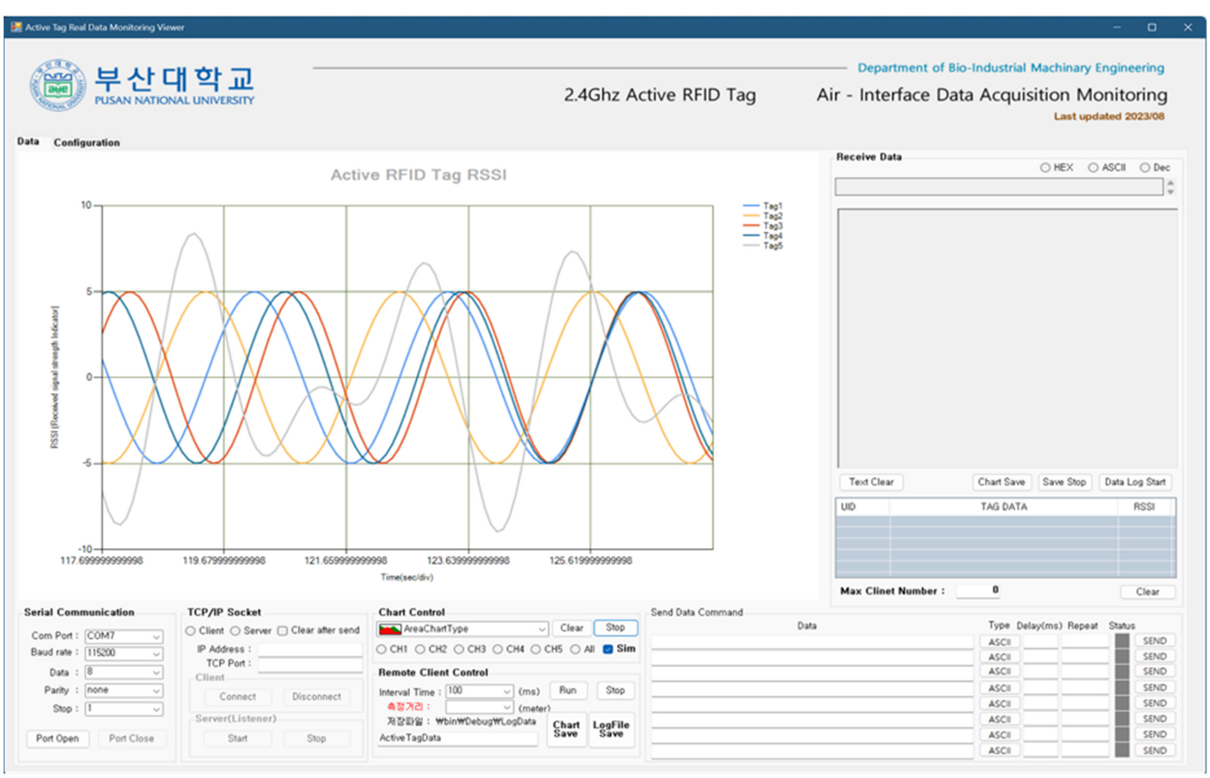


Fig. 5. Dedicated receiving program for collecting RFID data.

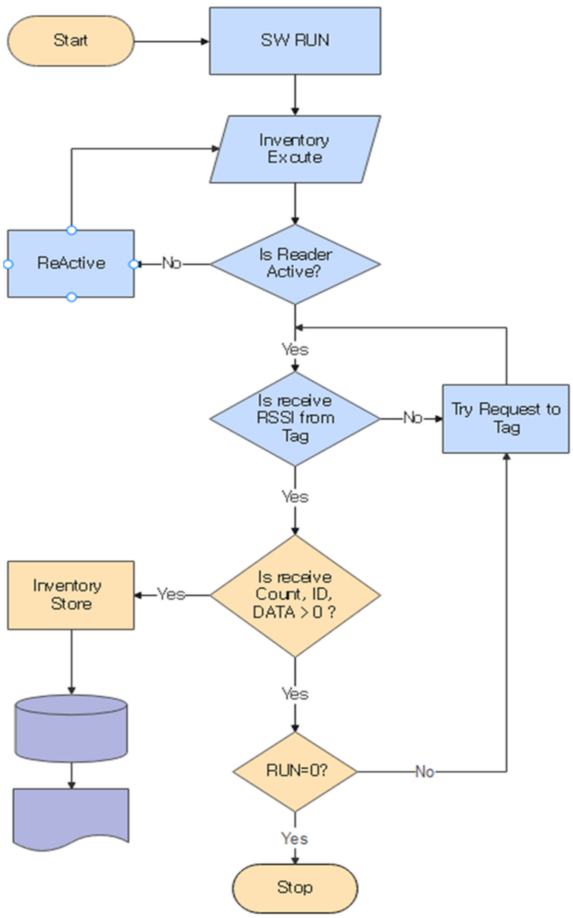


Fig. 6. RSSI measurement flowchart between RFID tag and reader.

TIME	TAG ID	EPC DATA	RSSI
16:06:32	4	E00400001000D234510017E001000D	-78
16:06:32	4	E00400001000D234510017E001000D	-78
16:06:32	4	E00400001000D234510017E001000D	-78
16:06:32	5	E00500001000E234510017E001000E	-72
16:06:32	5	E00500001000E234510017E001000E	-72
16:06:32	2	E00200001000B234510017E001000B	-69
16:06:32	2	E00200001000B234510017E001000B	-69
16:06:32	2	E00200001000B234510017E001000B	-69
		⋮	
16:08:47	3	E00300001000C234510017E001000C	-55
16:08:47	5	E00500001000E234510017E001000E	-60
16:08:47	1	E00100001000A234510017E001000A	-55
16:08:49	3	E00300001000C234510017E001000C	-56

Fig. 7. Example of the received file of stored raw data.

output. The circuit implemented in schematic was artworked for 1:1 physical mapping. Fig. 9 shows the layout of the gerber file made of RS-274 format, and Fig. 10 shows the actual picture of the reader produced.

Fig. 11 and 12 show the circuit diagram and PCB layout of the 2.4 GHz active RFID tag designed and manufactured, respectively.

Fig. 13 shows the design results of the apparatus housing case of active RFID tag. It is designed with a width of 34 mm, a length of 91 mm, and a height of 20 mm to facilitate attachment to the pallet, and the protrusion hole size of the antenna is set to be easily coupled by placing a margin tolerance of 0.8 mm. In addition, the antenna was placed adjacent to the PCB to minimize the loss of transmission radio waves and reduce the

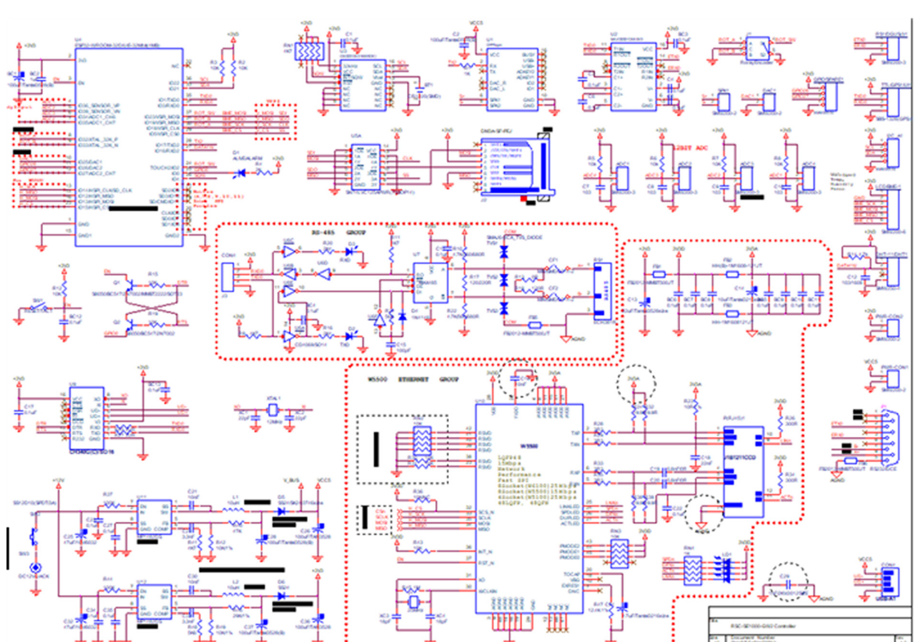


Fig. 8. Circuit the active RFID tag reader.

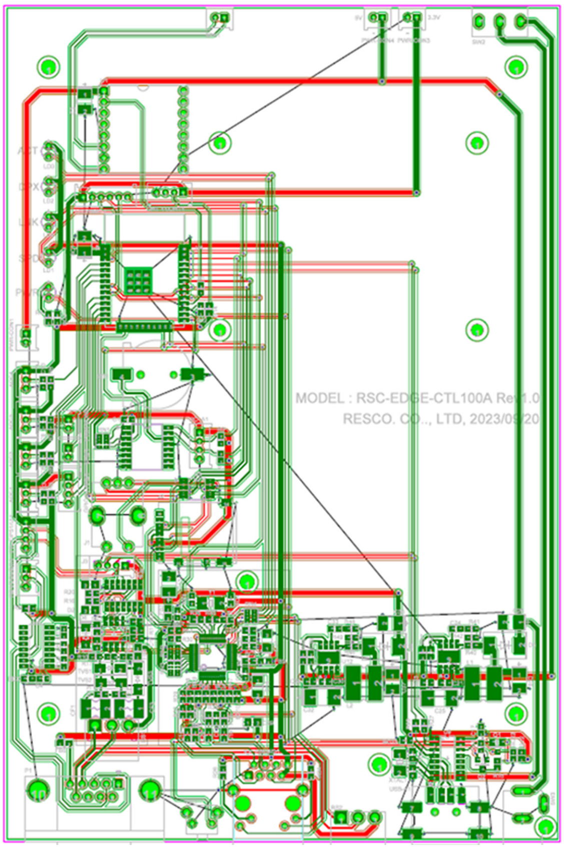


Fig. 9. PCB layout of the active RFID tag reader.

interference between the upper and lower covers and the internal circuit.

The basic functions of the implementation operation were tested to check the performance of the active RFID tag and reader. When the reader's transmission output is set to -18 dBm, it was found that a maximum value of -38 dBm RSSI was received at a distance of 1 m. In other words, -20 dBm lost within 1 m was identified as the RF output loss value between the reader and the tag according to the circuit output and distance, and was used as basic information for correction during subsequent field test.

Fig. 10. Physical photos of the designed and manufactured active RFID tag and reader.

2. Receiving strength of positive RFID tag according to tag location and travel distance of palletized unit-load

Fig. 14 is a test view of the receiving strength for a passive RFID tag on the palletized unit-load of apple package at the APC site. The receiving strength of the passive RFID tag was measured for each combination of three types of tag (A, B, C)

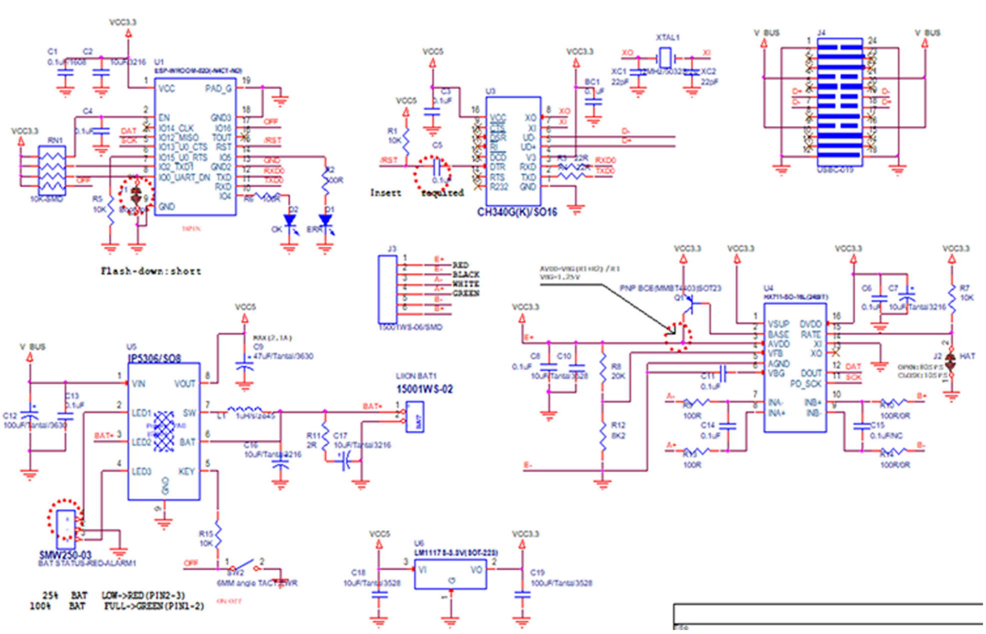


Fig. 11. Circuit of the active RFID tag.

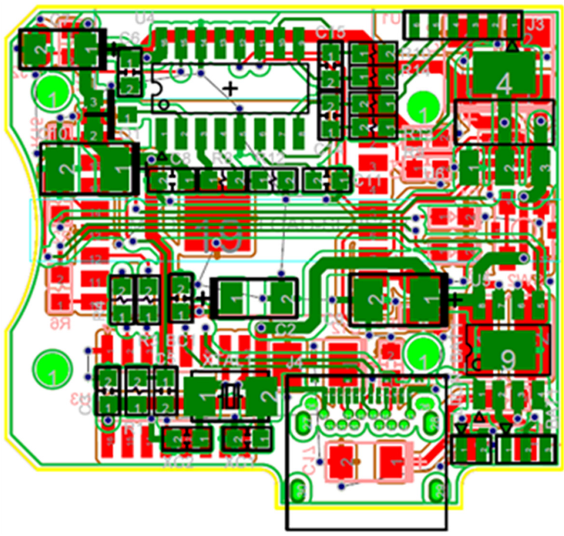
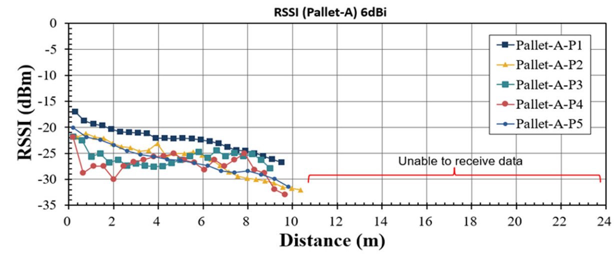


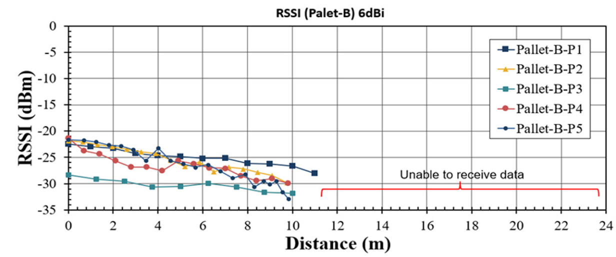
Fig. 12. PCB layout of the active RFID tag.

Fig. 14. Field test sight of passive RFID tag's receiving strength (Hamyang APC).

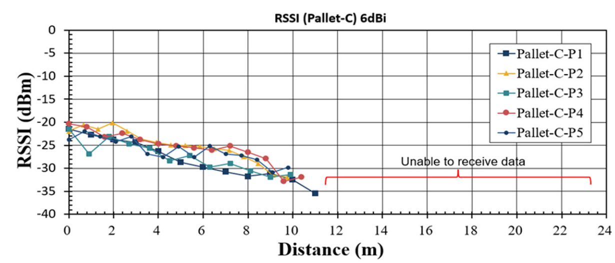
and two types of reader antennas (6 dBi, 12 dBi). As shown in Fig. 15 and 16, the 6 dBi antenna was able to receive good EPC data within a maximum distance of 0 to 9.8 m, and the



(a) Tag-A group



(b) Tag-B group



(c) Tag-C group

Fig. 15. Test results of receiving strength for the passive RFID tag when using a 6 dBi antenna.

receiving strength according to the pallet tag location was in the order of P5 < P4 < P2 < P3 < P1 based on the average value of RSSI for the entire receivable section (Fig. 15). On the other hand, in the case of a 12 dBi antenna, as shown in Fig. 16, it was found that reception was possible up to 0 to 19.5 m, and the receiving distance was expanded by about 10 m or more compared to a 6 dBi antenna. In addition, the

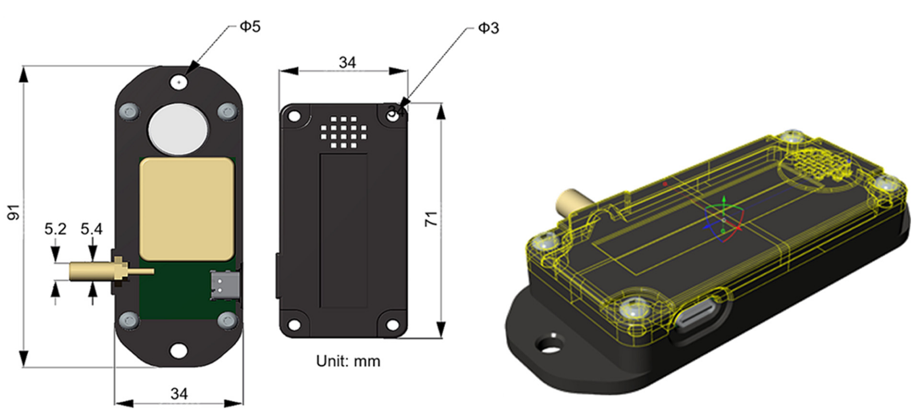
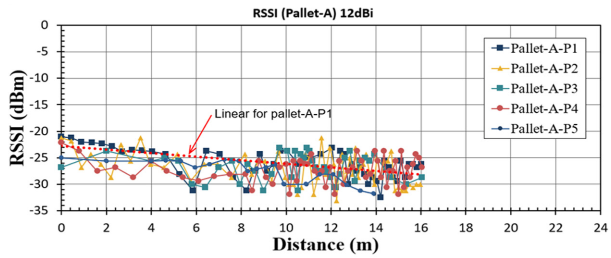
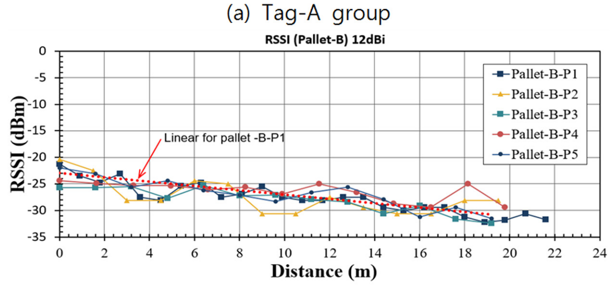


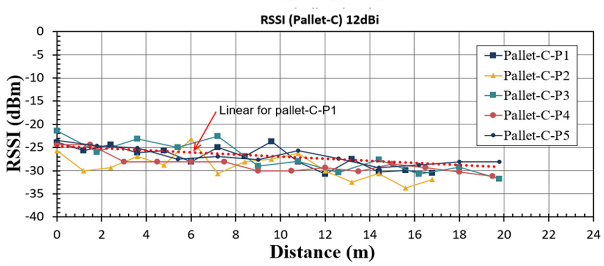
Fig. 13. 3D model for printing and size of housing case of active RFID tag.



(a) Tag-A group



(b) Tag-B group



(c) Tag-C group

Fig. 16. Test results of receiving strength for the passive RFID tag when using a 12 dBi antenna.

receving strength according to the pallet tag location was in the order of P2 < P5 < P4 < P3 < P1 based on the average value of RSSI for the entire receivable section. In both antennas, the receving strength measured at the same distance was found to be better for tag A, which is a solid type made of ABS material, than tags made of other PVC or paper materials.

As a result, passive RFID tag showed generally good receving strength in tags attached to positions 1 and 3 based on the front of the forklift truck (Fig. 15 and 16), and when applying a 12 dBi antenna, tag information can be collected up to 19.5 m in all tags. However, although there are some countries that use 12 dBi abroad, the application of 12 dBi antennas in Korea violates the radio law, so measurement data based on 6 dBi antennas are considered useful in practice.

3. Receiving strength of active RFID tag according to tag location and travel distance of palletized unit-load

Fig. 17 is a test view of the receiving strength of the active RFID tag on the palletized unit-load of the melon package at the APC site. In the analysis of the receiving strength by

Fig. 17. Field test sight of active RFID tag's receiving strength (Seongju APC).

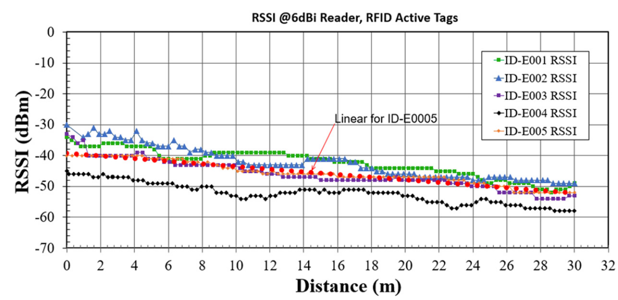


Fig. 18. Test results of receiving strength for the active RFID tag when using a 6 dBi antenna.

distance for passive RFID tag, the reader's acceptable distance through the 6 dBi antenna was found to be within 10 m, whereas in the case of active RFID tag (Fig. 18), it was found that all data could be uniformly received even at 30 m in the same 6 dBi antenna. In addition, in the case of passive RFID tags, the uniform receiving strength could not be expected due to large deviations between continuously received RSSI values (Fig. 16 and 17), whereas in the case of active RFID tags (Fig. 18), the deviation between subsequent RSSI values was small (less than -2 dBm), indicating uniform reception strength. This uniform receiving strength appeared at all five locations of the pallet, and the EPC reception data was good even at a maximum of 30 m or more.

It is difficult to directly compare the receiving strength between the two RFID tags through the received RSSI value of the passive tag and the active tag. Because passive RFID tags rely on wireless power transfer (WPT), but active RFID tags transmit radio waves without relying on WPT. In the results of this study, data could be received even at an RSSI value of −70 dBm in the case of active tag, whereas data could not be received even at a higher −50 dBm in passive tag. Therefore, the RSSI value should be used as a means of relative comparison, not an absolute means of comparison of receiving strength.

Summary and Conclusions

The receiving strength (RSSI) between the 2.4 GHz active RFID tag and the reader designed and manufactured through this study was capable of receiving EPC data within 30 m. This is a very good reception condition compared to that the reliability section of the 6 dBi antenna of the passive RFID tag (900 MHz) is within a maximum of 10 m. In addition, within 30 m, the difference in receiving strength by pallet attachment location of the active RFID tag was not large, so there was little interference according to pallet location. On the other hand, the receiving strength of the passive RFID tag received a lot of interference depending on the travel distance and the pallet tag attachment location. In relation to the application of RFID tags for palletized unit-load of agricultural products, active RFID tags are considered more suitable from the perspective of multiple recognition of large-space warehouses, and passive RFID tags when used for single entry and exit gates, respectively. In particular, when an active RFID tag is applied, its own battery must be built in, so it lacks economic feasibility, such as manufacturing costs, and to compensate for this, not only hardware but also software wakeup power management technology should be studied at the same time as a low-power technology to minimize the power consumption of the battery.

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