Read-Rate Improvement in 920MHz RFID System with Circular-Polarized 2D Beam Scan R/W Antenna

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***Abstract*— Radio frequency identification (RFID) is a promising Internet of things (IoT) solution that bring about innovation in supply chain management. However, RFID has a read reliability issue in multipath radio propagation environment. In order to improve the reliability, we proposed a reader/writer (R/W) beam modulating scheme with a moving conductor. By modulating the R/W antenna beam, the multipath propagation structure can be changed and null points caused by standing waves are shifted. Thus, read success rate can be improved by the combination of repeated transmission and selection combining. In this paper, we propose a new 2D beam scan antenna for circular-polarized operation that is necessary for actual RFID systems. It has been confirmed from the simulation that the electric field distribution in a typical storage shelf can be changed by the proposed scheme. A prototype beam modulator with a decentered rotating circular conductor is fabricated and tested. RFID read measurement result shows that the proposed scheme can reduce the dead zone rate to less than half of the normal system.**

Keywords—IoT, RFID, read rate, beam scan, standing wave

I. Introduction

Internet of Things (IoT) technologies are playing important roles in wide areas of our lives. Radio Frequency Identification (RFID) [1] is an automatic recognition technology that connects an object to Internet by a small RF tag. Information stored in the tag can be read through wireless communication initiated by a reader/writer (R/W). It is expected to bring about revolution in the supply chain management (SCM) [2]. It is also expected to be integrated into sensor networks and can collect wider range of information that is not obtained by normal sensor devices [3].

Passive RFID system using UHF band (920MHz) attracts much attention for SCM because the tag is small, cheap and needs no battery, nevertheless it has relatively long range of a few or more meters [4]. However, read accuracy is a great concern because both wireless power transfer to the tag and reply communication from the tag should be successful at the same time. It is well known that the gain of tag antenna is greatly affected by the object that the tag is attached on. Therefore, many studies have been focused on the design of RF tag antennas [4-6].

On the other hand, wireless environments where SCM RFID system is operated are mainly indoor such as shops and warehouses, where floor, wall, ceiling, and other objects including metal storage shelves create multipath radio propagation. In such environments, the read accuracy is a serious issue because multipath propagation causes standing waves in the space. It was found that commercial tags could not be read at the null position of standing waves [7], hereafter we call it “dead point” or “dead zone”. Reference [8] proposed to cancel the standing wave by inserting a conductive film in the space. However, considering application of RFIDs in storage shelves, the film limits space utility of the shelves and will be difficult to deploy the technique. Another solution is to move a R/W antenna mechanically while reading the tags. Although the null position can be shifted by moving the antenna, it is necessary for the R/W-antenna connecting cable to be flexible and durable to tolerate the repetition of bends. Such cables are expensive and antenna moving mechanism makes the R/W complex and bulky in the UHF band.

In order to give a practical solution, we proposed a simple R/W beam scanning scheme with a moving conductor in the vicinity of the R/W antenna [9]. It can modulate the multipath propagation without moving antenna. Then, read success rate can be improved by the combination of repeated transmission and selection combining in time domain. In actual systems, however, a circular-polarized R/W antenna is mandatory because orientations of RF-tag antenna have variety depending on goods and environments. The beam scan system in [9] only shifts the beam linearly and does not consider circular-polarized operation. Therefore, it is necessary to develop a 2D beam scan R/W antenna for the circular-polarized operation and confirm the improvement effect by experiment.

In this paper, we propose a new circular-polarized 2D beam modulating R/W antenna with a decentered rotating circular conductor plate. By rotating the conductor plate in the vicinity of conventional circular-polarized patch antenna, the beam presents precession movement. It changes the structure of multipath propagation and shifts the null positions of the standing waves. The improvement of read success rate is confirmed by simulation and prototype measurement.

II. Propagation Contorol by Beam Scanning Antenna

Dead zone of RFID in static multipath environments corresponds to the null points of standing waves caused by multipath propagation. Fig. 1 explains by an example how null point appears in multipath environment. In Fig. 1 (a), three vectors originated from the direct-wave and two reflected-waves are summing at a receiving point and the resultant phasor has null amplitude. If the amplitude balance of three component vectors changes, the resultant phasor can escape from the null as shown in Fig. 1 (b). This means that the dead point moves to another area after the propagation structure has been changed. In order to change the amplitude balance of paths, the most

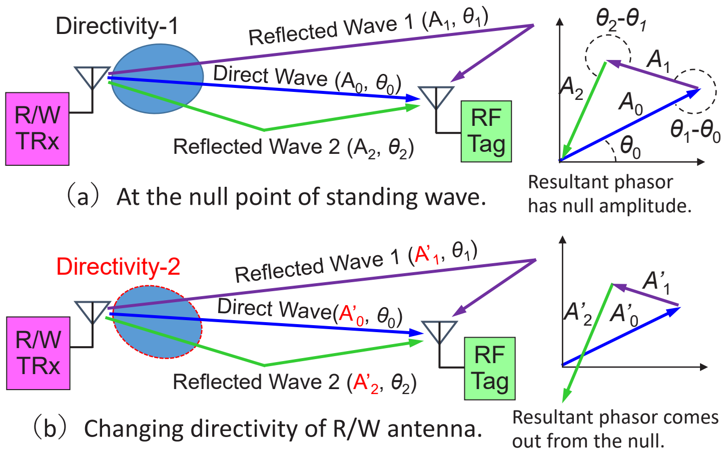


Fig. 1 Resultant phasor in multipath environment.

simple method is to modulate the radiation directivity pattern of transmitting antenna by beam scan. For realizing the beam scan, we proposed a method to add a passive-element conductor that is moving in the vicinity of the R/W antenna radiator [9]. Since the proposed method only changes the amplitude balance of paths by moving the director, the beam modulation is very easy, not requiring any complicated and expensive beam forming array antenna.

III. Circular-Polarized 2D Beam Scan R/W antenna

A. Structure

Fig.2 shows the whole structure of proposed R/W antenna consisting of a circular patch antenna and a rotating director plate. Same as commonly-used R/W antenna, we choose a circular-polarized patch antenna with two (V, H) feed points on the patch. The diameter of the radiator R_r is λ/2 (At 920MHz, around 16 cm). The added director metal plate has a diameter slightly smaller than λ/2 in order to work as a circular-polarized director. It is an electrically-floated passive conductor plate made by thin copper patch without ground plane. It is rotated mechanically but its rotation center is decentered by ΔR. This center offset gives a continuous position shift moving for the director. The conductor moving plane is set with the distance of D above the radiator, which is around a quarter wavelength.

Due to the moving director, R/W antenna beam is modulated in a precession mode according to the move of the conductor. Then, the amplitude ratio of direct wave to reflected waves at each receiving point changes, which causes shifts of the null position as shown in Fig. 1. This effect can be obtained without increasing the number of R/W antennas. Moreover, the method can apply all kind of RF tags and improve read accuracy. Since the beam scanner operates in circular-polarization mode, it can achieve high read rate not depending the orientation of RF-tag antenna.

Time diversity effect by repeated transmission and selection combining can improve the read success rate. The rotation speed of the director plate should be faster so as to generate sufficient change of radiation directivity during the interval of repeated transmissions. Suppose that frequency of R/W transmission is $f_{R/W}$ and the number of repeated transmissions for single read interval is N, the rotation speed f_{rot} is better to satisfy

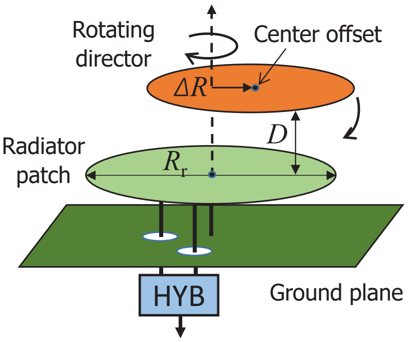
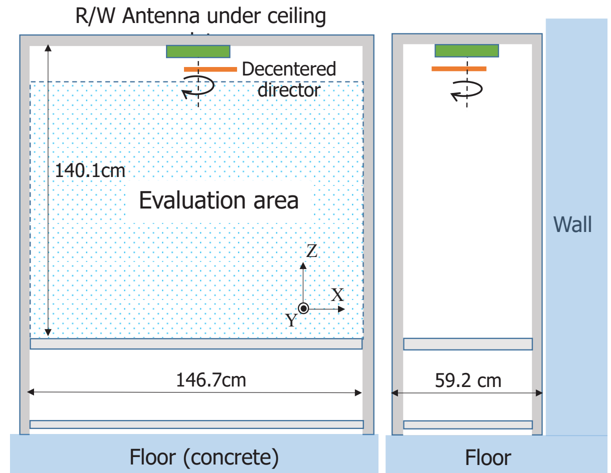


Fig. 2 Proposed circular-polarized 2D beam scan R/W antenna.



(a) Front view (b) Side view

Fig. 3 Supposed metallic storage shelf with R/W antenna.

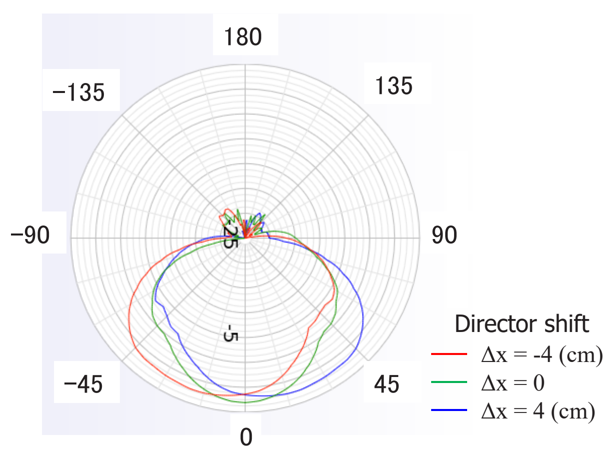


Fig. 4 Antenna directivity vs. director shift in metallic storage shelf.

$$f_{rot} \geq f_{R/W}/N. \qquad (1)$$

For example, supposing $f_{R/W}$ is 10 (Hz) and N is 10, f_{rot} is 1 rot/s (60 r.p.m.) or higher to cover full beam scanning. Degree of beam tilt by the director rotation depends on the center offset ΔR. This characteristic is analyzed supposing a model environment shown in Fig. 3. A metallic storage shelf is set indoor with the R/W antenna installed just under the ceiling

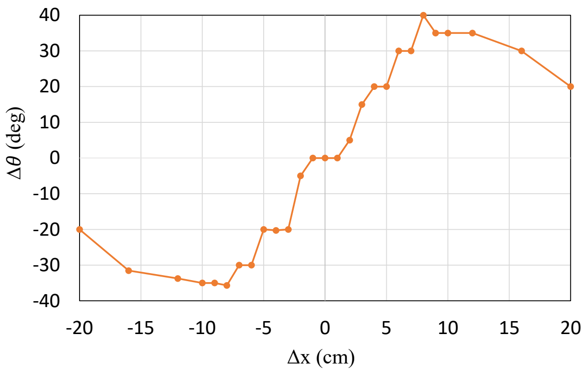


Fig. 5 Antenna directivity angle vs. director displacement [9].

plate. The backside and bottom side of the storage shelf are occupied with concrete wall and floor. Fig. 4 shows an examples of antenna radiation directivity patterns for three director displacements with ΔR of 4 cm ($\lambda/8$). It is obtained by electro-magnetic field analysis using Finite-Difference-Time-Domain (FDTD) method [10]. It is seen from the figure that the radiation directivity pattern changes according the director positions. The dependance of directivity angle $\Delta\theta$ on the x-axis displacement is shown in Fig. 5. $\Delta\theta$ changes when Δx shifts within ± 8 cm. Hereafter ΔR of 6 cm is mainly employed, which causes the $\Delta\theta$ of ± 30 degree.

IV. Electromagnetic Field Analysis

A. Analysis Model

Typical storage shelf model considered in this paper is shown in Fig. 3 When RFID is used in an iron storage shelf, standing waves occur due to the strong reflections from metal shelf boards in addition to those from wall, floor and ceiling. The R/W antenna is placed under the center of the ceiling board. It is expected to cover the evaluation area inside the storage shelf shown by the shaded area in Fig. 3. Table I shows system and simulation parameters. Table II shows the electrical characteristics of the materials used in FDTD analysis. Commercial FDTD software XFdtd was used for obtaining both radiation characteristics of the proposed R/W antenna and electric field strength (E.F.S.) in the evaluation area. The FDTD mesh size was set to one-tenth of the wavelength for the free space part and less than that for the other part including antenna, shelf board, wall and floor.

B. E.F.S. Maps in Metallic Storage Shelf

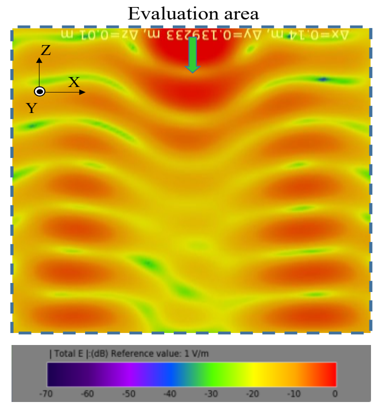
The distribution of the E.F.S. in the evaluation area were obtained as colored maps for several displacements of the conductor. Fig. 6 shows the E.F.S. maps in dBV/m for the proposed R/W antenna with director. As seen from the figure, standing waves with null area periodically appear in the evaluation area for all cases. In the null area, RF tags cannot receive necessary RF power for its operation. Fig. 6 (a) is for the case with no displacement of director. Fig. 6 (b) and Fig. 6 (c) are for the cases with left and right displacements of director, respectively. Comparing three displacement conditions, null area pattern changes due to the modulation of the directivity pattern. The E.F.S. is mostly higher than the normal antenna, which comes from the increase of antenna gain by the director.

TABLE I Simulation parameters.

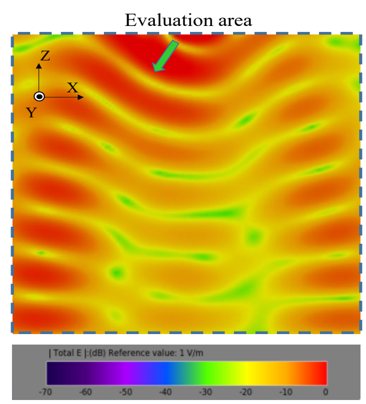
RF frequency	921 MHz
Transmit power	24 dBm
FDTD mesh size	< 0.1λ

TABLE II Electrical characteristic of materials.

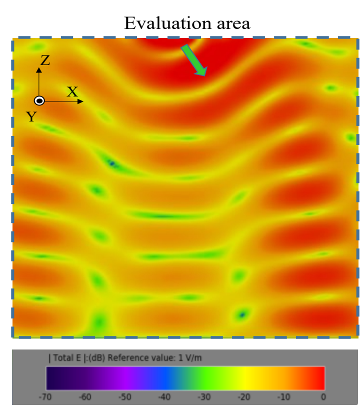
Conductivity	Iron	1.03×10^7 S/m
	Copper	5.98×10^7 S/m
Permittivity	Concrete	7.2+2.0j
	FR-4 circuit board	4.5+0.02j
	Acrylic	2.3 + 0.005j



(a) $\Delta x = 0$



(b) $\Delta x = -6$ (cm)



(c) $\Delta x = 6$ (cm)

Fig. 6 E.F.S. maps for three displacements of director.

Although the null area still exists widespread in the evaluation area for all cases, time diversity combining of the cases is possible by the director rotation and repeated transmission.

V. Prototype Measurement

In order to verify improvement of the reading rate for actual RFID system, a prototype beam modulating R/W antenna has been designed and fabricated. Fig. 7 shows the prototype R/W antenna with 2D beam modulator. It adds a motorized rotating director to the normal R/W antenna. The frame structure to hold the rotating director is made with acrylic material. The commercial RFID R/W, Fujitsu TFU-WR651A, and strip-type RF tag, Fujitsu TFU-TL4AxA, were employed for the measurement. The required E.F.S. for the tag is around -30 dBV/m. The R/W repeats transmission 15 times by transmission interval of 100 ms. Then the rotating speed of director is set around 42 r.p.m. After finishing repeated transmission trials, R/W combines the trial results and confirm the read success. The tag position in the evaluated area was one of mesh points with a mesh size of $\lambda/10$. More than 1700 mesh points were measured to create a read success area map.

Fig. 8 shows an example of measured read success area map for the R/W antenna with fixed conductor. The R/W antenna is set at the upper center of the evaluation area with conductor displacement (x, y) of (6cm, 0cm). In the figure, white area shows the RF tag positions of successful read, and black area shows dead zone. Although the antenna beam shifts to the right in this case, black areas appear periodically in evaluation area except for the vicinity of the R/W antenna. This trend can be expected from the FDTD analysis results in Fig. 6 and suggests that the null area caused by standing waves corresponds to the black areas. From the result, it is found that the addition of the fixed conductor cannot suppress the generation of standing waves. If we place an RF tag in the black area, R/W cannot read it even if we use repeated transmission and selection-combining time diversity. The dead zone rate is 22.5 % in the area.

Fig. 9 shows the measured read success area map for the R/W antenna with the rotating conductor. The unreadable area colored in black is remarkably reduced compared with that in Fig. 8. The ratio of black area is reduced to 9.1 %, which is less than half of the fixed director. Table III compares the median E.F.S. and dead zone ratios for the fixed director with four difference displacements A, B, C, D and for the rotating director. As shown in the table, the median E.F.S. and dead zone ratio for the rotating director is superior not only than the fixed directors A, B, C, D but also than the selection combining result of A to D. It is because the rotating director can generate variety of displacements not limited to A, B, C, D.

VI. Conclusion

For achieving high read accuracy of RFID, we proposed a new 2D beam scanning R/W antenna for circular-polarized operation. The radiation pattern of the antenna is modulated by rotating a decentered circular-patch director in the vicinity of circular-polarized R/W antenna. It has been confirmed from the FDTD EM simulations that the multipath propagation structure can be changed by the beam modulation, which shifts the null

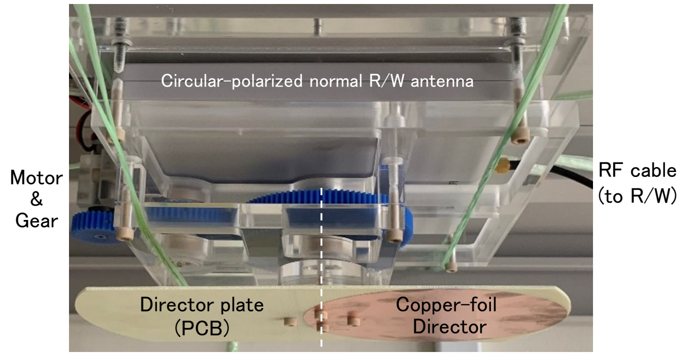


Fig. 7 Prototype R/W antenna with 2D beam modulator.

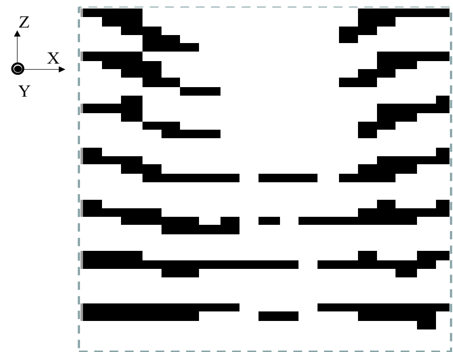


Fig. 8 Measured read success area map for the R/W antenna with fixed conductor (white: success, black: unreadable).

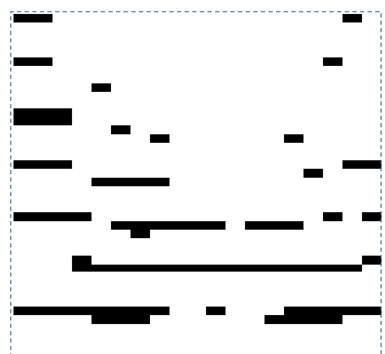


Fig. 9 Measured read success area map for the R/W antenna with rotating conductor.

TABLE III Measured median E.F.S. and Dead area ratios for different director displacement.

Displacement status(x, y)	Median of received E.F.S. (dBV/m)	Dead zone ratio (< -30 dBV/m)
Displacement A (-6cm, 0cm)	-25.3	21.5 %
Displacement B (6cm, 0cm)	-24.0	22.5 %
Displacement C (0cm, -6cm)	-26.0	29.2 %
Displacement D (0cm, 6cm)	-27.8	39.3 %
Selection combining (A, B, C, D)	-16.2	10.9 %
With director rotation	-15.9	9.1 %

position of the standing waves. Then, read success rate can be improved by time diversity effect of repeated transmission.

A prototype beam modulator with a decentered rotating copper plate is fabricated and tested. The measured read success area map shows that the prototype can reduce the dead zone to less than half of the normal antenna system.

It is concluded that the proposed scheme can reduce the impact of standing waves without employing complex R/W antenna systems such as moving antenna and beam forming array antenna. By adding the proposed beam modulator to the conventional R/W antenna, the dead zone can be greatly reduced.

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