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UHF RFID Tag Antenna Impedance Measurement Using an Imaging Theory Approach

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Abstract The communication performance between reader and transponder in ultra-high frequency (UHF) radio frequency identification (RFID) strongly depends on the matching between the chip in absorbing state and the antenna of the transponder (tag). In this contribution a measurement method is introduced to determine the tag antenna input impedance versus frequency using imaging theory. Additionally, the influence of the relative permittivity of the substrate on the impedance of the printed antenna is demonstrated, highlighting the importance of understanding the dielectric constant of the substrate in the design of UHF RFID tag antennas.

Key words RFID, UHF, tag antenna, impedance matching, power transmission coefficient, imaging theory

1. Introduction

Ultra-high frequency (UHF) radio frequency identification (RFID) is a wireless identification system used for power and data transmission [1]. It consists of a reader and a transponder (tag), where power and data transfer from the reader is carried out through wireless communication using electromagnetic fields [2]. Particularly, in passive RFID, the tag does not have its own power supply, so all the power required for its operation must be supplied by the electromagnetic field emitted from the reader.

An RFID tag is composed of an antenna and a chip. The chip functions as a switch that alternates between two impedance states to match or mismatch with the antenna [3]. In the matched impedance state, impedance matching occurs between the chip and the antenna, allowing the power received from the reader to be absorbed. In the mismatched impedance state, the impedance mismatch results in power reflection. These modes are controlled to achieve modulated backscattering reference.

Therefore, the impedance matching between the chip and the antenna in the absorbing state significantly affects the communication performance between the reader and the tag. To maximize the power transferred to the internal circuit of the chip, the antenna-chip power transmission coefficient τ at the antenna-chip interface must approach one at the operating frequency. τ is defined by:

$$\tau = \frac{4R_{Abs}R_{Ant}}{|Z_{Abs}+Z_{Ant}|^2} \qquad (1)$$

where Z_{Abs}, Z_{Ant} are the input impedance of the chip in absorbing state and the antenna, and R_{Abs}, R_{Ant} are their resistances [4][5]. Since the chip impedance cannot be arbitrarily selected due to ship design constraints, the antenna design must take the chip's impedance into consideration.

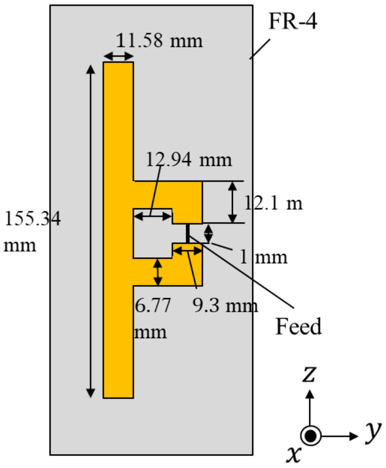
In this paper, a T-matched dipole antenna [4] is newly designed for a specific chip device, and the antenna input impedance is investigated via simulation using the finite element method (FEM) with Ansys' three-dimensional high-frequency electromagnetic simulator (HFSS) and measured versus frequency using imaging theory [6][7].

2. Tag Antenna Design

The RFID tag chip used in this work is from the Impinj M700 series [8]. The chip input impedance in absorbing mode is $Z_{Abs} = (11.3 - j177.3)\ \Omega$, at 864 MHz based on the chip equivalent circuit [8].

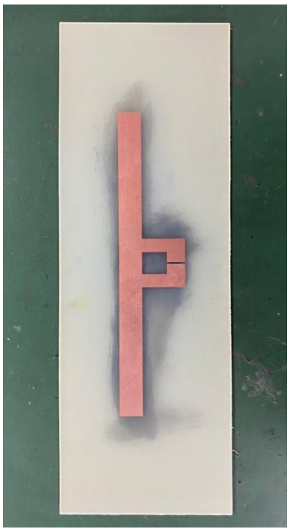
A T-matched dipole antenna was designed that better matches the chip at 864 MHz using HFSS printed on FR-4 substrate with a thickness of 1.6 mm. The dimensions obtained by simulation can be seen in Figure 1(a) and (b). The antenna input impedance is $Z_{Ant} = (18.85 + j173.21)\ \Omega$ at 864 MHz. The corresponding transmission efficient is $\tau = 0.9$ at 864 MHz, so it can be concluded that the power flowing into the chip's internal circuitry is maximized at the operating frequency.

Next, a substrate with unknown relative permittivity in the lab was used to estimate the relative permittivity of the substrate based on simulation. We used a random substrate with the sickness of 1.6 mm and designed an antenna with the same dimensions as in Figure 1 (a) and (b) (shown by Figure 1(c)).



(a) Top view

(b) Side view



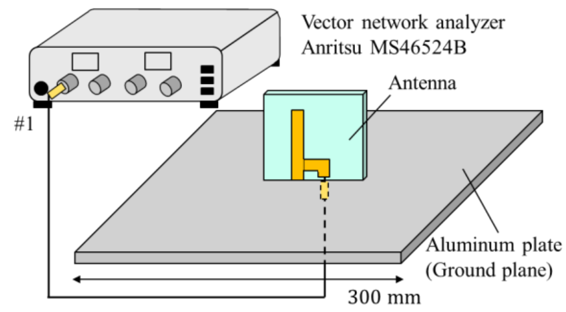
(c) Antenna prototype

Figure 1. Antenna model

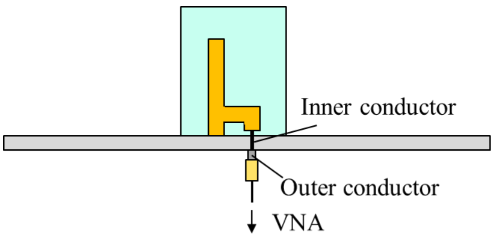
3. Impedance Measurement

Imaging theory is a method of splitting a dipole antenna into two symmetrical parts and measuring the impedance by treating them as monopole antennas [9]. A monopole antenna is placed on a conductive plate (ground plane) that can be considered to be infinitely large. An unbalanced monopole antenna can be considered to be a balanced dipole antenna by using the base plate. Therefore, the impedance of the monopole antenna measured by this method is half that of the dipole antenna being measured.

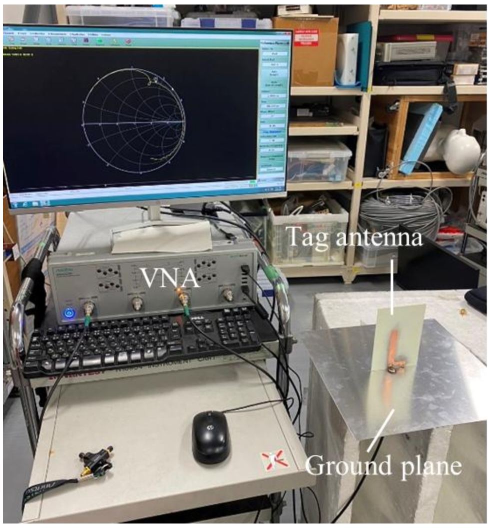
For verification, the input impedance of the prototyped tag antenna is measured versus frequency. Figure 2 shows the measurement setup. The antenna was created according to the dimensions in Figure 2 and cut along the center of the feed line. The antenna was set on an aluminum plate that was sufficiently larger than half the wavelength, and a hole was made in the area where the antenna feed section was connected. The size of the ground plane is verified in detail in [9] and [10]. An SMA connector was passed through from the back and soldered to the antenna. The inner conductor of SMA connected to the antenna, and the outer conductor connected to the ground plane. With a vector network analyzer (VNA: Anritsu MS46524B), the reflection coefficient at the input of the antenna is measured.



(a) Bird view



(b) Side view



(c) Measurement setup in lab
Figure 2. Measurement setup

A calibration was performed based on Short-Open-Load-Through calibration kit (Anritsu TOSLKF50A-20) at the coaxial cable connected to the VNA. Then, the measurement reference plane was shifted by attaching the same type of SMA connector to the cable and short-circuit the inner conductor with aluminum foil.

In Figure 3 measurement and simulation results of the antenna's input impedance versus frequency f are depicted. As shown in Figure 3, the antenna impedance measurement results generally match the simulation results at low frequencies, but at high frequencies, the frequency characteristics shifted toward the high-frequency side. In other words, the resonance frequency is higher in measurement than simulation. Although there is a shift, the general shape of the impedance graph is consistent, demonstrating the high accuracy of this impedance measurement method.

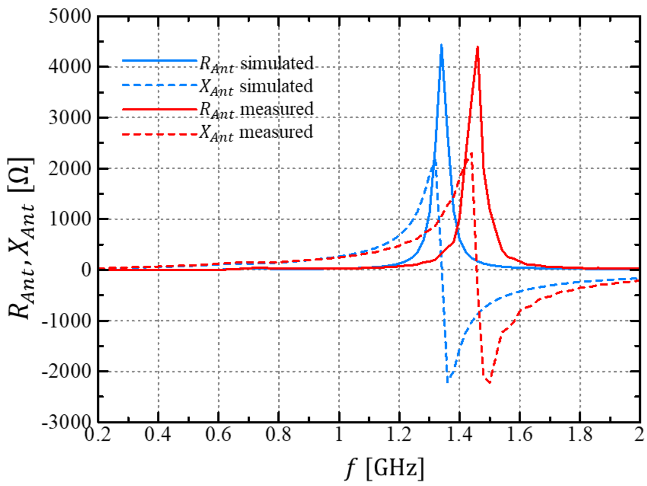


Figure 3. Simulation and measurement results of the antenna impedance versus frequency

4. Permittivity Considerations

The relative permittivity of the substrate can affect the impedance of the printed antenna. To verify this, the antenna impedance is calculated in HFSS changing the relative permittivity of the substrate.

Figure 4 and Figure 5 show the relation between the relative permittivity of the substrate and the impedance of the printed antenna. These results clearly show that lowering the relative permittivity of the substrate shifts the resonance frequency higher, which correctly reflects the theory [6] [11].

Finally, the simulation result when the relative permittivity of the substrate is $\epsilon_r = 3.4$ are compared with the measurement results in Figure 6. In other words, the results indicate that the material has the relative permittivity $\epsilon_r = 3.4$. Therefore, it was found that understanding the relative permittivity of the substrate is extremely important when measuring the impedance of printed antennas.

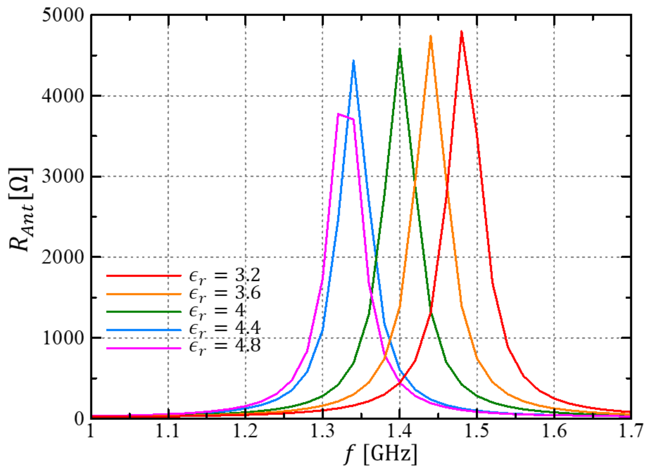


Figure 4. Relationship between the relative permittivity and the antenna resistance

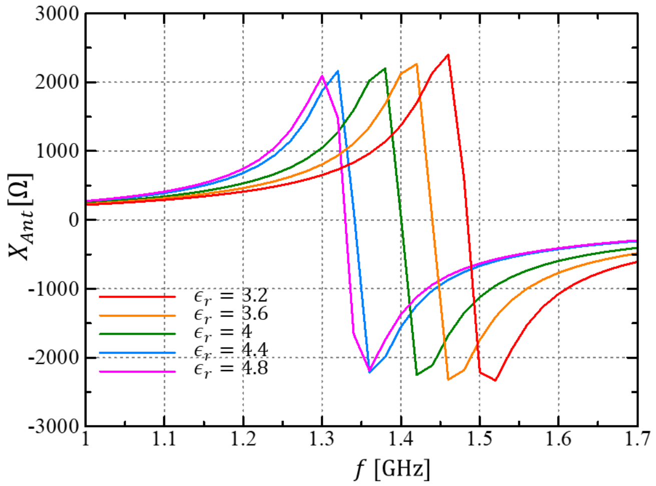


Figure 5. Relationship between the relative permittivity and the antenna reactance

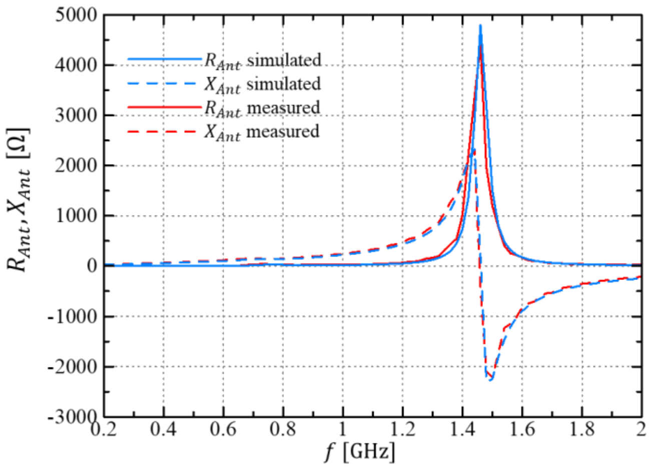


Figure 6. Simulation and measurement results of the antenna impedance at the relative permittivity of the substrate $\epsilon_r = 3.4$

5. Conclusion

In this paper, we newly designed a T-matched dipole antenna with good performance for a specific chip. Then the method for measuring antenna impedance are explained and it be clarified that it is excellent agreement between measurement and simulation. Furthermore, we demonstrated the influence of the relative permittivity of the substrate on the impedance of the printed antenna, highlighting the importance of understanding the dielectric constant of the substrate in the design of UHF RFID tag antennas.

6. References

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