A 2.45GHz band Passive RFID system using a single wire transmission line

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1. Introduction

Unique Identification codes offered by Radio-frequency identification (RFID) technologies enable a detection and recognition of tagged items. In a preliminary development phase, RFID technologies were mainly applied to an object tracking in logistics and inventory management. However, advantages of this technology were rapidly extended to other areas like management of books and documents.

Recently, the RFID system is used in a library. As a result, efficient collection management is realized. In the City of Kita Library in Tokyo, the RFID system is employed, and librarians can manage books by using a handy reader. As more effective managerial system, RFID smart shelf is proposed by some papers [1], [2]. However, the systems are generally very expensive, because it requires a lot of reader antenna to cover the entire shelf. In this paper, we propose a smart shelf utilizing a single wire transmission line [3] in order to reduce fabrication cost. This system manages the entire bookshelf by using a single wire and a reader.

2. The Passive RFID system using the single wire transmission line

Figure 1 shows a system configuration of 2.45 GHz band passive RFID system using the single wire transmission line. As shown in Fig. 1, a RFID tag is placed near the wire and a quarter wave length monopole antenna is arranged at the feed point. The RFID tag communicates with a reader by electromagnetic wave that propagates along the wire. Because of this feature, communication distance is greatly extended in comparison with that of a ordinary reader in the free space.

3. Simulation results

3.1 An analysis model

The single wire transmission line is modelled by conducting wire with radius of a mm. Electrical conductivity is infinitely. The monopole antenna in length of l_{Ty} is arranged on the wire, and T_{xl} is a distance between the antenna and the edge. As shown in Fig. 1, a dipole tag that is modelled by conducting wire with radius of a' mm and in length of l_{Ry} is placed near the wire, and S_R is a distance between the dipole tag and the wire, and D_{Ry} is a distance between the center of the dipole tag and the wire. The dipole tag has a matched load in the free space. Power is fed by a voltage source that has source impedance of 50 ohm. In Fig. 1, values of the parameters are as follows: W_{Rx} = 2060mm (16.9λ), T_{xl} = 36mm (0.3λ), l_{Ty} = 28mm (0.23λ), a = 0.605 mm ($4.96\times10^{-3}\lambda$). Operating frequency is f = 2.45 GHz. a' = 0.1 mm ($8.2\times10^{-4}\lambda$), l_{Ry} =51.5 mm (0.42λ), D_{Ry} =21.5 mm (0.18λ), S_{Rz} = 2.0 mm (0.016λ). The load of the dipole antenna is Z_L = 47.8 + j107.9 ohm that is complex conjugate of input impedance in the free space.

Simulation results were obtained by EEM-MOM ver. 1.6 [4] that is based on method of moment.

3.2 Characteristics of single wire transmission line

Input impedance of the single wire transmission line without the dipole tag is Z_{in} = 37.7 + j10.4 ohm, and Return Loss is -14.8 dB.

Current distribution on the wire is shown Fig. 2. The position of the monopole antenna T_y is 0 mm, and the wire edge is 2060 mm. As shown in Fig. 2, current distribution exhibits a standing wave pattern along the wire. This is because the current is reflected at the end of the wire. It is found that there are nodes on the wire in every half wave length. Therefore, the electric field also becomes a standing wave pattern. There is no electric field component E_x. The electric field near the wire is only E_y and E_z component.

3.3 Characteristics of single wire transmission line with the dipole tag

Figure 3 shows the relationship between transmission gain and distance *D*. *D* is the distance between the monopole antenna and the dipole tag. Transmission gain in the free space is also shown as a reference when both transmitting and receiving antenna are half-wave length dipole antenna. The gain of dipole antenna is assumed to be 2.15 dBi and receiving power is obtained by the Friis transmission formula. The transmission gain can be obtained by the following equation:

$$\text{Transmission Gain} = 10\log_{10}\frac{P_R}{P_T}\,[\text{dB}]$$

Where, P_T is transmitted power and P_R is received power. In Fig. 3, although there is a fluctuation that depends on the standing wave, it is found that the transmission gain of the single wire transmission line is much larger than that of the free space.

Figure 4 shows the relationship between the received power of dipole tag and the distance *D*. The minimum threshold power of the IC (integrated circuit) on the RFID tag is also shown as a reference. Where, the transmitted power is 24.8 dBm (300 mW), and the minimum threshold power is 3.42 dBm (2.2 mW) [5]. As shown in Fig. 4, the receiving powers at the nodes are below the threshold value around the end of the wire. The result suggests that dead spots occur at the antinodes of the current distribution.

3.4 A solution to suppress the dead spot

The dead spot is formed by reflected current wave from the edge of the wire. If the reflected current doesn't exist on the wire, the dead spots don't exist. It is necessary to attenuate the reflected current wave. Because the reflected current wave attenuates at the position far from the edge, the received powers at the nodes are larger than those around the edge of the wire. If the wire is much longer than 2060 mm in order to attenuate the reflected current, the dead spots can be suppressed. Therefore, the length of the wire W_{Rx} in Fig. 1 is changed to ten times longer one (W'_{Rx} = 20600 mm). This model is shown in Fig. 5. In this case, input impedance is Z'_{in} = 41.4 + j9.51 ohm, and Return Loss is -17.8 dB.

The receiving power distribution of extended wire model is shown in Fig. 4. As shown in Fig. 4, the receiving power up to the distance *D* of 2060 mm is larger than the threshold power. Therefore, dead spot can be avoided. However this structure is not applicative, because extended part is too long.

In order to solve this problem, we have meandered the extended parts. Figure 6 shows the meandered structure model. The design value is as follows: W_{Rx} = 2076mm (17.0λ), T_{xl} = 36mm (0.3λ), l_{Ty} = 27mm (0.22λ), a = 0.605mm (4.96×10^{-3}λ), M_y = 210 mm (1.72λ), m_y = 120 mm (0.98λ), M_x = 344 mm (2.81λ), m_x = 4 mm (3.2×10^{-2}λ). In this case, input impedance is Z_{in} = 52.9 + j11.0 ohm, and Return Loss is -19.1 dB. The power distribution of the meandered structure up to the distance *D* of 2060 mm is almost same as that of the extended wire model.

4. Experimental results

4.1 An experimental set up

The single wire transmission line and the extended wire with meander line structure model are configured by the copper wire and SMA connector. Figure 7 shows the photo of an experimental set up. The single wire transmission line models are connecting to a reader by coaxial cable, where the reader is HE-MU380-SH07 by HITACHI Ltd. [6]. And μ-chip tag is used as the dipole tag [7].

Position of the RFID tag is S_{Rz} = 2 mm, D_{Ry} = 21.5 mm. And it was moved along x axis with interval of 5 mm (0.04λ). Recognition rate is measured in the experiment.

The reading distance of the ordinary reader in the free space is about 545 mm.

4.2 Evaluation results of the single wire transmission line

Figure 1 shows the configuration of the single wire transmission line. The design value is as follows: l_{Ty} = 29 mm, T_{xl} = 36 mm, W_{Rx} = 2060 mm. In this case, return loss is -14.8 dB. Figure 8 (a) shows experimental result of the single wire transmission line. As shown in Fig. 8 (a), it is possible to read the tag up to the edge of the wire and this reading distance is much longer than that of the ordinary reader. In addition, the communication distance can be further extended by increasing the length of the wire. However, as well as the simulation, there exist dead spots in every half-wave length around the edge of the wire.

4.3 Evaluation results of the extended wire with meander line structure model

Figure 6 shows the extended wire with meander line structure model. The design value is as follow: W_{Rx} = 2300 mm, T_{xl} = 36mm, l_{Ty} = 30m, a = 0.605mm, M_y = 214 mm, m_y = 122 mm, M_x = 338 mm, and the meander was turned 42 times. In this case, return loss is -25.5 dB. Figure 8 (b) shows experimental result of meander structure model. As shown in Fig. 8 (b), the dead spots are removed. It is found that the meander structure is effective to minitualize the extended wire model.

5. An application image to a bookshelf

Figure 9 shows an implemented image of the single wire transmission line for a bookshelf. Where we assume the bookshelf consists of non-electroconductive materials. As shown in Fig. 9, the single wire transmission line communicates with RFID tag attached to the book. We think that a smart shelf will be realized by the system. As a result, it is thought that the book on the shelf can be managed in a low cost.

6. Conclusion

This paper has proposed the 2.45 GHz band passive RFID system using the single wire transmission line. The simulation and experimentation results show the standing wave is formed on wire, because the current is reflected at the edge of the wire. As a result, there was a point where RFID tag cannot be recognized on the wire. Therefore, the structure that could attenuate the reflected current was necessary. In this paper, the extended wire model and the extended wire with meander line structure model have been proposed and the experimental results that confirmed dead spots were removed by these method.

In addition this paper introduced application image of the proposed RFID system to bookshelf. The performance evaluation of simulations read of multiple RFID tags should be studied in the future.

Reference

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[7] http://www.hitachi.co.jp/Prod/mu-chip/jp/product/2004998_13904.html

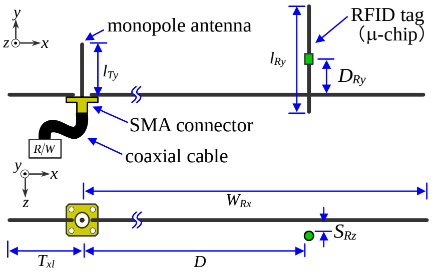

Figure 1 The RFID system utilizing the single wire transmission line.

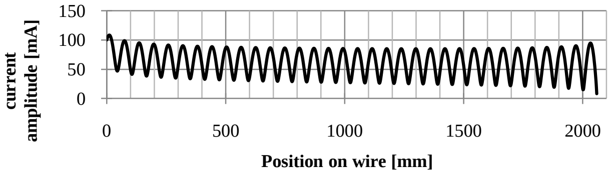

Figure 2 The current distribution on the wire of the single wire transmission line.

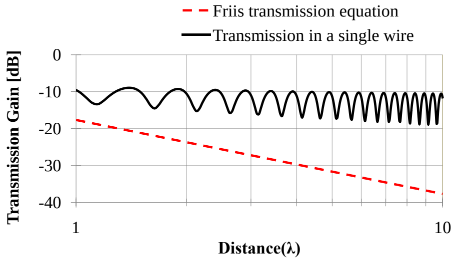

Figure 3 A comparison of transmission gain between the free space and the single wire transmissio line (S_{Rz} = 2.0 mm, D_{Ry} = 21.5 mm).

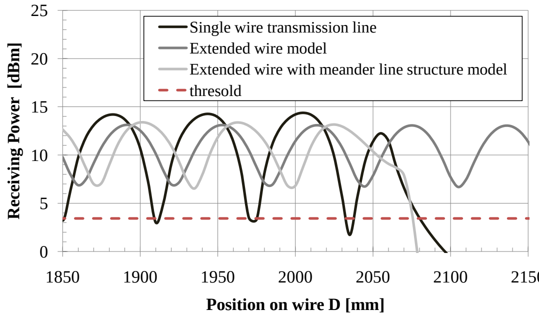

Figure 4 The comparison of receiving power of the RFID tag between the single wire transmission line, the extended wire model and the extended wire utilizing meander structure model as a function of D.

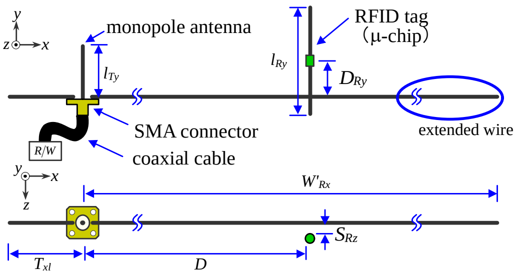

Figure 5 The extended wire model.

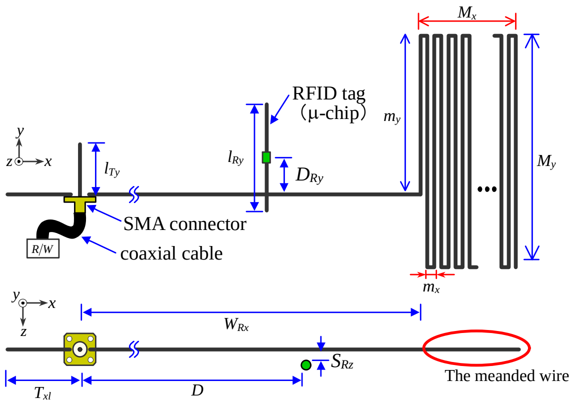

Figure 6 The extended wire with meander line structure model.

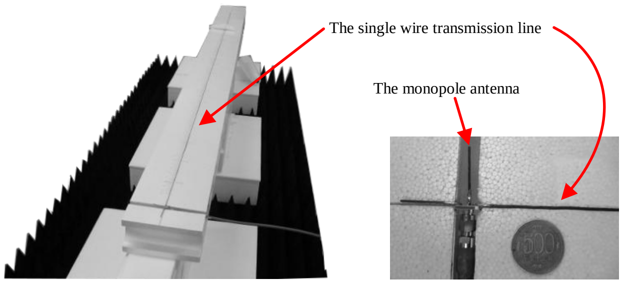

Figure 7 The photo of a experimental set up.

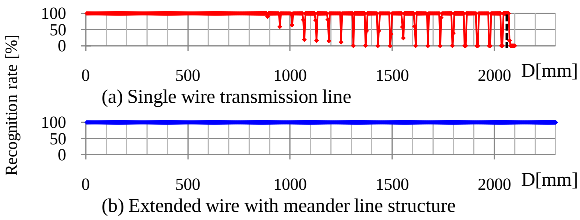

Figure 8 Experimental results.

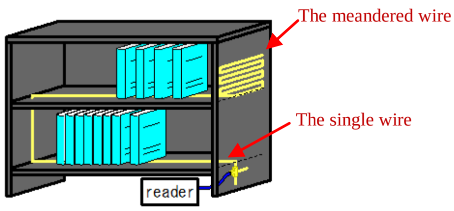

Figure 9 An implemented image of the single wire transmission line for a bookshelf.