# Reading Technique for Use with 2.45-GHz-Band Small RFID Tags

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## 1. Introduction

The 2.45-GHz-band small passive radio-frequency identification (RFID) tag [1] is only several millimeters in size, and is ideal for use with very small objects to which dipole tags cannot be attached. However, the small RFID tag available in today's market has poor impedance-matching characteristic and radiation efficiency, and cannot provide enough power to an integrated circuit (IC) chip by itself. To solve this problem, two techniques have been proposed for reading the tag. One uses a reader antenna consisting of parallel transmission lines [2]. The other uses an inductive coupling feed structure [3], [4].

In a previous work, we investigated placing a half-wavelength metallic wire beside the small RFID tag [4]. This paper extends that work by reporting development of an adapter that uses a square half-wavelength meander-line (ML) conductor, placed in the vicinity of the tag. Simulations and experiments confirm the effectiveness of this technique. The conductor improves the impedance-matching characteristic and radiation efficiency of the tag and its square shape relaxes requirements on alignment.

## 2. Proposed reading technique of the small RFID tags with the adapter

Figure 1 shows the proposed reading technique, which uses an adapter consisting of a square half-wavelength ML conductor installed on an ordinary reader. When the adapter is placed in the vicinity of a small RFID tag, sufficient power is provided to activate the IC chip to the load so that the tag can be recognized.

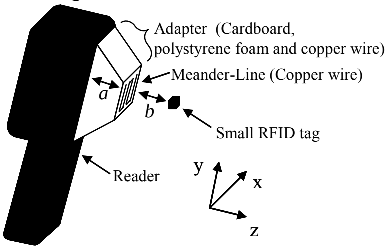


**Fig. 1** Configuration for the proposed reading technique.

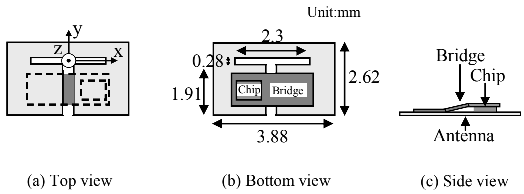


**Fig. 2** The small RFID tag.

## 3. Reading technique of the small RFID tags with the ML conductor

### 3.1 Antenna geometry and analysis of the small RFID tag

Figure 2 shows the geometry of the 2.45-GHz-band small RFID tag. There is a T-shaped slit on the tag. The IC chip is installed on one antenna terminal and a double-surface electrode is connected to the other antenna terminal by the bridge.

Simulations by the method of moment show that the input impedance of the tag is $Z_a = R_a + jX_a = 0.001 + j32.8\ \Omega$. Simulation parameters are as follows: number of expansion functions in the x axis = 60, in the y axis = 40; wire radius = 0.013 mm. The analysis software is EEM-MOM ver. 4 [5].

Since the metallic trace of the tag is very small compared to the wavelength at the operating frequency, the antenna can be considered to be a small loop antenna with input impedance of small resistance and positive reactance, and constant phase distribution of current along the T-shaped slit.

### 3.2 Assumption on a load impedance of the small RFID tag

Before analyzing the impedance-matching characteristic of the small RFID tag, we need to know the input impedance of the IC chip on the small RFID tag. However, we cannot know its value from the product literature [1].

Therefore, we assume that the small RFID tag uses almost the same μ-chip IC as a dipole tag [6] available in today's market. Figure 3 shows the antenna geometry of the dipole tag with L-shaped slit [7], [8]. Since this dipole tag antenna is assumed to be perfectly matched to the chip, we can determine the input impedance of the chip by analyzing the input impedance of the dipole antenna.

The input impedance of the dipole antenna obtained by the method of moment is 6.3 + j48.3 Ω, similar to the complex conjugate of the input impedance of an IC chip mentioned in [9]. Parameters are as follows: number of expansion functions in the x axis = 265, in the y axis = 7; wire radius = 0.031 mm. Finite-difference time-domain (FDTD) analysis to confirm the validity of the simulation result obtained by the method of moment yields almost the same input impedance as the method of moment. Thus, the input impedance of the IC chip $Z_L$ is the complex conjugate of that in the dipole antenna: $Z_L = R_L + jX_L = 6.3 - j48.3$ Ω.

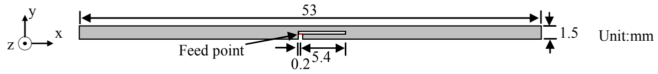


**Fig. 3** The dipole tag.

## 3.3 Reading principle of the small RFID tag

The power transmission coefficient τ [10] in the Friis transmission formula in Eq. (1) is as small as $9.08 \times 10^{-5}$ for the small RFID tag. It is so small because the real part $R_a$ of the small RFID tag antenna is much smaller than that of the IC chip impedance. The coefficient is obtained by substituting $Z_a$ and $Z_L$ into Eq. (2), where $P_r$ is the receiving power of the chip, $P_t$ is the transmitting power of the reader, $G_t$ and $G_r$ are the gains of a transmitting and a receiving antenna, r is the distance from reader to tag, and λ is the wavelength at the operating frequency.

$$\mathbf{P}_r = \left(\frac{\lambda}{4\pi \mathbf{r}}\right)^2 \mathbf{P}_t\mathbf{G}_t\mathbf{G}_r\tau \qquad (1) \qquad\qquad \tau = 1 - \left|\frac{\mathbf{Z}_L - \mathbf{Z}_a^*}{\mathbf{Z}_L + \mathbf{Z}_a}\right|^2 = \frac{4\mathbf{R}_L\mathbf{R}_a}{\left|\mathbf{Z}_L + \mathbf{Z}_a\right|^2} \qquad (2)$$

Furthermore, for a small RFID tag, loss resistance may be comparable to or larger than radiation resistance. Large loss resistance results in a large reduction in radiation efficiency and thus decreases gain.

These are the reason why an ordinary reader cannot read the tag.

Impedance-matching characteristic and radiation efficiency can be improved by placing a square half-wavelength ML conductor in the vicinity of the small RFID tag. Figure 4 shows the geometry of the tag and conductor. Electromagnetic radiation from the reader induces electric current on the conductor, and this current causes a magnetic field that induces current on the tag. Current flows on the tag and electric power is supplied to the load. This principle is based on the inductive coupling feed structure [3].

Figure 5 shows the equivalent circuit for input impedance analysis [3]. When the square half-wavelength ML conductor resonates, the input impedance $Z_a'$ of the small RFID tag is given by

$$\mathbf{Z}_a' = \mathbf{R}_a' + \mathbf{jX}_a' = \frac{(2\pi \mathbf{f}_0\mathbf{M})^2}{\mathbf{R}_{rb}} + \mathbf{j}2\pi\mathbf{f}_0\mathbf{L}_{loop}, \qquad (3)$$

where $f_0$ is the resonance frequency, $L_{loop}$ is the inductance of the tag, M is the mutual inductance, and $R_{rb}$ is the resistance of the conductor. From Eq. (3), the real part $R_a'$ of $Z_a'$ is proportional to the square of the mutual inductance M and inversely proportional to the resistance $R_{rb}$ of the conductor. The imaginary part $X_a'$ is independent of M and $R_{rb}$, and $X_a'$ is determined only by the structure of the tag. Therefore, it is possible to adjust the real part $R_a'$, while keeping the imaginary part $X_a'$ constant by placing the conductor.

For example, if the resistance of a half-wavelength straight conductor is 72 Ω and that of a square half-wavelength ML conductor is 8 Ω, as described above, the latter increases $R_a'$ and more effectively improves the impedance-matching characteristic and radiation efficiency of the small RFID tag. Parameters for this analysis are as follows: number of expansion functions for the half-wavelength straight conductor = 913, for the square half-wavelength ML conductor = 633; wire radius = 0.3 mm.

We also investigated the magnetic field distribution around the square half-wavelength ML conductor, with a 1 V source at the center. Figure 6 shows the $H_z$ component that contributes to inductive coupling. The calculated area is 20 x 20 mm in the x-y plane. There is a strong magnetic field inside the conductor, implying that alignment between tag and conductor can be relaxed.

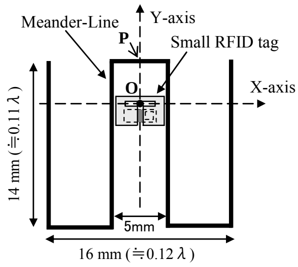


**Fig. 4** The small RFID tag and the square half- wavelength ML conductor.

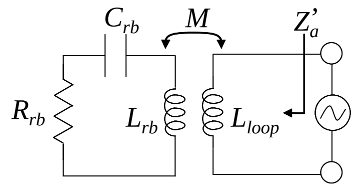


**Fig. 5** Equivalent circuit of an inductive coupling feed structure.

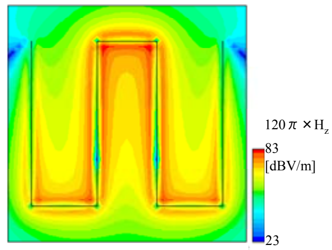


**Fig. 6** Magnetic field around the square half-wavelength ML conductor.

# 4. Experiment and analysis of the small RFID tag with the ML conductor

Figure 1 shows the composition of the small RFID tag and the square half-wavelength ML conductor. In Fig. 1, *a* is the maximum distance between the reader and conductor, and *b* is the distance between the tag and conductor. The tag is coated by some insulator to a thickness *b* of 0.3 mm. The conductor is moved every 0.5 mm along the y axis and the coordinate of the tag is fixed as shown in Fig. 4.

Figures 7 and 8 show the input impedance and gain of the tag with the conductor, calculated by the method of moment. The horizontal axis shows the y-axis coordinate of point P on the conductor; zero means that point P exists on the horizontal slit of the tag. The gain in the reader direction largely deteriorates at y-axis coordinate -0.5 mm because coupling between the tag and conductor becomes weak and current on the conductor is considerably reduced.

Figure 9 shows the power transmission coefficient $\tau'$ calculated using Eq. (2) rather than $Z_a$ in $Z_a'$. The real part of the input impedance is relatively large and the matching condition is considerably improved when the coordinate of the conductor is greater than zero; that is, the tag exists mostly inside the conductor.

Figure 10 shows simulation and experimental values for the maximum read range *a*. The simulation results are obtained by

$$\mathbf{a} = \frac{\lambda}{4\pi}\sqrt{\frac{\mathbf{P_t G_t G_r' \tau'}}{\mathbf{P_{th}}}}. \qquad (4)$$

The reader is an R001M (Sekonic Company) and the output power is 10 mW/MHz. Bandwidth is 20 MHz, therefore, the transmitting power $P_t$ is 200 mW. $P_{th}$ (2.2 mW) is the required minimum threshold power [11], and $G_r'$ and $\tau'$ are the gain and power transmission coefficient of the tag with the conductor. The gain of the reader antenna is determined as follows. The maximum read range of the dipole antenna in experiment is 297 mm under free space. The gain of the dipole antenna is about 2.14 dBi, and power transmission coefficient is assumed to be one. Therefore, from the Friis transmission formula for the dipole tag, reader gain $G_t$ is expected to be 8 dBi.

When *b* = 0.3 mm, the maximum read range has been obtained. We can see by Fig. 10 that experimental results are in close agreement with simulation results.

Evaluation of the effect of coating thickness for *b* = 1, 2, and 3 mm (Fig. 10) confirms that thicknesses up to *b* = 3 mm are acceptable. At *b* = 4 mm, the tag cannot be recognized even for *a* = 0 mm.

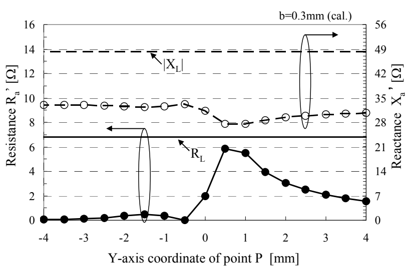


**Fig. 7** Input impedance.

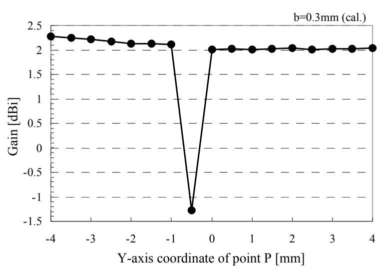


**Fig. 8** Gain to the reader direction.

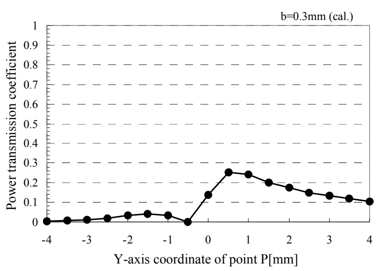


**Fig. 9** Power transmission coefficient.

## 5. Analysis of the adapter employing the ML conductor

Figure 11 shows a prototype adapter, constructed, based on the preceding discussion, from cardboard, polystyrene foam, and copper wire. The adapter thickness is 23 mm which can support the coating thickness of up to 2 mm.

Figure 12 shows that the small RFID tag can be read in most regions of the adapter. Thus, the requirement concerning alignment between adapter and tag can be relaxed. Furthermore, this region corresponds to where strong magnetic field exists, so the validity of the proposed reading technique is confirmed.

In addition, we verified that the proposed technique can read a dipole tag. The maximum read range in the x- and y-axis-oriented dipole antenna are 149 and 115 mm, respectively. Therefore, the reader can read both a small RFID tag and a dipole tag.

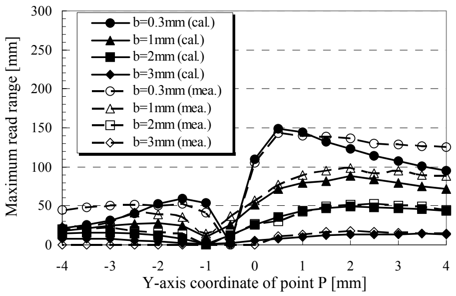


**Fig. 10** Maximum read range.


**Fig. 11** Reader with the adapter.

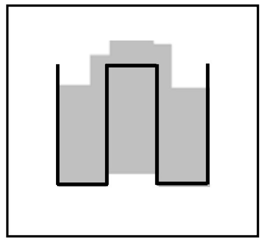

**Fig. 12** The small RFID tag can be read in the shade region on the adapter.

## 6. Conclusions

We have described a new technique for reading a small RFID tag using a squared half-wavelength ML conductor as adapter. We show that the tag and adapter compose an inductive-coupling feed structure with considerably improved impedance-matching characteristic and radiation efficiency. A coating of 3 mm thickness is allowed for the case of an R001M reader (Sekonic Company). Experimental results confirm that the proposed shape of the adapter effectively relaxes the requirement for alignment between the tag and adapter. Results also confirm that the technique is effective for reading the dipole tag 149 mm away from the reader, although with reduced maximum read range.

### References

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