Expansion of Communication Range of IC Tags Using Re-radiation of Passive Antennas

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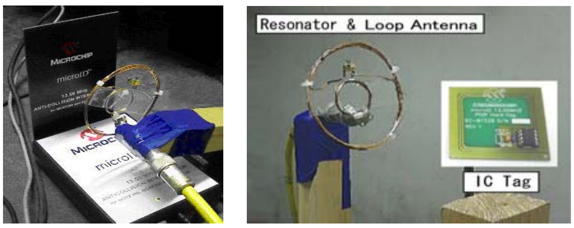
1. Introduction

This study proposes a wireless communication system [1]-[3] which transmits signals between an existing IC tag and an IC tag reader through a coaxial cable, and uses re-radiation from a passive antenna which incorporates no active element such as an amplifier. Using a coaxial cable, it becomes possible to extend the propagation distance to re-radiate electric waves in an area to which they are essentially unreachable by controlling their irradiation. We constructed this system using 13.56 MHz RFID of the electromagnetic induction method, and 2.45 GHz RFID of the microwave method, evaluated the properties of the reader and IC tag for realizing this method, measured the propagation loss of electric waves irradiated from the reader from various aspects, and considered the feasibility of this method both theoretically and experimentally.

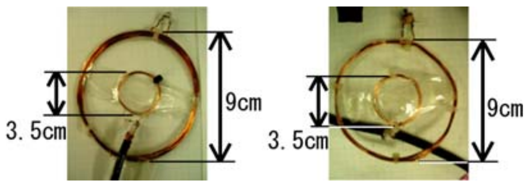
2. Experiments involving 13.56 MHz RFID

As shown in Fig. 2, we introduced the proposed system, which utilizes a coaxial cable between a reader and an IC tag. Resonators were installed in the loop antennas at the terminal and leaking parts of the coaxial cable, and one of the loop antennas was fixed to a position at which the level of the signal received by the reader's antenna was optimal, as shown in Fig. 2. Fig. 3 shows the appearances of the antennas used for reception and re-radiation at the terminal and leakage parts, which are of the same size and configured with a resonator and loop antenna, respectively. To confirm the operating principle, numeric calculation was also conducted using the moment method employing Rao Wilton Glisson's edge element [4].



(a) The reader and receiving part. (b) The re-radiation part and IC tag.

Fig. 2: The proposal system for 13.56MHz RFID.



(a) The end part. (b) The leakage part.

Fig. 3: Resonators and loop antennas.

2.1 Distance property of resonator

To survey the re-radiation property of the resonator, as shown in Fig. 4, a loop antenna for reception, which was connected to a spectrum analyzer, and a resonator were aligned together, moved respectively, and the signal strength of the loop antenna corresponding to the distance from the reader was measured. Fig. 5 shows the distance property when the resonator was fixed at position Dr and the loop antenna was moved. As a result, it was confirmed that the signal strength decreased as the distance from the reader increased, the threshold was -24.6 dBm when no resonator was installed, and the IC tag responded up to 16 cm away from the reader. On the other hand, when

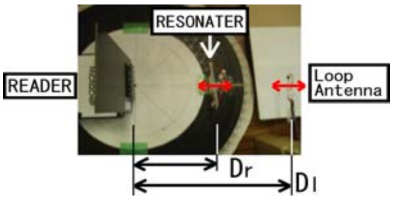


Fig. 4. The experimental configuration.

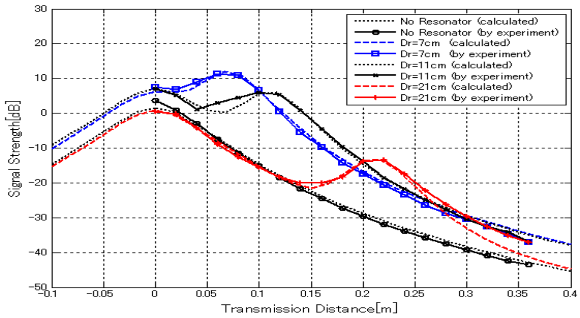


Fig. 5. The characteristic of the distance (the resonator is fixed to Dr).

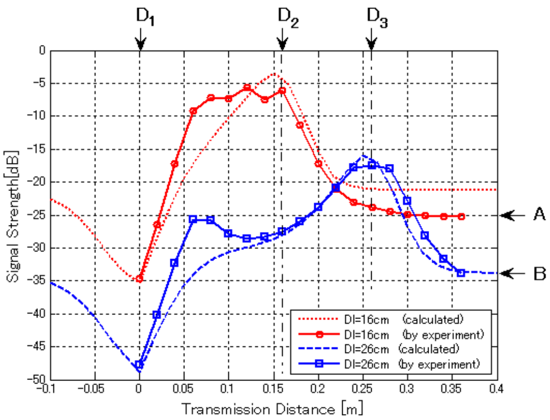


Fig. 6. The characteristic of the distance (the loop antenna is fixed to Dl).

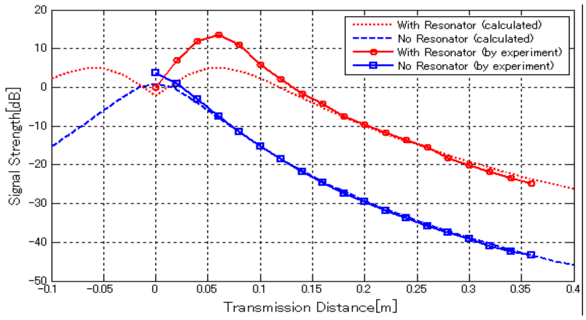


Fig. 7. The characteristic of the distance (the loop antenna with the resonator).

a resonator was installed, the signal strength increased as the loop antenna moved closer to the resonator, and showed a value of up to approximately 20 dBm higher than that when the resonator was not installed. Fig. 6 shows the distance property when the loop antenna was fixed to position Dl shown in Fig. 4, and the resonator was moved. The signal strength of the direct wave from the reader was A at a position of Dl= 16 cm, and B at a position of Dl = 26 cm. The figure shows that the signal strength of the loop antenna became lower when the resonator was very close to the reader (D1), and became higher as the resonator moved closer to the loop antenna (at D2 and D3). It seemed that misalignment of the resonance frequency due to the coming together of the two components influenced the former phenomenon. On the other hand, it seemed that re-radiation of the resonator influenced the latter phenomenon. Fig. 7 shows the distance property when a resonator was attached to a loop antenna, and they were moved together. It was confirmed that the signal strength increased by around 20 dB due to installation of the resonator, and the maximum communication range was almost doubled compared with when no resonator was installed. However, regarding the proximity of the reader, the signal strength when the resonator was installed was lower than that when it was not installed. This drop seemed to have been caused by the influence of the misalignment of the resonance frequency due to the mutual coupling between the antenna and resonator. Furthermore, a graph of dotted lines, as shown in Fig. 5-7, was obtained by this calculation, and such properties of the resonator were confirmed, although there were slight differences among the maximum values of signal strength.

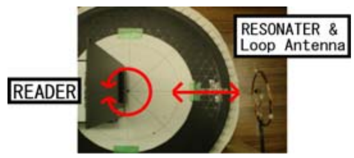


Fig. 8. The experimental configuration.

2.2 Angle property of resonator

As shown in Fig. 8, a loop antenna with a resonator was connected with a spectrum analyzer, and fixed at a position 25 cm away from the reader. The reader antenna was installed at the center of the turntable, electric waves were measured on rotating the antenna. Fig. 9 shows the results. Since the rear of the antenna could not be measured because of the structure of the reader, experimental values up

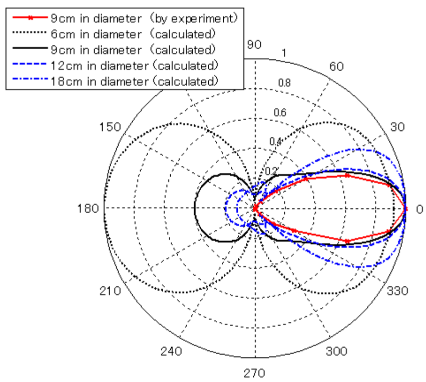
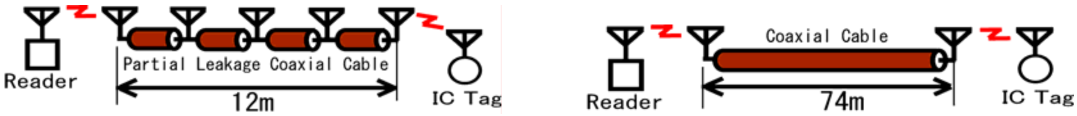


Fig. 9. The characteristic of the angle.

to ±90 degrees were shown by unbroken lines with markers. Although the IC tag was able to communicate up to ±50 degrees if there was no resonator, this range was ±20 degrees when the resonator was installed. As shown by the results in Fig. 5, there is a tendency whereby the antenna's vertical directivity becomes narrower as the influence of the resonator increases. As the resonator's diameter becomes closer to 9.5 cm, which is the width of the reader antenna, directivity is narrowed, and the signal strength of the loop antenna increases. When constructing the proposed system, we manufactured it with a resonator diameter of 9 cm. It was confirmed based on calculated values that this size was appropriate.

2.3 System application

We constructed a system as shown in Fig. 10 based on these property data of the resonator, and confirmed system operation. With one of the ends of the coaxial cable fixed to the antenna part of the reader, an IC tag was moved closer to the other four access points, and it was confirmed that the IC tag operated normally at all access points. It was also confirmed that the IC tag can be read and written up to 74 m if an antenna and a resonator are installed at both ends of a 3C-2V coaxial cable without providing leakage parts.



(a) The partial leakage coaxial cable. (b) The coaxial cable without leakage.

Fig. 10. The application of the proposal system.

3. Experiments involving 2.45 GHz RFID

To introduce the proposed system into the reader and IC tag, in which the electric wave method is adopted, we manufactured a coaxial cable equipped with antennas at both ends, as shown in Fig. 11. Using a 3-m long 5D-FB coaxial cable, the distance property was measured in the unechoic room using the following five antennas as antennas A and B at both ends: Dipole antenna, loop antenna, 3-element Yagi antenna, 6-element Yagi antenna, and patch antenna (the same product as the reader's antenna) (Refer to Fig. 12).

3.1 Distance property of antenna A

By moving antenna A connected to a spectrum analyzer from the position of the reader (at a distance of 0 mm, the reader is firmly attached to the case surface of the patch antenna), changes in electric field strength depending on the distance were measured. Fig. 13 shows the results.

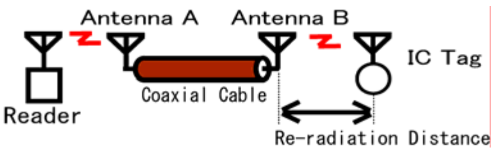


Fig. 11. The application of the proposal system.

(a) Reader antenna and A antenna (b) B antenna and the IC tag

Fig. 12. The antennas connected with the coaxial cable.

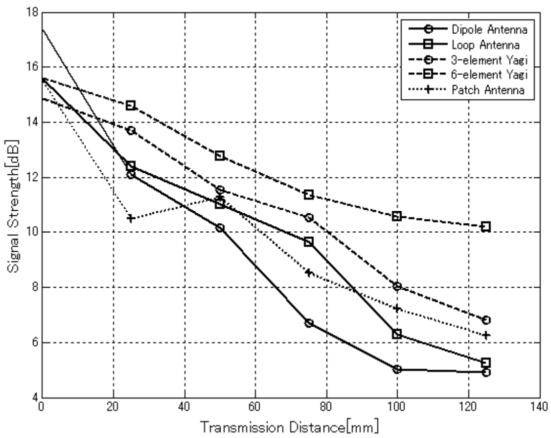


Fig. 13. The characteristic of the distance (A antenna).

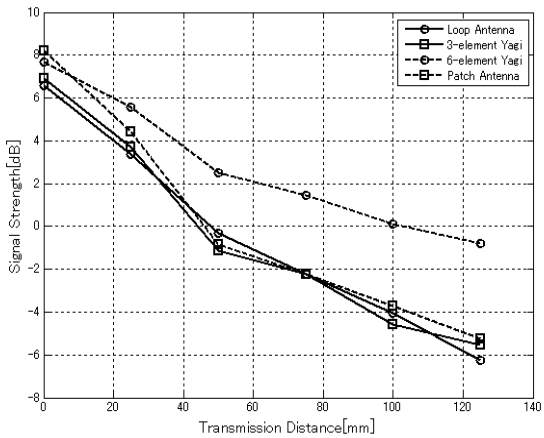


Fig. 14. The characteristic of the distance (B antenna).

Although the dipole antenna showed a good performance when firmly attached at a distance of 0 mm, the electric field strength decreased more sharply than in the other antennas as the distance increased, and showed the lowest value at a distance of 50 mm or more. The 3-element Yagi, 6-element Yagi, patch, and loop antennas showed almost equivalent performances when firmly attached; however, multi-element Yagi antennas showed a smaller attenuation than the other antennas as the distance increased.

3.2 Distance property of antenna B

Based on the results of 3.1, the dipole antenna was selected as antenna A, it was firmly attached and fixed to the reader antenna, and the strength of the electric field re-radiated from antenna B connected to the target antenna was measured by the reference dipole connected to the spectrum analyzer. Fig. 16 shows the results. At a distance of 0 mm, the patch antenna showed the strongest electric field strength, and the loop and 3-element Yagi antennas showed property curves similar to each other. The 6-element Yagi antenna showed a good distance property overall, in which the decrease in electric field strength was moderate or good over the distance range from 0 to 150 mm.

3.3 IC tag detection distance of antenna B

Using an IC tag instead of the reference dipole mentioned in subsection 3.2, the detection distance of the IC tag of antenna B was measured. Reading was conducted 100 times at each position of 10 mm intervals from 0 to 50 mm, and the distance just before the success rate dropped below 100% was judged as the maximum detection distance. The maximum detection distance of each antenna when the antenna was installed as antenna B was 10 mm for the loop antenna, 0 mm for the 3-element Yagi antenna, 30 mm for the 6-element Yagi antenna, and 10 mm for the patch antenna. By applying these results to Fig. 14, it was found that just under 5 dB was the threshold.

In this experiment, using a coaxial cable with antennas at both ends, the maximum detection distance of the reader, which was originally 120 mm, could be extended up to 3,030 mm. As a result, it is important to reduce the space propagation loss and extend the communication range to control how efficiently antenna B can receive microwaves irradiated from the reader via antenna A and re-radiate them.

4. Conclusion

In this study, we proposed an indoor wireless transmission system utilizing a coaxial cable having partially leaking parts. Moreover, we evaluated the properties of the resonator and antenna required for extending the communication range of IC tags, and considered the feasibility of introducing this proposed system into existing RFID systems of electromagnetic induction and microwave methods by conducting numerical calculations and experiments. The operating principle of the proposed system has been applied to relay microwaves in home-use cellular phones [5], helping minimize regions which cannot be reached by microwaves. It is expected that this technology, which extends the communication range using re-radiation from a passive antenna, will play an important role in so-called ubiquitous communication networks, educational technology, logistics, and so forth in the future.

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