Frequency Tunable Antenna with Zeroth Order Resonator for UHF Near-field RFID Systems

Xiao-Dong Wei, Hong-Lin Zhang, and Bin-Jie Hu
School of Electronic and Information Engineering
South China University of Technology, Guangzhou, China

Abstract— This paper presents a frequency tunable antenna with epsilon negative (ENG) zeroth order resonator (ZOR) for ultra-high frequency (UHF) near-field radio frequency identification (RFID) systems. The ENG ZOR unit cell is composed of a toroidal inductor, a metal pin, a variable capacitor and an additional ground plane. The additional ground and the variable capacitor affect the shunt right-handed capacitance of the ENG ZOR unit cell. The measured resonant frequency of the antenna can be swept from 846 MHz to 1039 MHz by changing the capacitance of the variable capacitor. The measured maximum reading distance is 85 mm at 30 dBm input power. And the minimum input power for successful detecting of the near-field tag is −12 dBm, which is much lower than the conventional UHF near-field RFID reader antennas. The proposed antenna is suitable for UHF near-field RFID systems.

1. INTRODUCTION

The radio frequency identification (RFID) systems are widely used in tracking and detection objects in the past decades. Recently, ultra-high frequency (UHF) near-field RFID systems have gained much attention since they exhibit a better read rate for detecting objects surrounded by metals and/or liquids in their vicinity, such as drugs, bottles of water, clothes, and retail goods. The challenge to design a UHF near-field RFID antenna is to generate strong and uniform magnetic field in its interrogation zone.

Some UHF near-field loop antennas have been reported to generate strong and uniform magnetic field. A segmented loop antenna with lumped capacitor has been presented in [1] in order to generate strong and uniform magnetic field distribution. Some other techniques, such as distributed capacitor [2, 3], dash-line [4–6], dual-printed dipoles [7] and grid array antenna [8], are used to configure a UHF near-field loop antenna, the currents along the loop antennas are kept inphase. Left-handed metamaterials (LHM) can be applied to designing UHF near-field RFID reader antenna [9]. Recently, zeroth order resonator (ZOR) antenna applications using artificial epsilon negative (ENG), mu negative (MNG), and double negative (DNG) composite right/left-handed transmission line (CRLH-TL) have been reported in [10–12]. But the impedance band width of those antennas are very narrow. So that the band width of the antenna designed using conventional ZOR technoloty cannot cover the entire UHF RFID frequency band.

In this letter, we present a frequency tunable UHF near-field RFID reader antenna using ENG ZOR for handheld devices. The ENG ZOR unit cell is composed of a toroidal inductor, a metal pin, a variable capacitor and an additional ground plane. By changing the capacitance of the variable capacitor, the shunt capacitance of the ENG ZOR unit cell can be changed, thus the resonant frequency of the antenna changed. The measured resonant frequency of the antenna can be swept from 846 MHz to 1039 MHz. And the maximum reading distance is 85 mm at 30 dBm input power. What's more, the maximum reading distance can still achieve 9 mm at −9 dBm input power. The antenna shows good performance in UHF near-field RFID systems.

2. ANTENNA STRUCTURE AND DESIGN

Figure 1 shows the configuration of the proposed antenna. The antenna is composed of a interdigital capacitor and an ENG ZOR unit cell. The ENG ZOR unit cell consists of a toroidal inductor, a metal pin, a variable capacitor and an additional ground plane. The additional ground plane is connected to the ground plane of the antenna through the variable capacitor. The antenna was fabricated on an FR4 substrate ($\varepsilon_r = 4.7$, $\tan\delta = 0.2$, $h = 1$ mm). Figure 1(c) shows the equivalent circuit of the antenna. The capacitive effect between the top plane and the ground plane is modeled as C_G. The toroidal inductor provides the inductances of L_L. The interdigital capacitor is marked as C_0. The capacitive effect between the toroidal inductor and the additional ground plane is marked as C_A. The capacitance of the variable capacitor is marked as C. The interdigital capacitor C_0 is used to match the antenna to 50 Ω [12]. The parameters of the proposed antenna are as follows:

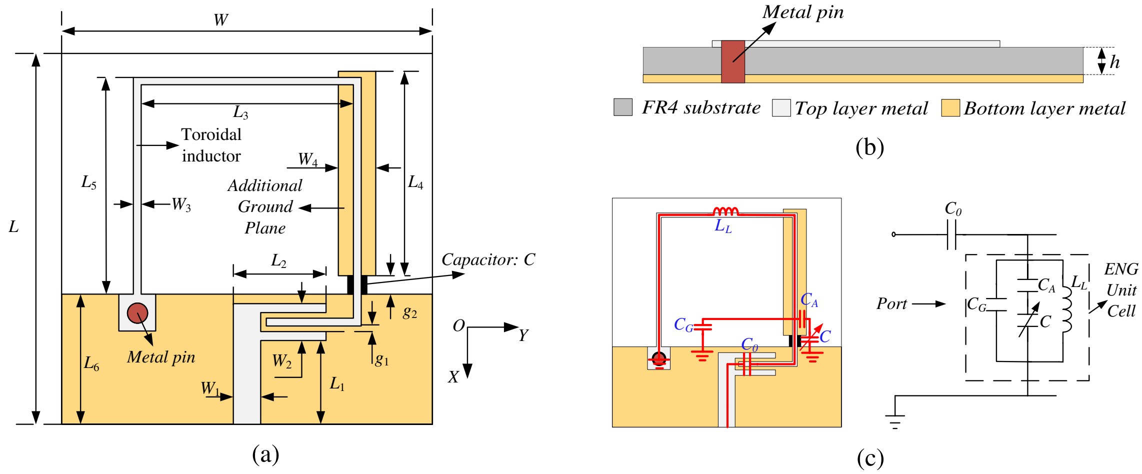

Figure 1: Configuraton of the proposed antenna: (a) top view; (b) side view; and (c) equivalent circuit model.

$L = 20\,\text{mm}$, $W = 20\,\text{mm}$, $L_1 = 4.5\,\text{mm}$, $W_1 = 1.5\,\text{mm}$, $L_2 = 5\,\text{mm}$, $W_2 = 2\,\text{mm}$, $L_3 = 11.7\,\text{mm}$, $W_3 = 0.4\,\text{mm}$, $L_4 = 11\,\text{mm}$, $W_4 = 2\,\text{mm}$, $L_5 = 11.3\,\text{mm}$, $L_6 = 7\,\text{mm}$, $g_1 = 0.3\,\text{mm}$, $g_2 = 1\,\text{mm}$, $C = 1\,\text{pF}$.

In order to better understand the performance of the proposed antenna and the effect of the parameters on the antenna performance, parametric studies are conducted. Only one parameter is varied at a time while the others are kept unchanged unless indicated.

Figure 2 plots the reflection coefficient of the proposed antenna at different values of L_5. As can be seen, the resonant frequency of the antenna decreases from 0.98 GHz to 0.86 GHz while the value of L_5 increases from 9.7 mm to 12.7 mm. With the increasing of L_5, the inductance of the toroidal inductor L_L increases, thus the resonant frequency decreases.

The capacitance of the variable capacitor (C) affects the shunt right-handed capacitance of the ENG ZOR unit cell. The shunt right-handed capacitance increases as C increases, thus the resonant frequency of the antenna decreases as can be seen from Figure 3. The simulated center frequency of the antenna can be tuned between 834 MHz to 1046 MHz.

Surface current distribution in the antenna plane is important for near-field analysis. Figure 4 shows the simulated current distribution of the proposed antenna at 904 MHz. It is observed that the current is in-phase along the toroidal inductor of the antenna. Such current distribution results in uniform and strong magnetic field distribution. Figure 5 shows a superposition of the simulated magnetic field distribution at the center frequency for different values of C. The input power is 30 dBm in the simulation. As can be observed, the magnetic field shape and strength are kept nearly constant over the tuning range. This means that the near-field performance of the antenna

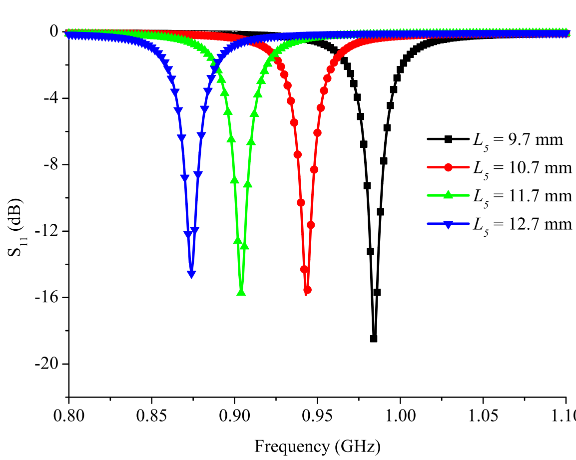

Figure 2: Simulated reflection coefficient of the proposed antenna for different values of L_5.

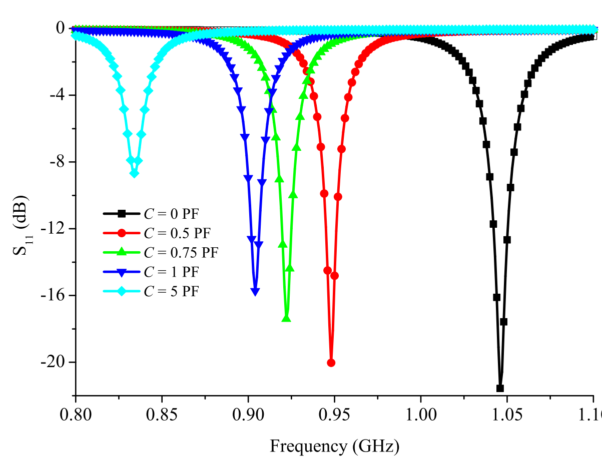

Figure 3: Simulated reflection coefficient of the proposed antenna for different values of C.

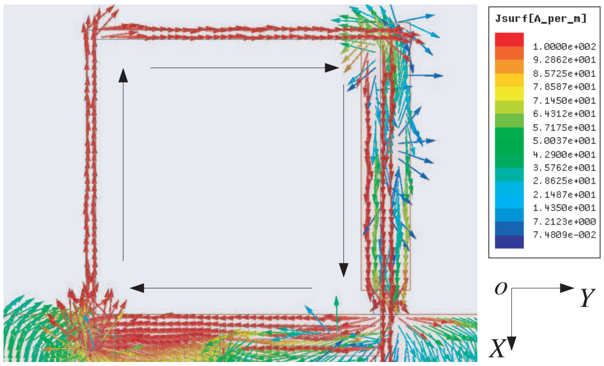

Figure 4: Simulated current distribution of the proposed antenna at 904 MHz.

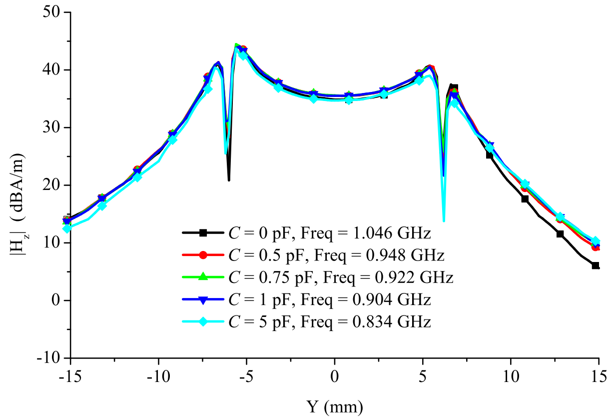

Figure 5: Simulated vertical magnetic field distribution of the proposed antenna along Y-axis.

is stable. The magnitude of the magnetic field in the center of the antenna is 35 dBA/m which is much stronger than the antennas in [5–8].

3. MEASUREMENTS AND RESULTS

The proposed antenna was fabricated and measured with the same dimensions as the simulated ones. The reflection coefficient ($|S_{11}|$) of the fabricated antenna was measured using Agilent E5071C network analyzer as shown in Figure 6. The measured resonant frequency can be varied from 846 MHz to 1039 MHz, which covers the entire UHF RFID frequency band. The measured results agree well with the simulated ones. The slight shift of $|S_{11}|$ is believed to be caused by the fabrication error and the accuracy error of the variable capacitor.

To further verify the near-field performance of the proposed antenna, the antenna was used as the reader antenna in a UHF near-field RFID system to detect near-field tags. The measurement configuration is shown in Figure 7. The antenna prototype was connected to the Impinj Speedway Revolution reader R220, with 30 dBm output power, to detect 25 Impinj button type tags (J41, 11 mm in diameter). The tags were positioned on an 80 mm $\times$ 80 mm squar foam plate.

Figure 8 shows the measured reading rate of the antenna at different heights. As can be seen, the maximum reading distance is 85 mm which is about 48 mm higher than the antenna in [7]. And a 100% reading rate is achieved within the distance of 13 mm. The readable area is about 4 times larger than the area of the antenna.

Figure 9 shows the maximum reading distance at different input power for successful detecting of the tag. Because of the minimum out power of the reader is 10 dBm, an attenuator was used in the measurement. It is observed that the tag can be successfully detected while the input power is larger than -12 dBm. And the maximum reading distance can still achieve 9 mm at -9 dBm (0.126 mW) input power, which is very low input power. The antenna can be used in low-power

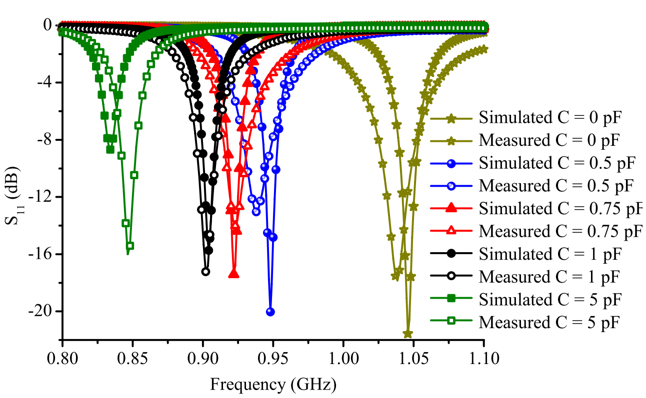

Figure 6: Simulated and measured reflection coefficient of the proposed antenna.

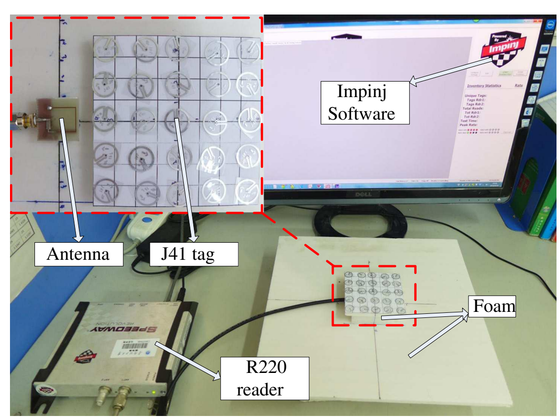

Figure 7: Near-field RFID measurement setup for the reading rang performance.

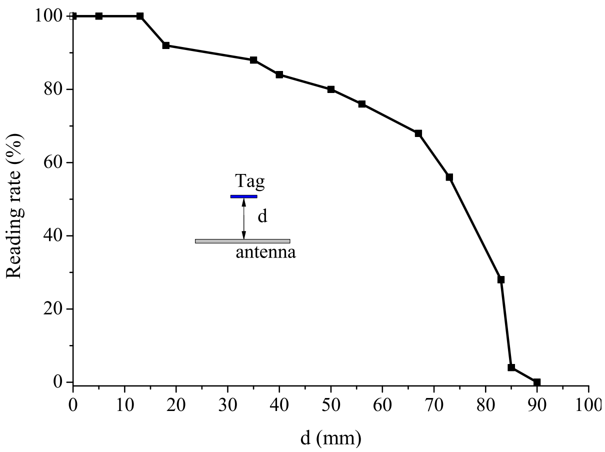

Figure 8: Measured reading rate of the proposed antenna at different heights.

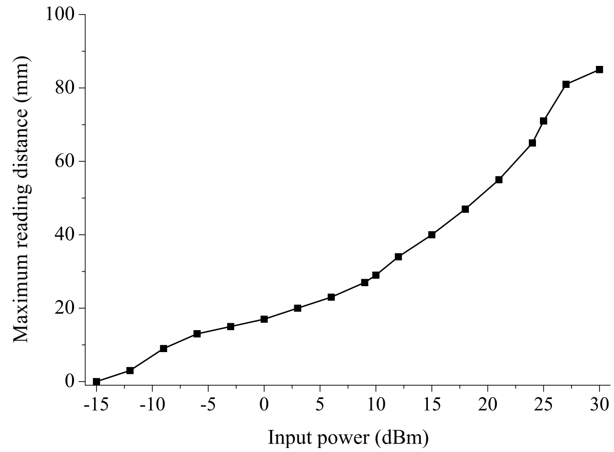

Figure 9: Maximum reading distance of the antenna at different input power.

consumption devices.

4. CONCLUSION

In this paper, a novel frequency tunable antenna with ENG ZOR for UHF near-field RFID systems is presented. The ENG ZOR unit cell is composed of a toroidal inductor, a metal pin, a variable capacitor and an additional ground plane. The variable capacitor is used to change the capacitance of the shunt capacitor of the ENG ZOR unit cell. The proposed antenna was fabricated and measured. By changing the capacitance of the variable capacitor, the measured resonant frequency of the antenna can be swept from 846 MHz to 1039 MHz. The measured results show that the maximum reading distance is 85 mm at 30 dBm input power. And the tag can still be successfully detected at very low input power. The antenna is suitable for UHF near-field RFID systems.

ACKNOWLEDGMENT

This work was supported by the NSFC-Guangdong under Grant No. U1035002, Guangdong-Hong Kong Key Project of Science and Technology under Grant Nos. 2011A011305001 and 2011A0113020 01, and University-Industry Key Project of Department of Education of Guangdong Province under Grant No. CGZHZD1102.

REFERENCES

1. Dobkin, D. M., S. A. Weigand, and N. Iyer, "Segmented magnetic, antennas for near-field UHF RFID," *Microw. J.*, Vol. 50, Jun. 2007.
2. Qing, X., Z. N. Chen, and C. K. Goh, "UHF near-field RFID reader antenna with capacitive couplers," *Electron. Lett.*, Vol. 46, 1591–1592, 2010.
3. Yong, S. O., X. Qing, C. K. Goh, et al., "A segmented loop antenna for UHF near-field RFID," *Antennas and Propagation Society International Symposium*, 1–4, Jul. 2010.
4. Qing, X., C. K. Goh, and Z. N. Chen, "A broadband UHF near-field RFID antenna," *IEEE Trans. Antennas Propag.*, Vol. 58, 3829–3838, 2010.
5. Li, X. and L. Cao, "Microstrip-based segmented coupling reader antenna for near-field UHF RFID applications," *Microw. Opt. Technol. Lett.*, Vol. 53, 1774–1777, Aug. 2011.
6. Jin, S., X. Qing, Z. N. Chen, et al., "Electrically large dual-loop antenna for UHF near-field RFID reader," *IEEE Trans. Antennas Propag.*, Vol. 61, 1019–1025, 2013.
7. Li, X. P. and Z. J. Yang, "Dual-printed-dipoles reader antenna for UHF near-field RFID applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 10, 239–242, 2011.
8. Shi, J., X. Qing, and Z. N. Chen, "Electrically large zero-phase-shift line grid-array UHF near-field RFID reader antenna," *IEEE Trans. Antennas Propag.*, Vol. 62, 2201–2208, Apr. 2014.
9. Borja, A. L., A. Belenguer, J. Cascon, et al., "A reconfigurable passive UHF reader loop antenna for near-field and far-field RFID applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 580–583, 2012.
10. Lee, J. G. and J. H. Lee, "Zeroth order resonance loop antenna," *IEEE Trans. Antennas Propag.*, Vol. 55, 994–997, Mar. 2007.

11. Kim, J., G. Kim, W. Seong, et al., "A tunable internal antenna with an epsilon negative zeroth order resonator for DVB-H service," *IEEE Trans. Antennas Propag.*, Vol. 57, 4014–4017, Dec. 2009.
12. Huang, J. Q. and Q. X. Chu, "Compact epsilon negative zeroth-order resonator antenna with higher radiation efficiency," *Microw. Opt. Technol. Lett.*, Vol. 53, 897–900, Apr. 2011.