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AUTOMATED RFID-BASED IDENTIFICATION SYSTEM FOR STEEL COILS

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Abstract—This paper describes the radio frequency identification (RFID)-based steel coil identification system for supply chain management in the steel and iron industry. During crane operation, coil information is automatically updated by reading an RFID tag which is attached to the coil. One of the technical challenges associated with the RFID-based coil identification is the fall of the identification performance due to neighboring metallic objects. In order to cope with this problem, a system was developed in two directions. First, an effective tag attachment method considering the work process and the environmental conditions was proposed. Second, an antenna case was developed to improve the reading performance by minimizing the influence from the attached surface and focusing the RF signal to the target tag. The simulation and experimental results at the POSCO steel company verify that the proposed system can sense the target RFID tag successfully.

1. INTRODUCTION

The track and trace system is a key method for improving supply chain efficiency by preventing counterfeiting, stealing, and the mixing of products. In order to track and trace items, the efficient identification of target items is required while transporting them from the supplier to the end customer. Radio frequency identification (RFID) is a technology that allows simultaneous identification in a fully automated manner without the need for a line-of-sight via radio waves. Based on these advantages, RFID is widely spreading in various fields, such as smart card, localization, supply chain management, and so on [1–4].

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This paper describes an RFID-based automated steel coil identification system. After manufacturing, the steel coil is paper-packaged, banded, and kept in storage until it is delivered to a customer. The coil information is managed using a coil-storing map. Also, workers check the barcode label to prevent the mixing and lose of products if there is an error in the map. However, as the crane operation to carry the steel coil is automated, the workers encounter danger under the heavy steel coil which weighs over several tons. Thus, an automated coil information management system instead of a barcode systems highly required.

With respect to this problem, an RFID-based steel coil identification system is proposed in this paper. An RFID tag is attached to the center of a steel coil whereupon coil information is automatically updated during crane operation using an antenna installed in the crane shoe. One of the technical challenges associated with the RFID-based coil identification is sustaining the identification performance which is easily affected by environmental conditions such as reflection, refraction, and the scattering of the RF signal from the metallic surfaces of the coils, crane and neighboring equipments [5]. The pretest results using an alien RFID reader and UPM tags show that the more tag-attached coils are placed on the storage, the higher the identification fail rate is due to the detection of neighboring tags and the missing of the target tag.

In order to cope with this problem, two kinds of techniques are proposed in this paper. First, an effective tag attachment method, which considers the attached surface of the coil and the transmitted RF signal conditions, is proposed. Second, the reader antenna is improved using a metallic antenna case. The antenna case is designed to reduce the effect from the attached surface and to control the radiation beam pattern of the reader antenna in order to prevent it from detecting the neighboring tags.

The RF signal transmission was simulated using an MWS 2008 EM simulator and HFSS, and tag identification performance was tested using various model coils in our laboratory environment. Also, a real industrial environment test was performed in POSCO to verify the validity of the developed RFID system. The experimental results show that the target coil identification rate can be dramatically improved using the developed system.

This paper is organized as follows. In Section 2, the RFID-based metallic coil identification system is described and the pretest results and exposed problems are shown. Section 3 shows the further improvement of the RFID system in two directions and its simulation and experimental results are shown in Section 4. Finally, conclusions are drawn in Section 5.

2. BACKGROUND OF THE RESEARCH

The large size and heavy weight of steel products cause difficulties in logistics management, becoming the main causes of high logistics cost in the steel industry. Under the recent economic environment, since all industries have to acquire an international competitive edge in order to survive, an effective supply chain management system is highly required to reduce cost. The steel industry is a material supplier for others, such as the automotive industry, and thus, it plays a significant role.

This paper focuses on steel products, specifically steel coils, and the corresponding identification system for tracking and tracing autonomously. After manufacturing, the coil is packaged, banded, and kept in storage until delivered to the customer. Since the coil is extremely heavy, weighing over several tons, a crane is used for transport. The stored coil information is managed in two ways. First, a coil-storing map is used. When a crane moves a coil, information is updated. Second, if there is a problem on the map, workers check it by reading printed barcode labels attached to the coils. However, since the workers come close to the coils to read the barcodes one by one, the checking process takes time and can be very dangerous within the crane-operating boundary.

To address this problem, an RFID-based steel coil identification system is proposed in this paper. Unlike the barcode system, RFID reader can read distant tags simultaneously without the need for an optical line of sight. If an RFID tag is added to the label, the coil information can be read without human intervention.

2.1. Brief Introduction of the Proposed System

Figure 1 shows the proposed RFID-based steel coil identification system and its working environment. An ultra high frequency (UHF) RFID tag is attached to a coil, which is identified by a reader installed in the crane. Since the crane must lift up the coil at least two times (once for transporting to storage and a second time to loading to a vehicle for shipping as shown in Fig. 1, the inaccurate coil information caused by the error in the storing map data is corrected automatically during the crane operation. The photos of the crane and steel coil are shown in Fig. 2.

Table 1 shows the comparison between LF, HF, and UHF RFID system [6]. Since the tag could be easily damaged during transport

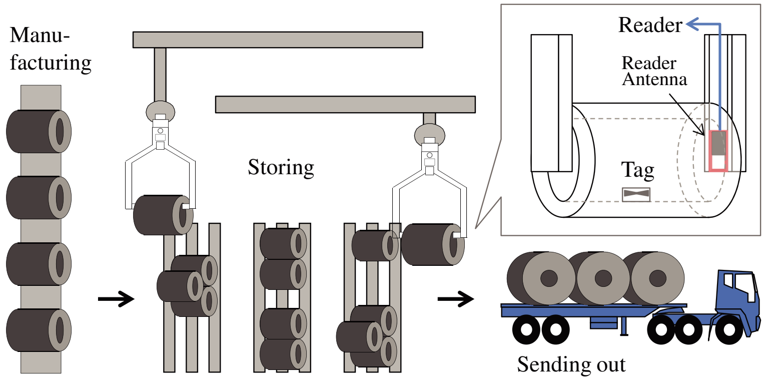

Figure 1. Overview of the developed system.

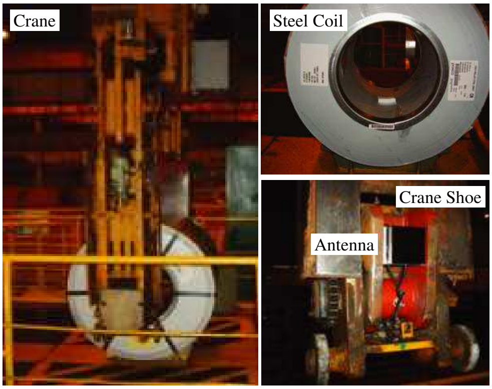

Figure 2. Snapshot of the crane and steel coil.

Table 1. Comparison of LF, HF, and UHF RFID.

Frequency Range	< 135 KHz (LF)	13.56 MHz (HF)	860–960 MHz (UHF)
Read Range	< 0.5 m	∼ 1 m	∼ 4–5 m
Tag Type	Passive Inductive Coupling		Passive or Active
Applications	Access control, Animal tagging, Immobilizer	Smart cards, Item-level tagging, Libraries	Supply chain pallet-box-level tagging, Toll collection

if attached to the bare outside surface, the tag is attached inside the coil hole. In order to sense the tag at least over 50 cm away from the coil plane in such an environment that the transmitted RF signal is easily distorted, UHF passive RFID is chosen. Table 2 shows the RFID system used in the proposed system.

It is true that the high frequency RF signal is easily distorted by environmental effects and it creates challenges for RFID-based identification. The metal causes eddy currents in the vicinity of the antenna; therefore, system performance factors, such as the identification rate, range and reliability are greatly reduced compared with the experiences in the ideal lab environment [6, 7].

Recent development of the metal mount RFID tags helps apply the RFID system to environment teeming with metallic objects. However, since most tags use a dielectric material [8–11] or high impedance surface substrate [12] to make an interval between the tag antenna and the attached surface and slit metallic plate with the appearance of a window [13], the price and the size prevent from applying them widely.

Regarding this problem, the flag-tag technique developed by UPM is used in the proposed system. If there is enough space between the antenna and metal, the RF communication becomes available. Flag-tag is a very simple idea used to make space by standing a tag upright,

Table 2. RFID system employed in the proposed system.

Reader	Alien ALR-9900 reader
Reader antenna	Ceramic Patch antenna (□ 80 × 7mm)
Tag	UPM Reflatac Dogbone Type
Tag on Metallic surface	Flag tag technique

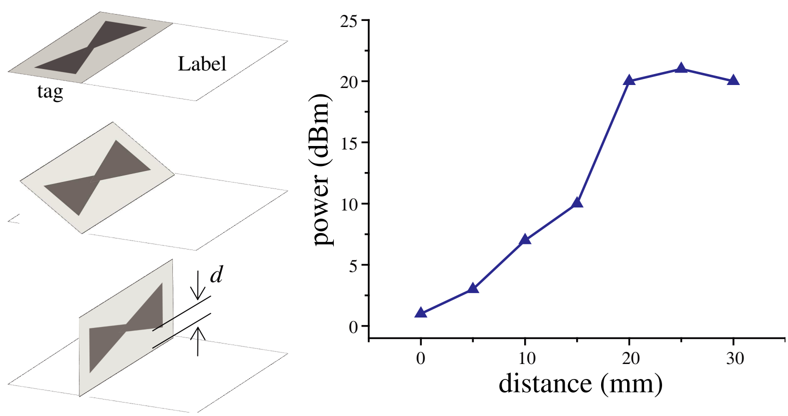

Figure 3. Basic concept of the flag-tag technique and the relationship between the transmitted RF signal and the gap distance, *d*.

as shown in Fig. 3 [14, 15]. This technique is similar to the tag using folded monopole antenna [16]. However, the flag tag technique can work with ordinary label tags and is less affected by the folded shape which produce enough space. The right of the figure shows the received RF signal strengths from a tag size of 93×23 mm according to the gap distance, d, between the metal surface and the bottom of the tag. As shown in the figure, the strength is not changed if the distance is over 2 cm.

2.2. Pretest Results and Problems

In order to verify the validity of the proposed system, the coil identification test was performed in POSCO. The test results are shown in Table 3. A printed label, including the RFID tag, was folded and attached inside the coil. When a crane transported a tag-attached coil, it checked to make sure the identified tag information was in accordance with the stored map information. If a wrong tag or no tag was detected, it was regarded as a failure. As shown in the results, the failure rate increased. This was caused by the increase of the tag-attached coils. Every day about 500 tag-attached coils are stored in the storage. As more tags are positioned, more neighboring tags are detected by the back-radiation of the RF signal from the reader antenna. To solve this problem, transmitted RF signal power from the reader was reduced from 12 dB to 8 dB starting from third day. However, RF power reduction caused an increase in the target tag missing rate. Note that the sensing range changed according to the radiated RF signal power from the reader antenna. Therefore, as the power increased, the neighboring tags were detected together and the radiated RF signal decreased; as a result, the reader could not detect any tag, as shown in Fig. 4.

Furthermore, the distortion of the tag by the attached surface condition affected the identification performance. The tag stood parallel to the curved surface in order to make the tag plane face the reader antenna located at the crane shoe, as shown in the left of Fig. 5. When two antennae are parallel, maximum energy can be transmitted

Table 3. Tag identification test results.

Day	1st	3rd	5th	7th
Wrong tag identification rate (%)	0.9	2.2	1.8	1.2
Target tag missing rate (%)	0.3	1.1	3.1	7.9
Total error rate (%)	1.2	3.3	4.9	9.1

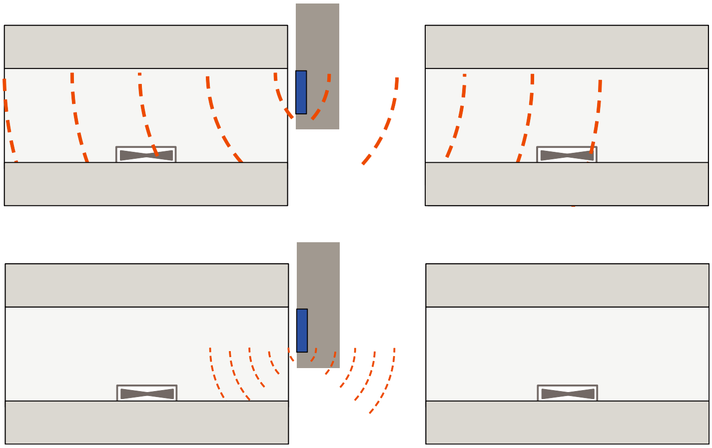

Figure 4. Relationship between the transmitted RF wave power and the identification performance.

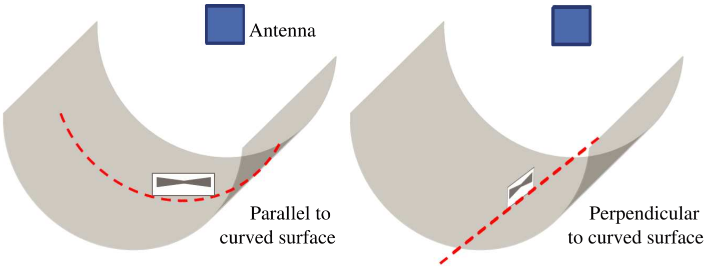

Figure 5. Tag attachment methods.

between them. However, since the lower part of the tag was straight but the inside surface of the coil was curved, the tag became displaced as time passed. decreasing the gap between the tag and the metal. The tags, of course, were not detected.

In order to solve the problems exposed from these test results, the RFID system was improved in two directions: (1) change of the tag attachment method and (2) beam radiation pattern control from the reader antenna.

3. SYSTEM IMPROVEMENT

3.1. Tag Attachment Method

The tag attached parallel to the curved surface is distorted, affected by the surface. It is possible to solve the problem by making the lower part of the tag fit to the curved surface. However, this would complicate the label folding process as various tags would need to be designed according to the various coil sizes.

A more simple method involves turning the tag attachment direction at an angle of 90 degrees, as shown in the right side of Fig. 5. The attached surface becomes flat, and thus the tag is not distorted. Note that the transmitted RF signal between the two antenna is maximized when the antenna are parallel. Thus, the perpendicularly attached tag would probably not receive the transmitted RF signal well. However, it should ne noted that the RF signal is transmitted in the hole of the coil. Since the RF signal is reflected from the inner curved surface, the transmitted RF signal strength is different from that in the free space.

In order to measure the transmitted RF signal strength changes according to the tag direction, RF signal propagation in various coils were simulated using the 2008 EM simulator of CST AG. Two kinds of coils with inside diameters of 50.8 and 60.1 cm were tested, reflecting the manufactured coil sizes from POSCO. The tag was positioned 50 cm inside the coil and the reader antenna was placed 15 cm above the coil hole center. The simulation results are shown in Table 4. When the inside radius of the coil was 61 cm, more energy was transmitted from the reader antenna to the tag, which was positioned parallel to the curved surface. However, the result were reversed when the radius was 50.8 cm.

The results of the real experiment test proved to be the same, as shown in Fig. 6. The x-axis of the graph refers to the attached tag position and the y-axis represents the attenuation value of the reader. Since the radiated signal from the reader antenna decreases when a higher attenuation value is set, the results at a higher y-

Table 4. Transmitted RF signal in various conditions.

	Transmitted RF signal (dB)	
Antenna relations	Parallel	Perpendicular
Inside diameter 61 cm	−31.37	−35.78
Inside diameter 50.8 cm	−38.78	−28.91

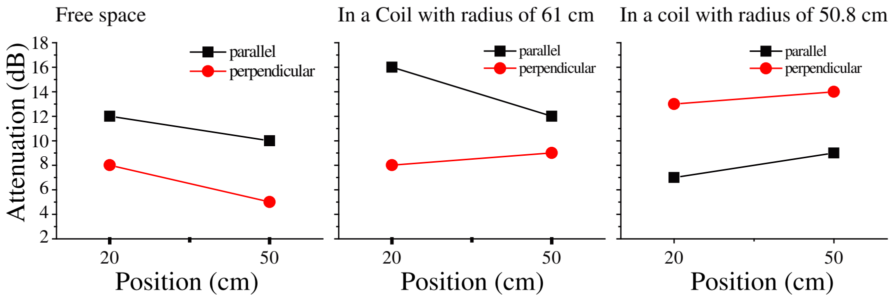

Figure 6. Test results according to the tag attachment methods.

value show that the RF signal is transmitted well. The inner hole of the coil works as a cylinder waveguide of which the propagation mode is determined by the inside diameter. Since various coils with different inner diameters are manufactured, the parallel attachment is not always advantageous in RF signal transmission, as proved by the experiment results. Therefore, the perpendicularly attachment is the chosen method, since it is robust due to the distortion caused by the attached surface.

3.2. Radiation Beam Pattern Control

The proposed attachment method prevents the tag from being displaced and may reduce the tag missing rate. However, the problem of sensing the neighboring tags by back-radiation of the antenna still remains. The radiated RF signal from a reader antenna propagates along the metal surface, causing back-radiation from the antenna. Thus, the wrong tag identification rate can be reduced by cutting down the surface wave. Also, it is helpful for increasing the tag identification performance by focusing the radiated RF wave to the target tag.

If the ground substrate of the patch antenna widens enough, the back-radiation can be canceled. However, since the antenna is installed to the crane shoe, the available space is only $\square$ 120 $\times$ 20 mm. It is possible to control the RF signal radiation pattern by using antenna array [17–19] and the lens aperture with the shielding structure [20]. However, there is not enough space to install the antenna array or shielding structure. Also, since the lens aperture projects out over the crane shoe plane, it can be easily broken during the crane operation. In this paper, an antenna case is recommended to control the radiated beam pattern of the reader antenna. The corrugated line technique is used to reduce the surface wave.

Figure 7 shows the corrugated line filled with a dielectric material.

The field on the corrugated surface can be derived from a potential function given by

$$\Psi = A_1 \exp\left(\frac{-2\pi bx}{\lambda}\right)\exp(-jk_z Z), \tag{1}$$

where A_1 is an amplitude, λ a wavelength of the field, b an attenuation constant, and k_z a wave number, respectively. Then, b can be determined from an impedance calculated as a ratio of the z-directed electric field and x-directed magnetic field, given by

$$b = \tan k_0 d\sqrt{\varepsilon_r}, \tag{2}$$

where k_0 is the free space wave number, d the corrugation depth and ε_r the relative dielectric constant, respectively. For a wave propagated along the corrugated surface in the z-direction, the wave number can

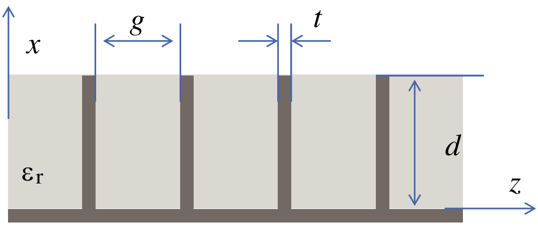

Figure 7. Overview of the corrugated surface.

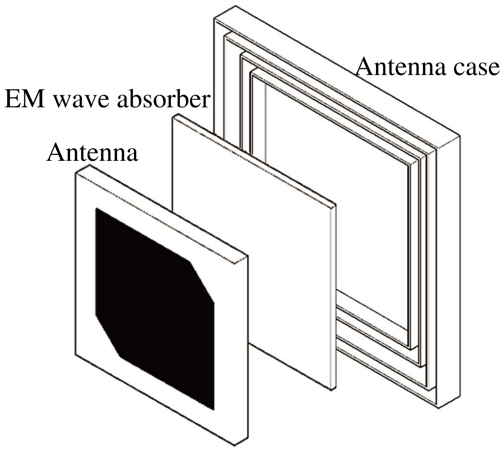

Figure 8. Developed antenna case.

be calculated as

$$k_z \approx (k_0\sqrt{\varepsilon_r})\sqrt{(1+\left(\frac{g}{g+t}\right)\tan^2(k_0 d\sqrt{\varepsilon_r})}, \tag{3}$$

where g is the width of each corrugation and t is the width of the edge. Approximately, $\frac{g}{g+t}$ becomes 1, if the t is much smaller than g. As the corrugation electrical depth, $k_0 d\sqrt{\varepsilon_r}$, is close to $\pi/2$, the attenuation constant b approaches infinity and the propagated wave becomes more tightly bound. As a result, the back-radiation of the antenna caused by the edge diffraction is reduced and the forward gain is increased [21–23].

Figure 8 shows the developed antenna case design. Three square corrugations cover the ground plane to reduce the edge diffraction. The size of the case is □ 110× 20 mm which considers the available installation space. The corrugation depth and slot width are about

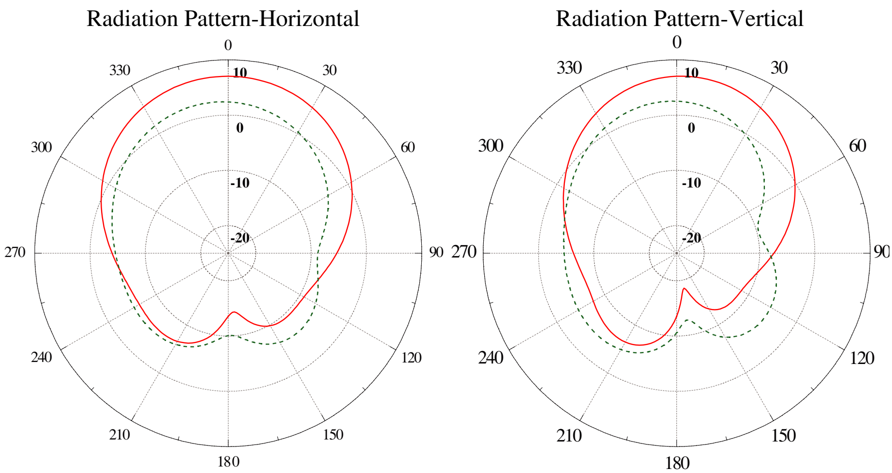

Figure 9. RF signal radiation pattern with and without the antenna case.

Table 5. Detailed RF signal radiation patterns with and without antenna case.

Property	Gain (dB)		Beam-width (deg.)		FBR (dB)	
	H	V	H	V	H	V
Without Case	2.10	1.48	131.81	104.59	1.66	3.49
With Case	3.98	1.49	110.39	94.99	13.31	16.29

Table 6. Detailed RF signal radiation patterns with and without antenna case.

Property	Gain (dB)		Beam-width (deg.)		FBR (dB)	
	H	*V*	*H*	*V*	*H*	*V*
Without Case	2.52	2.44	76	90	6.89	7.76
With Case	7.05	7.00	72	86	13.40	13.25

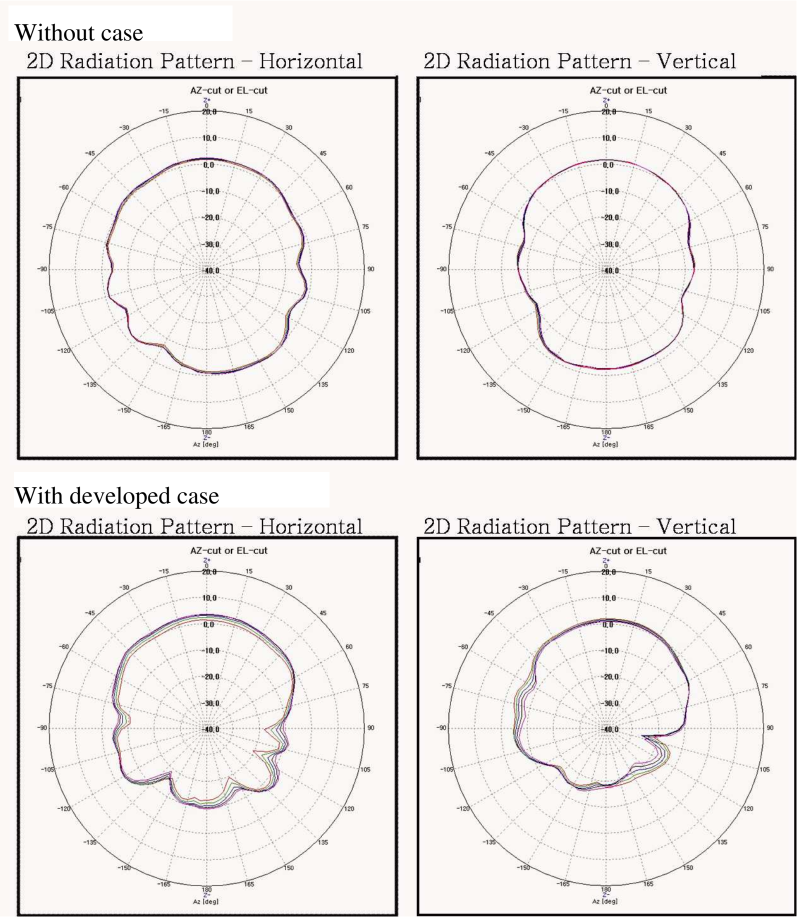

Figure 10. Overview of the developed system.

19 mm and 8.66 mm, respectively, and accounts for the required space needed to install a patch antenna of □ 80 and a metal plate of 1 mm thickness to make the case.

The corrugation slot is filled with polyvinylidene fluoride of which the relative dielectric constant is about 7.25. Therefore, the corrugation electrical depth from 917 to 913 MHz, the permissible frequency range in the Republic of Korea, is about 0.31π. Since it is over $\pi/4$, the propagated wave is reduced.

The back-radiation reduction performance was simulated using HFSS. Fig. 9 shows the simulation results. The green short-dashed-line in the graph show shows the simulation results of the ceramic patch antenna and the red straight line in the graph illustrates when the antenna is packaged in the case. As shown in the figure, the front-to-back ratio (FBR) decreased and was expected to reduce the wrong neighboring tag identification rate. The detailed measured data, including gain, beam-width, and FBR in horizontal (H) and vertical (V) view, are shown in Table 5.

Based on the simulation results, the antenna case was made using a Steel US Stainless (SUS) metal plate and tested in an electromagnetic dark room with dimensions of $L4.5 \times W9 \times H4.5$ m. In order to reflect the real working environment more accurately, the antenna was installed to a model crane shoe made from sheet zinc.

The test results are shown in Fig. 10. The upper graph is the radiation pattern without the case and the lower graph is with the case. The detailed measured data are shown in Table 6. As demonstrated in the corresponding figure and table, the developed antenna case with corrugations can reduce the back-radiation drastically and increase the gain, which in turn, reduces the wrong tag detection rate.

4. EXPERIMENT RESULTS

To confirm the validity of the proposed tag attachment method and the beam pattern control by the antenna case, the tag identification test was performed in a laboratory environment. Since it was impossible to use the real coil, model cylinder coils made from zync sheets with dimensions of ◯ 60 × 90 cm were used. In order to test the effects from the neighboring tags, two model coils were positioned as shown in the Fig. 11. The intervals between the coils and between coil and reader antenna were determined based on coil storing condition in the real storage and on the crane shoe position when it has descended to lift up a coil. Considering the case of the coil turning when it moves, a tag was attached clockwise from the top at a 30 degrees interval. Without the case, the reader could not detect the tag attached at 30,

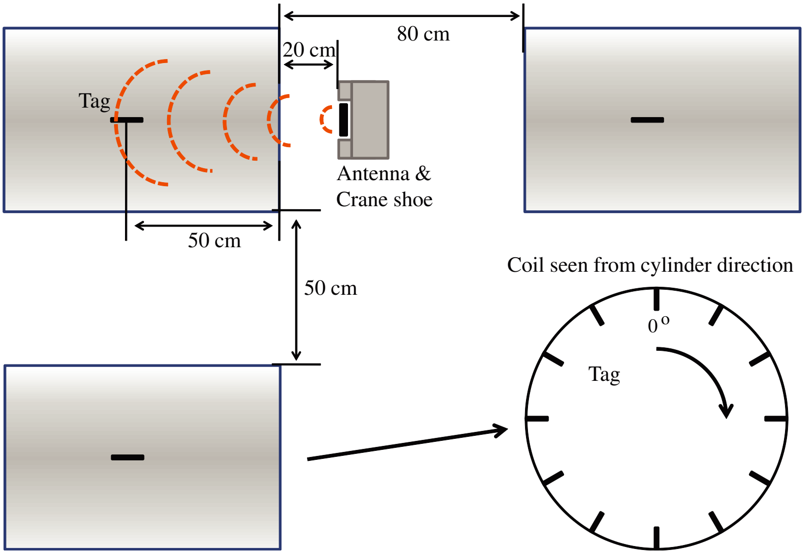

Figure 11. Test condition.

120, and 240 degrees. Also, the tags at 120 and 240 degrees attached to the coil positioned behind the antenna were detected. However, the reader could detect the target tag exactly when the case was applied for every condition.

Finally, the real working environment test was performed at POSCO. The test results are shown in Table 7. Since there were many tag-attached coils in the storage from the previous test, the test employing the perpendicular tag attachment method and the antenna case was performed over two days. The numbers in the parentheses are the number of cases when the reader identified a parallel-attached tag from the previous test. As shown in the table, the error rate was dramatically decreased almost by 0.5%.

When the crane lifted up a coil. the crane shoe is unfolded and the antenna faced downward. The tag, which was attached to the coil under the target, was detected in the test at that time. If the coil-checking process is modified to exclude the identified tag while the crane shoe is unfolded, it is possible to erase the error.

The proposed approach can improve the identification performance of RFID in the environment surrounded by metallic objects by controlling the antenna beam propagating direction. Thus, it can be transferred to other application domains, not limited to the steel products identification.

Table 7. Tag identification test results employing the developed system.

Day		1st	2nd
Issued Tags		405	392
Error	Wrong tag	2 (1)	0 (1)
Error	Missing	0	0
Error Rate (%)		0.49 (0.25)	0 (0.26)

5. CONCLUSIONS

An RFID-based steel coil identification system is proposed in this paper. Exact real-time tracking and tracing of the coil becomes possible by checking the loaded coil by the crane. However, the tag identification performance is negatively affected by environmental conditions containing metallic objects. To address this the problem, the RFID system was improved in two ways. First, a tag attachment method was proposed. The test results proved that a perpendicularly positioned tag identification performance did not decrease when the tag was attached in the metallic hole. Second, a reader antenna case was developed to control the radiation beam pattern. The reduction of the back-radiation from the antenna prevented the detection of neighboring tags. The test results in POSCO shows that the coil can be identified very successfully using the developed system. Future efforts include the improvement of the identification performance by adjusting the identification process to be suitable to RFID, and the upgrade of the developed system to cover other products such as steel plates and be applied to other application fields which require antenna beam pattern control.

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