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*Application Article*

# Characteristics and Application of a Novel Loop Antenna to UHF RFID Receivers

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A broadband two-layer and two quasihalf loops antenna (TTLA) at UHF is characterized and analyzed for ultrahigh frequency (UHF) near-field radiofrequency identification (RFID) applications. The antenna is investigated in terms of impedance matching and distribution of magnetic field as well as applied in two scenarios which are the experiments of interrogation range and receiver circuit of RFID systems.

## 1. Introduction

Radiofrequency identification (RFID), which was developed around World War II, is a technology that provides wireless identification and tracking capability [1, 2]. The reader antenna is an important unit of the radiofrequency identification (RFID) systems. Many new developed RFID antennas are reported recently [3–7]. There are two different types of reader antennas including the near-field antenna and the far-field antenna. Currently, ultrahigh frequency (UHF) near-field RFID technology receives a lot of attention due to the promising opportunities in item-level RFID applications such as sensitive products tracking, pharmaceutical logistics, transport and medical products (blood, medicines, and vaccines), and biosensing applications [8–12]. Recently, the RFID receiver is a key component of RFID system and has received much attention because of increasing demands for near-field detection and management.

The basic concern of UHF near-field RFID is to make the RFID system working in a short distance as reliable as that of the LF/HF near-field RFID [8]. Inductive coupling systems are preferred in most applications of near-field UHF RFID, because most of reactive energy is stored in magnetic field. Capacitive coupling is opposite, because the energy is severely affected by the objects with high permittivity [13].

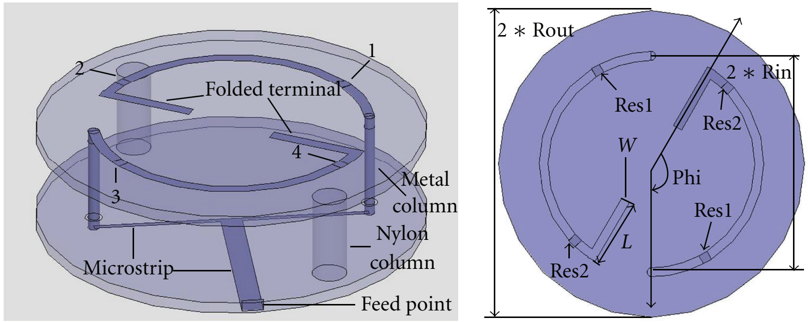
In an inductive coupling RFID system, the reader and the tag antennas are coupled mainly through magnetic field. If the tag antenna is electrically small, the magnetic field generated by reader antenna is hardly perturbed by tag, and coupling coefficient $C$ could be affected by the following factors [14, 15]:

$$C \propto f^2 N_{\text{tag}}^2 S_{\text{tag}}^2 B^2 \alpha, \tag{1}$$

where $f$ is operating frequency, $N_{\text{tag}}$ is the number of the turns of the coin tag antenna, $S$ is the cross-section area of the coil, $B$ is the magnetic field density at the tag location generated by the reader antenna, and $\alpha$ is the antenna misalignment loss. Formula (1) indicates the coupling coefficient $C$ between reader, and tag antenna is dependent on magnetic field generated by RFID reader antenna.

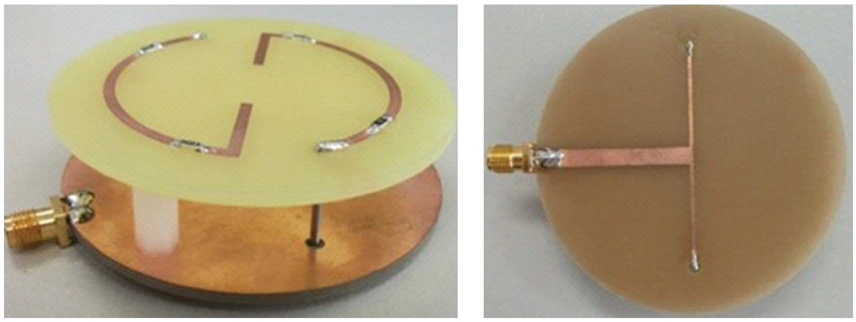
One important parameter of near-field RFID antenna is the interrogation range which is tightly related to the application fields of the RFID system. Useful experiment scenario is introduced to measure the interrogation range of near-field antenna and validate magnetic field distribution by a special tag in this paper.

Receiver circuit is a key component of RFID reader and rapidly developed during recent years so that some available experiments on near-field RFID system are proposed to measure the performances of receiver circuit. One efficient method is that one inserts receiver circuit into the RFID system and observes if the received signal is correct in any nodes of the circuit. It could infer that performances of antenna have great influence on the accuracy of the measurement.




(a) (b)

Figure 1: Model and structure of the proposed antenna: (a) 3D view and (b) Top view.



(a) (b)

Figure 2: Photograph of the antenna: (a) 45 degree view of the antenna and (b) Bottom view of the antenna.

This paper is organized as follows: modeling and performances of the antenna will be introduced in the Section 2. In Section 3, the experiment scenarios of the RFID system are proposed. In Section 4, the conclusion will be given.

## 2. Modeling and Performances of Antenna

*2.1. Modeling and Structure of Antenna.* Figure 1(a) shows the structure of the antenna which is composed of two PCB layers. The top layer includes two quasihalf loops which are connected with two folded straight terminals. Printed on the bottom layer, 50 ohm microstrip transmission line is connected with two 100 ohm branches which are connected to two metal columns in another end. The other end of each column is connected to metal quasihalf loop strip. There are two loads on each quasihalf loop which are marked by 1, 2, 3, and 4 in Figure 1(a). The two PCB boards are fixed by two nylon columns and connected by two metal columns.

Figure 1(b) shows the top view of antenna. Angle and radius of quasihalf loop is marked by Phi and Rin. Length of folded terminal, width of metal strip, and radius of PCB board are marked by $L$, $W$ and Rout, respectively. Because symmetrical structure of two quasihalf loops, the loads 1 and 3 have the same value of Res1 and value of 2 and 4 are Res2. The distance between two PCB layers and thickness of top PCB board is marked by $H$ and $T$, respectively. The size and material of bottom layer is same with top layer.

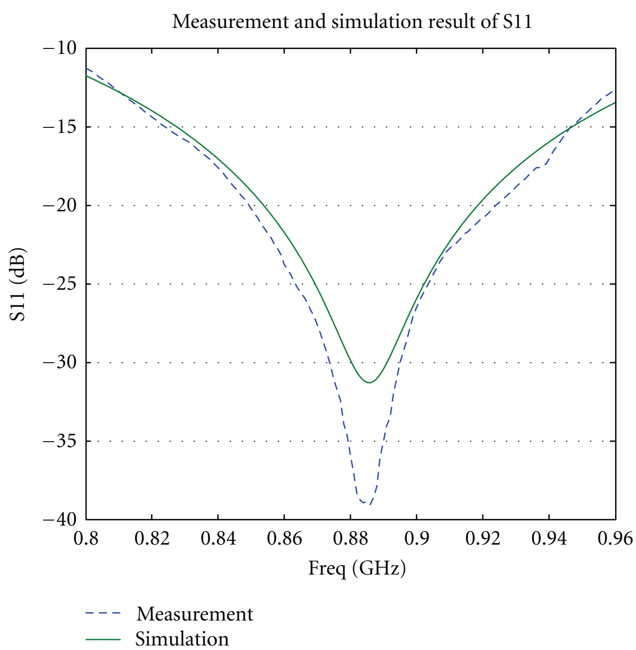



Figure 3: S11 of the actual antenna and simulation model.

The antenna prototype is printed onto an FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$, thickness $T = 2$ mm). The optimized antenna have parameters of $H = 15$ mm, $W = 2$ mm,

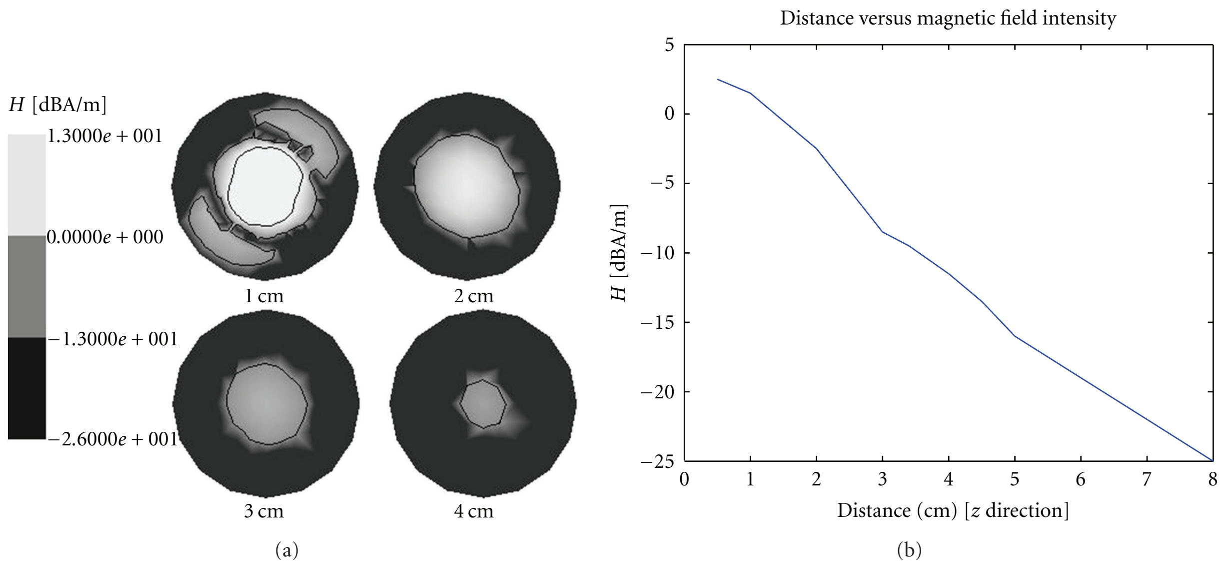



Figure 4: Simulated magnetic field distribution of the antenna operated at 868 MHz: (a) $z$-orientation magnetic field distribution at different $z$ and (b) magnetic field intensity along $z$-axis.

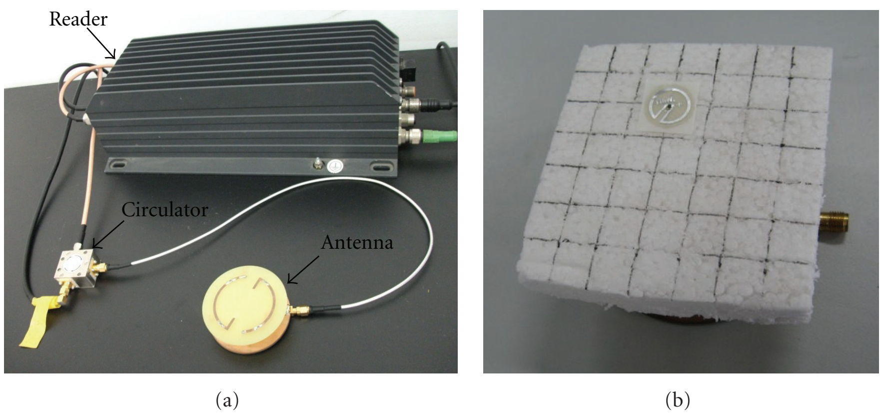



Figure 5: The configuration of interrogation range measurement: (a) Measurement scenario: reader antenna, circulator, and reader which is connected with computer. (b) Foam board and tag is positioned above the antenna.

Rin = 25 mm, Rout = 34 mm, Res1 = 30 ohm, Res2 = 50 ohm, $L$ = 8 mm, and $T$ = 2 mm. As shown in Figures 2(a) and 2(b), the antenna is fed by SMA port at the edge of bottom layer. The new proposed antenna has many advantages: strong magnetic field, wide bandwidth, small size, and so on.

*2.2. Design Principle.* It is a challenge to design a novel antenna with wide bandwidth, strong magnetic field, and low gain simultaneously. In order to obtain these performances, the antenna is designed with many adjustable parameters, which are showed in Figure 1.

Firstly, the proposed antenna with loop structure could generate concentrated $z$-orientation magnetic field which is easy to be absorbed by tags. In order to obtain stronger magnetic field, the novel antenna is designed to be a standing wave structure, because the magnetic field of standing wave antenna is much stronger than that of traveling-wave antenna due to ohmic consumption on matching loads.

Secondly, current distribution on the loop antenna naturally brings some shortages: asymmetrical current and narrow bandwidth, and so forth. Two quasihalf loops and loads (resistors) are designed to solve these problems. Four resistors on quasihalf loops are used for broadening the bandwidth and reducing the gain. The current on the two quasihalf loops is symmetrical, because they are fed by one power splitter so that the magnetic field could be strengthened by two loops simultaneously, which will be more even than that of a single-loop antenna. Because of a series resonant, length of quasihalf loop is shorter than 1/4 wavelength so that the current flowing along the loops is kept in a single direction. In other words, the current distribution on quasihalf loop is in-phase.

Another important innovation of the antenna is that it is designed with folded terminal which may enhance the current on the quasihalf loops and reduce the size of antenna. Obviously, the folded terminal could make the magnetic

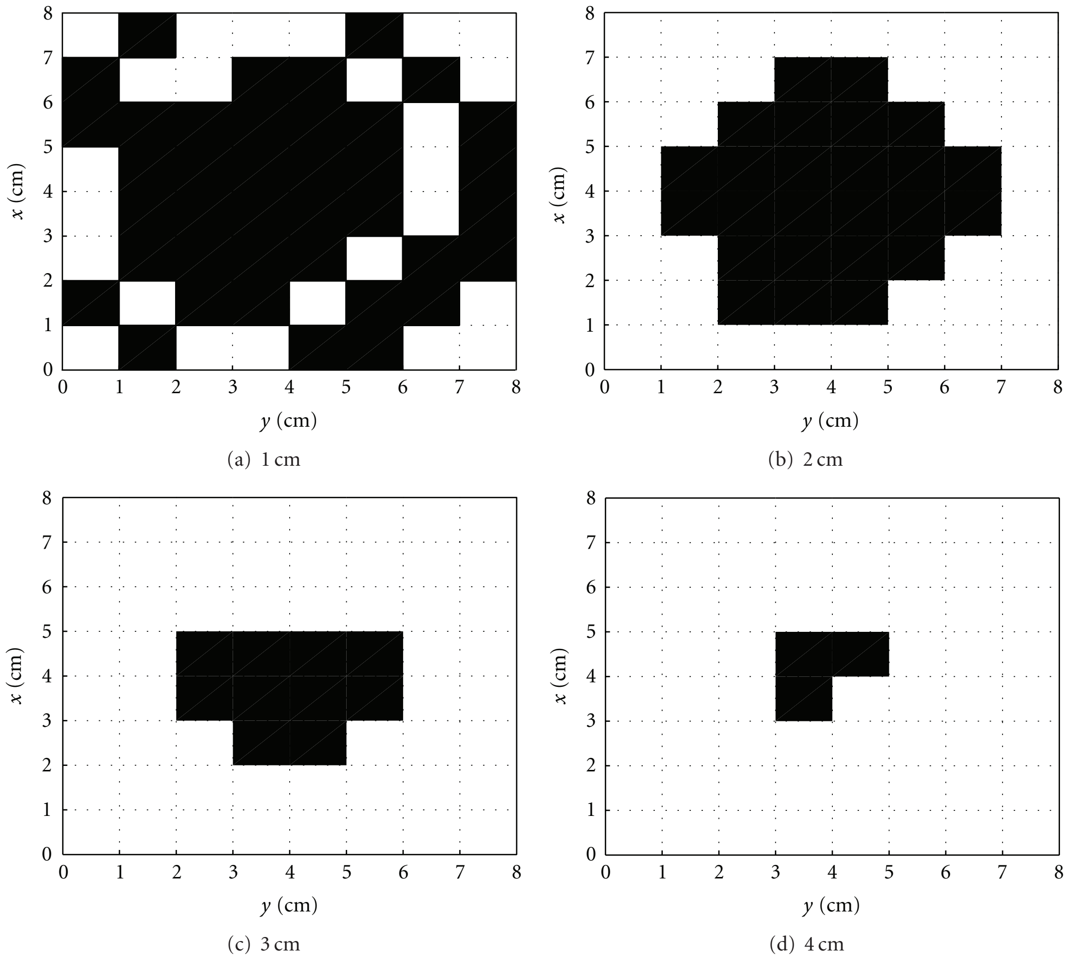



FIGURE 6: Interrogation range of antenna at different distances which are 1 cm, 2 cm, 3 cm, and 4 cm. Black grid marked the intersection which could be read when tag is put on, and white grid marked the opposite.

field to be more concentrated, because the current at the terminal region is weak and useless for generating magnetic field.

Finally, the ground plane and power splitter are used for concentrating magnetic field and supplying equal current for quasihalf loops, respectively. The two-layer structure of the antenna is useful for building isolation between radiation unit and feed network.

The antenna is fed at the edge of bottom layer. The current is divided into two parts by a power splitter. $z$-orientation magnetic field of antenna is mainly generated by the current on two quasihalf loops and easily absorbed by near-field tag. The antenna could generate strong magnetic field and large interrogation range if the current distribution on quasihalf loops is in-phase and strong.

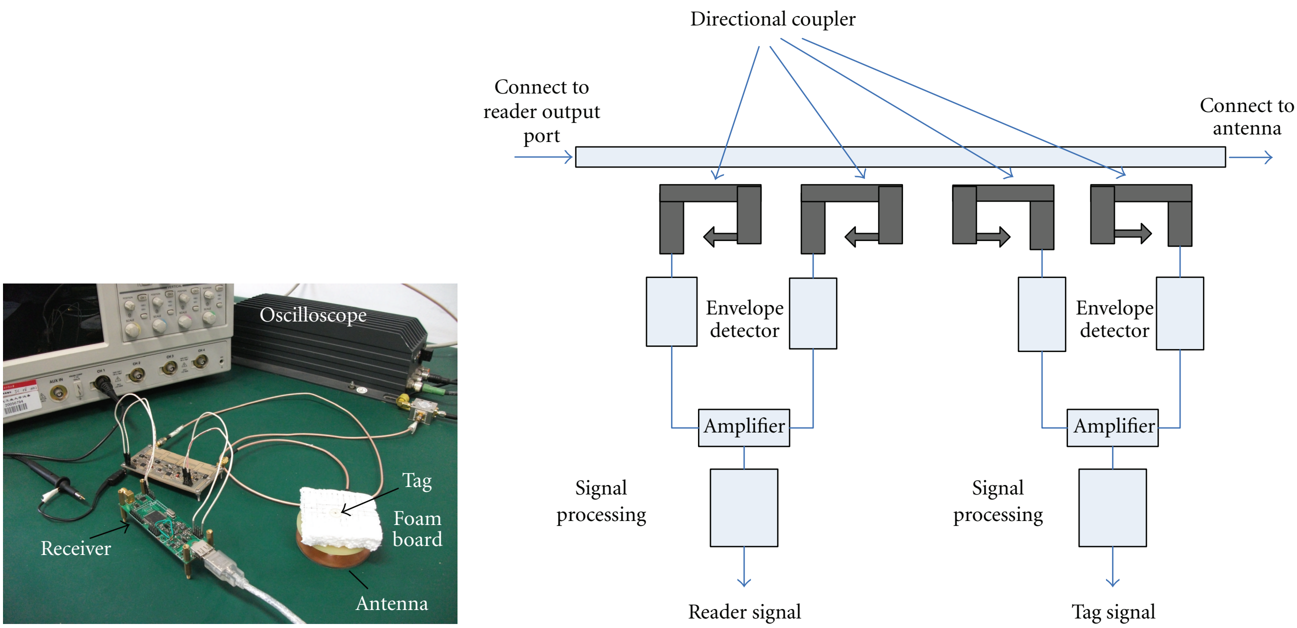
*2.3. S11 Performance.* The impedance matching measurement of the antennas was carried out using the Agilent N5230A vector network analyzer. Figure 3 shows the simulated and measured return loss. The proposed antenna exhibits broadband impedance bandwidth, and the frequency range for −15 dB return loss is from 826 MHz to 950 MHz (124 MHz bandwidth). The measured result agrees with the simulated result well.

*2.4. Magnetic Field Distribution.* Figure 4(a) shows the magnetic field distribution above the surface of antenna's top at different $z$ which is the distance between reference plane and the antenna. The reason of choosing such a graduation scale is narrowly related with interrogation range which will be discussed later. Figure 4(b) focuses on the magnetic field intensity attenuation versus $z$-axis. Compared with other antenna [8, 9], it could found that the $z$-orientation magnetic field of the new antenna is much stronger.

## 3. Application Scenarios in the RFID System

*3.1. Interrogation Region Measurement.* In Figure 5, antenna plays a very important part in the whole system which is a novel method to validate the magnetic field distribution of simulation. The circulator in the experiment is used to establish isolation between reader signal and tag signal.

To further verify the performance of the proposed two-layer and two quasihalf loops antenna, the prototype was




(a) (b)

Figure 7: (a) RFID receiver circuit connected with reader and antenna. (b) Diagram of receiver circuit.

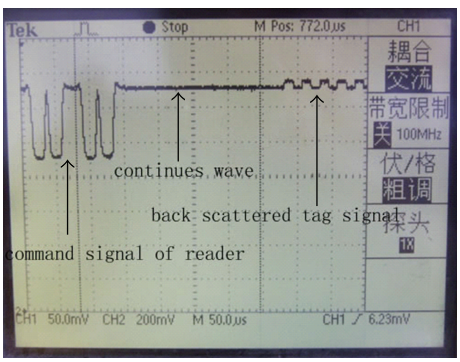



Figure 8: output port of the detector which contains the command signal, continuous wave of reader, and back scattered tag signal.

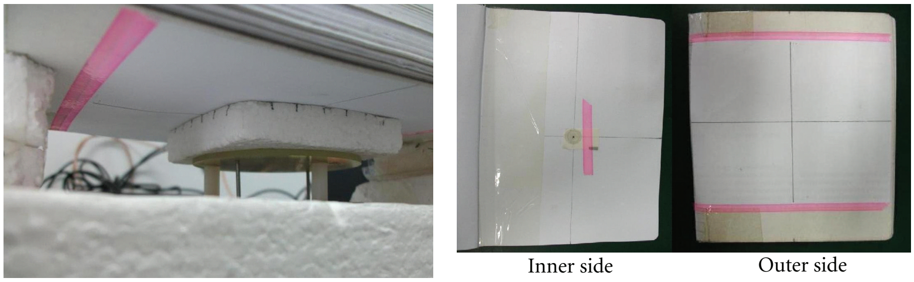
used as the reader antenna in a UHF near-field RFID system to detect UHF near-field tags. The proposed antenna was connected to the reader operating at 865 MHz–868 MHz of ETSI with 30 dBm output to detect tag. Tag is positioned on a foam board which is 70 mm $*$ 70 mm large, could be shown as Figure 5(b). Grid is marked on the top of the foam board with the size of 1 cm $*$ 1 cm. The data of the correctly detected tag on each intersection was recorded when the top surface of foam board was fixed at different $z$ above the antenna.

This paper adopt one annular tag which could be activated when magnetic field intensity of command signal is stronger than $-13$ dBA/m. But tag will be easier activated and quicker read if the magnetic intensity is stronger. The system choose ETSI band as the operating frequency, because the operating mechanism of FCC is HF (hopping frequency).

The measurement results of interrogation range are exhibited in Figure 6 which shows that reading range is decreased with the increase of distance. Comparing Figure 6 with Figure 4(a), it could be found that the reading range have a rough agreement with the magnetic field level line of $-13$ dBA/m at each $z$. This is the reason of choosing such a graduation scale of $z$-orientation magnetic field in Figure 4(a).

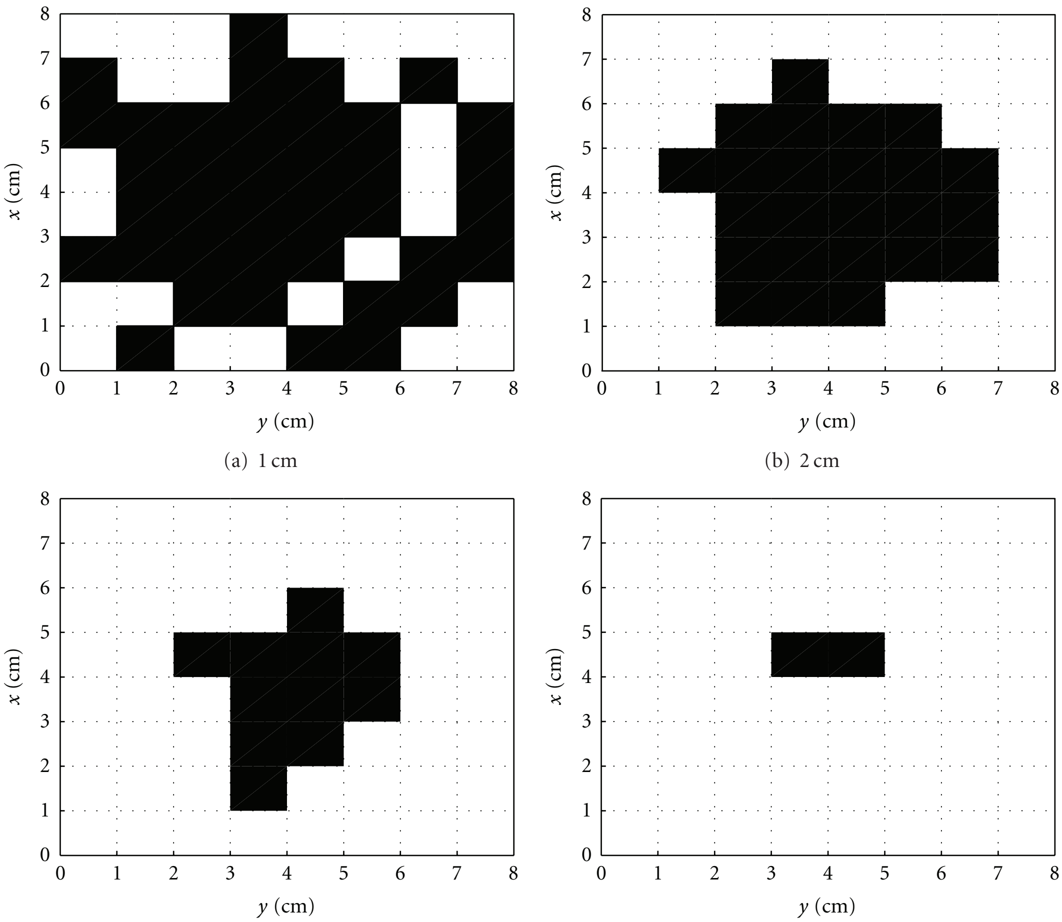
*3.2. RFID Receiver Measurement.* A receiver circuit is inserted into the RFID system and used to monitor the operating mechanism of RFID, shown in Figure 7(a). One simple diagram of the circuit is showed as Figure 7(b) which contains directional couplers at two directions to couple the power of both reader and tag signal. After coupler, envelop detector and signal processing module could demodulates signal and gets information of tag or reader, respectively. In this experiment, the return loss of the inserted antenna affects the detection tube greatly if the impedance matching is not very well. Because reflected reader signal will be mixed with back scattered tag signal and transmit to the reader at the same port and direction, envelop of tag signal is greatly disturbed and easily saturated distorted during the process of amplifying and comparing.

Oscilloscope is used to detect the output of detector could be seen as Figure 8. There are command signal, continuous wave, and tag signal which is approximately 70–80 mV square-waves. In this measurement scenario, the distance between reader antenna and tag is 0 cm with supply power of reader is 20 dBm.




(a) (b)

Figure 9: Measurement of interrogation range when real object equipped with NF tag: (a) book is located above antenna. (b) Inner and outer face of book cover, and intersection of the two lines on outer face is the center location of tag.




(a) 1 cm (b) 2 cm (c) 3 cm (d) 4 cm

Figure 10: Measurement result of the interrogation range.

*3.3. Object Equipped with NF Tag.* In order to observe the performances of reader antenna in a real industry transmission line system, one book is selected as a real object equipped with NF tag, and the same experiment is operated in Section 3.1. The configuration of the measurement is showed in Figures 9(a) and 9(b). In the measurement, NF tag is fixed on the inner face of the book's cover page and put on a foam board. The book is supported by foam boards with different height for keeping balance. In Figure 9(b), the location of the tag is marked by the intersection of two vertical lines on both inner and outer face of the book's cover page in order to put the tag on each grid of foam board accurately. In Figure 9(a), the location of tag is determined by the graduation on foam board and lines on outer side of book.

The experiment result is shown in Figure 10 which is similar as the conclusion in Section 3.1. It is clear that the book has not brought serious influence on the interrogation range of reader antenna. The experiment shows that the proposed antenna could be applied in industry transmission line to detecting books or some other objects normally. But the tiny differences between Figures 10 and 6 show that the interrogation range of reader antenna could be changed when it applied in different scenarios.

## 4. Conclusion

It is important to validate the simulated magnetic field of near-field RFID antenna and measure the performances of receiver circuit of RFID reader. The major consideration of validate magnetic field is using reader to detect tags and mark if the magnetic field is strong enough to activate tag in certain point. Tag could be awaked if the magnetic field is stronger than the threshold. Other application introduced in this paper is measuring of receiver circuit which is connected with antenna and reader to measure the wave shape in each nodes of the circuit during debugging. Furthermore, the investigation has shown that the proposed antenna could present strong magnetic field and wide bandwidth.

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