

A Card-type RFID Antenna with a T-type Matching Circuit for Bandwidth Enhancement

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1. Introduction

Radio-frequency identification (RFID) has attracted significant attention for sensing systems of worldwide logistics. The frequency band from 860 to 960MHz (universal UHF band) has been allocated for RFID systems in the USA, Europe, and Asian countries. Size reduction, impedance matching, gain enhancement, wideband performance and easy manufacturing of antennas are needed for widely used RFID systems [1].

This paper proposes a card-type RFID antenna consisting of a T-type circuit for the universal UHF band [2]. Equations for the maximum impedance bandwidth are derived with an equivalent circuit of the tag antenna, and dependency of parameters on the bandwidth is discussed. A prototype of the antenna is fabricated for a passive RFID system, and the performance is investigated. Radiation pattern and read range measurements are performed.

2. Antenna model and equivalent circuit

The card-type RFID antenna consisting of a T-type circuit is shown in Fig. 1. The antenna consists of a meander-line dipole, coplanar strip line (CPS), chip capacitor, and dielectric substrate. The T-type circuit is formed by a part of the CPS and the chip capacitor. The card has standard dimensions of 86 mm x 54 mm. An IC with a differential RF port is assumed to be located at the end of the CPS as shown in Fig. 1.

An equivalent circuit of the antenna is shown in Fig. 2. The circuit consists of the antenna's radiation impedance Z_a , T-type circuit, additional reactance X_m , and IC impedance. The T-type circuit includes the CPS reactance X_{T1} , X_{T2} and susceptance of the chip capacitor B_T . The additional reactance is also realized by the CPS line, and it works to compensate for the IC capacitive reactance. The IC impedance is assumed to be resistance R_{IC} and reactance X_{IC} . In Fig. 2, Z_T^L represents the load impedance looking into the antenna impedance with the T-type circuit.

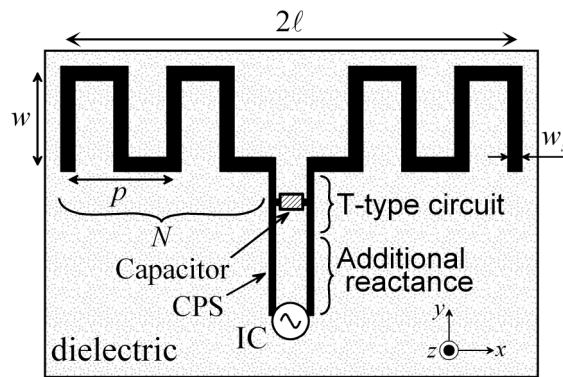


Figure 1: Antenna geometry of a card-type RFID antenna with a T-type circuit

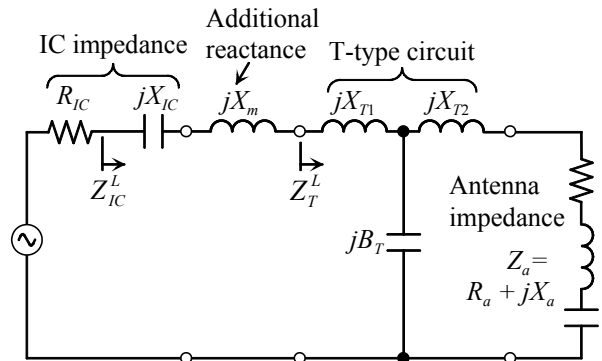


Figure 2: An equivalent circuit of the RFID antenna

3. Bandwidth enhancement with a T-type circuit

In regards to the equivalent circuit, theoretical maximum bandwidth can be achieved. At first, we assume the antenna impedance as a function of resonant frequency f_r , radiation resistance R_a , quality factor Q , and frequency f because the meandered dipole with series resonance can be described as follows:

$$Z_a = R_a + jX_a = R_a + jR_aQ\left(\frac{f}{f_r} - \frac{f_r}{f}\right). \quad (1)$$

Impedance Z_T^L at the resonant frequency f_r should be equal to resistance R_T^L , and the resistance can be expressed as

$$R_T^L = \frac{X_T^2}{R_a} \quad (2)$$

where $X_{T1} = X_{T2} = X_T = 1/B_T$.

Impedance characteristics of Z_a , Z_T^L , and Z_{IC}^L is shown in Fig. 3. When the value of X_m is taken to compensate X_{IC} at resonant frequency f_r , Z_T^L has a parallel resonance. Since impedance of the parallel resonance in wide range is cancelled by the series resonance circuit with X_m and X_{IC} , wideband characteristics can be obtained such as the contour of Z_{IC}^L indicates a circle on the Smith chart. When the contour passes through the points Z_0/ρ (1 in Fig. 3) and ρZ_0 (2 in Fig. 3), we can achieve maximum bandwidth as shown in Fig. 3. The maximum bandwidth can be derived from equations (1), (2) with an approximation procedure

$$BWR_{\max} = \frac{\sqrt{\rho^2 - 1}}{Q + \sqrt{\rho R_{IC}/R_a}}. \quad (3)$$

By using equation (3), the dependency of parameters on the maximum bandwidth can be estimated. We assume typical parameters such as $\rho = 2$, $Q = 10$, $R_a/R_{IC} = 3$ ($R_a = 30\Omega$, $R_{IC} = 10\Omega$), and the maximum bandwidth versus each parameter is obtained as shown in Fig. 4. Bandwidth of 16.0 % is possible for VSWR $\rho = 2$ criterion, while 25.7 % can be obtained for $\rho = 3$ criterion as shown in Fig. 4 (a). Q factor is important to obtain wideband characteristics as shown in Fig. 4 (b). For over 10 % bandwidth, we can see that Q factor of less than 16.5 is needed. Dependency of R_a/R_{IC} on the maximum bandwidth is small when the value of R_a/R_{IC} is larger than unity.

When we try to obtain the maximum bandwidth, reactance values of X_T and $X_{IC} = X_m$ at the resonant frequency have some fixed value. For the typical parameters as mentioned previously, the value of X_T should be 24.5Ω , and X_{IC} should be 29.6Ω . Since the value of X_{IC} will be decided by the IC impedance, possible bandwidth depends on the value of X_{IC} . Fig. 5 shows

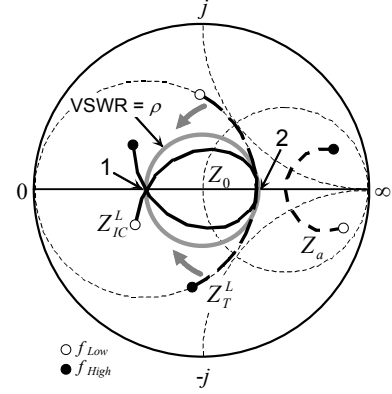


Figure 3: Impedance characteristics for each circuit model impedance ($Z_0 = R_{IC}$)

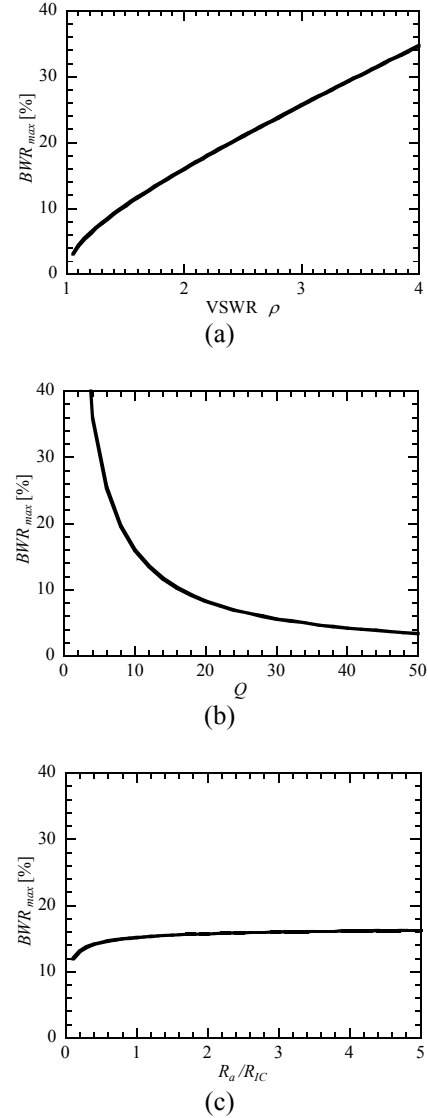


Figure 4: Dependency of parameters on $BWR_{\max}$ for (a) VSWR, (b) Q factor, (c) R_a/R_{IC}

dependency of IC reactance at resonant frequency on bandwidth for VSWR = 2 criterion. When the value of X_{IC} is smaller than 120 Ω , 10 % bandwidth can be achieved.

4. Performance of a prototype RFID antenna

On the basis of the bandwidth enhancement method discussed above, we fabricated a prototype RFID antenna with a passive UHF RFID Tag IC. The IC used was Higgs-2 produced by Alien Technology [3], which has an impedance of $14.3-j146.0 \Omega$ at 915MHz. In order to compensate for possible fabrication tolerances and measurement errors, we designed the antenna for VSWR = 3 criterion. The meandered dipole antenna with parameters $N = 2$, $2\ell = 80$ mm, $w = 18$ mm, and $w_s = 4$ mm was developed as shown in Fig. 6. $R_a = 21.9\Omega$, $Q = 12.1$, and $f_r = 915$ MHz were computed based on the equivalent circuit. Substrate used was a PTFE composites type of RT/duroid 5880 with a relative permittivity of 2.2, $\tan\delta$ of 0.0009, and thickness of 0.787mm. Line length, width, and spacing of the CPS of the prototype antenna are 30mm, 0.5mm, and 1.5mm. Capacitance of the chip capacitor was decided as 6pF and it was placed 2mm away from the bottom of the meandered line.

Comparison of impedance characteristics between the equivalent circuit, simulation with HFSS [4], and measurement are shown in Fig. 7. The measured results are compensated with a positive reactance in series of 20 Ω at 915MHz for fabrication error. In Fig. 7 (a), calculated and measured impedance have wideband characteristics within the circle of VSWR = 3. Theoretical (equivalent circuit) and simulated VSWR indicate wideband characteristics covering the range from 860 to 960MHz, however, measured VSWR is slightly shifted toward higher frequency and out of the range as shown in Fig. 7 (b).

A photo of the measurement set up is shown in Fig. 8. The tag and the reader were placed in the anechoic chamber at a distance of 1.3m (far-field region of the reader antenna). The reader power was incremented in steps of 0.1dBm to find the minimum transmitted RF signal required to activate the tag. This activation was based on the criterion that the back-scattered modulated signal from the tag should be read continuously for 90 seconds. The positioner was rotated in steps of 5°. Simulated and measured radiation patterns shown in Fig. 9 have excellent agreement. The radiation patterns in xy-

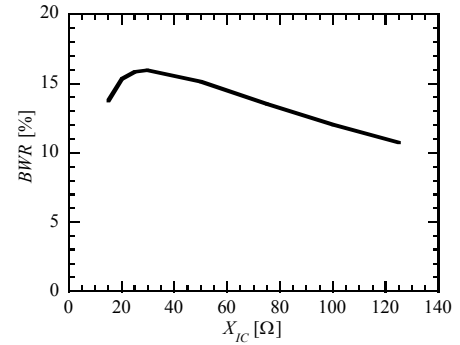


Figure 5: Bandwidth versus X_{IC}

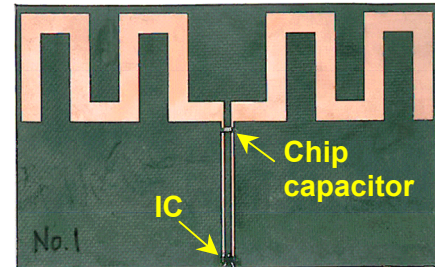


Figure 6: A prototype RFID antenna

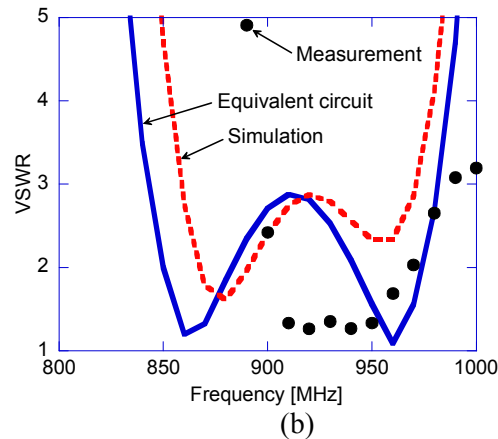
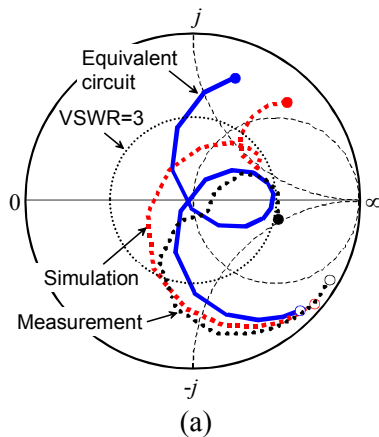
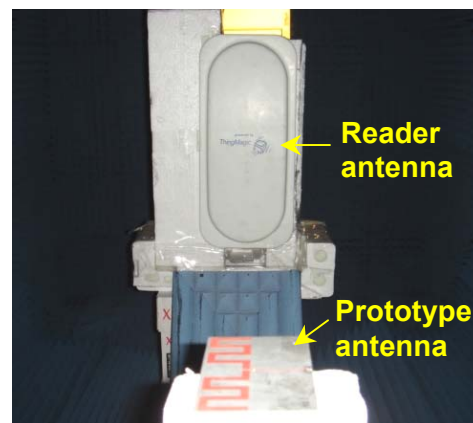


Figure 7: Comparison of impedance characteristics between theoretical, simulated, and measured results, (a) impedance characteristics (800MHz to 1GHz), (b) VSWR

and xz-plane indicate figure-8 dipole like pattern. The pattern in yz-plane was omnidirectional. Read range measurements were performed in open environment in order to avoid reflection from the surroundings. The maximum read range was defined as the maximum line-of-sight distance from the reader antenna where the reader detects the tag continuously without interruption. The output power of the reader is fixed at 30.1dBm. The reader antenna gain is 5.9 dBi (EIRP 36dBm). Initial investigations have shown that approximately 3.8m maximum boresight read range is obtained.



5. Conclusions

This paper presents a card-type RFID antenna with a T-type matching circuit to obtain wideband characteristics for worldwide UHF band use. An equivalent circuit of the antenna was shown and a bandwidth enhancement method was discussed. The equation of the maximum bandwidth was derived and estimated for different parameters. A prototype antenna was fabricated and its performance was simulated and measured. Wideband impedance characteristics were obtained under VSWR = 3 criterion in theory (circuit model) and simulation (HFSS), Radiation pattern and read range measurements were conducted.

Figure 8: Measurement set up of the communication between the prototype and a reader antenna

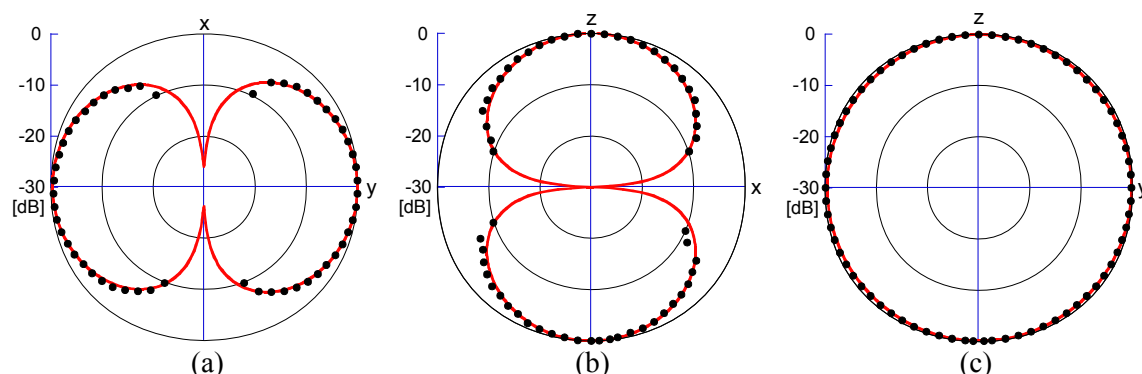


Figure 9: Radiation patterns of the prototype antenna, (a) xy plane, (b) xz plane, (c) yz plane, Solid line-simulated results, Dot-measured results

Acknowledgments

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