Three Overlapping Loop Antennas for 3D RFID 13.56MHz Access Control Gate

Sheng-yu Gong and Guang-jun Xie, *Senior Member, IACSIT*

***Abstract*—In this paper, we propose a novel design method of antenna for 3D RFID access control. This method can simple design a three dimensional RFID access control by only using the analysis for near-field magnetic coupling incorporating transformer inductance coil system. This system uses three overlapping loop antennas in walk-through gate. Simulation is given to explain the overlapping sequence of the three antennas.**

***Index Terms*—RFID; overlapping loop antennas; 3D access gate**

I. INTRODUCTION

In recent years, Radio Frequency Identification (RFID) system becomes very popular due to their usefulness and convenience in many applications. The access control is one of the most common applications of RFID system at 13.56MHz [1]. They can be used in convention registration, animal identification, anti-theft protection and so on.

The design of the overlapping loop antenna must consider the mutual inductance of the three overlapping antennas, which in return determines the communication between the reader and the tag [2]. If the overlapping antennas are not design correctly, the electromagnetic field will not fill the whole gate of walk through gate [3]. This method will not use the complicated algorithm. All antennas are controlled by the switching techniques [4]. The prototype antenna will be fabricated with walk-through gate installation to measure the percentage of volume. Measure results confirm the usefulness of the antenna for the further library application.

II. DESIGN THEORY OF OVER LAPPING LOOP ANTENNA

A. Single Loop Antenna Design

Most of RFID reader needs 50 ohms impedance. To achieve maximum power transfer, we need to match the impedance of the antenna to the reader. Impedance matching is important as it will ensure maximum amount of power is transmitted to the antenna. Otherwise, power will be lost during the transmission resulting in a poor reading range. Fig. 1 shows the match circuit of the antenna operating at 13.56MHz.

Manuscript received Feb. 25, 2012; revised May 5, 2012. This work was supported by the Intercollegiate Key Project of Nature Science of Anhui Province under Grant No. KJ2011A213.

Sheng-yu Gong is with School of Electronic Science and Applied Physics, Hefei University of Technology, Hefei 230009, Anhui, China.

Gang-jun Xie is with School of Electronic Science and Applied Physics, Hefei University of Technology, Hefei 230009, Anhui, China (e-mail: gjxie8005@hfut.edu.cn).

The rectangular loop of the antenna is simply modeled as the inductance, which is resonated with two series capacitors as C_{1a} and C_{1b} at its resonant frequency. To control the quality factor of the antenna, a series resistor as R can be added. There is a parasitical capacitor between antenna structure and ground. Because signal that send to receiver is an unbalance input, so a balun must be used to reduce common mode noise[5]. We use a transmission line transformer; the turn ratio of the transmission line transformer is 1:1.

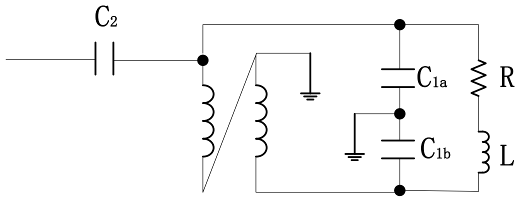


Fig. 1. A rectangular loop antenna with a transmission line transformer matching circuit.

To design a loop antenna, the inductance should be calculated first. Eq. (1) is reasonably accurate for calculating the inductance [6, 7]:

$$L[\mu H] = Side \times 0.008[ln(\frac{Side \times 1.414}{2 \times Diameter}) + 0.379] \quad (1)$$

where, Side means a center to center length of antenna in centimeter and Diameter means cable diameter in centimeter.

The two series capacitance can be determined by:

$$C_{1a} = C_{1b} = \frac{1}{2}C = \frac{1}{2} \times \frac{1}{\left(2\pi f_{res}\right)^2 L} \quad (2)$$

where, f_{res} means the resonant frequency.

From the two series capacitance Eq. (2), we calculate C_2:

$$C_2 = C \times \sqrt{\frac{Z_{in}}{Z_{out}}} \quad (3)$$

where, Z_{in} is 50 ohms. Z_{out} is equal to the total parallel resistance.

can be calculated from the formula:

EMBED Equation.DSMT4 (4)

where Q is the quality factor. In most RFID applications, antennas are designed for high Q parameters. We generally decide the Q is 30. So the series resistance R can be calculated from:

EMBED Equation.DSMT4 (5)

By using these equations, the six resonant antennas can be designed without the complicated EM simulation. Then we discuss the mutual inductance (M) between all of the six antennas.

Analytical Model for Mutual Inductance Between Two Antennas

EMBED Visio.Drawing.11

Fig. 2 Two same cable wire 50 ohms impedance matching antennas with excitation and the other no excitation.

Fig. 2 shows the separate rectangular geometry of our HF RFID antennas operating at 13.56MHz.

The two antennas are placed separately in the same plane. The left loop is connected with the reader. The right loop is placed a distance away. La and Lb are length and width of the two antennas. d1 is the distance between two edges of the two antennas.

The inductance is caused by the self inductance of the loop. If the two independent loop antennas are placed closer, there will be a mutual inductance between the two antennas based on the number of field lines from the current in one loop that completely surrounds the wire of the other antenna. When the distance of the two antennas is more and more further, the coupling coefficient k will be very small

The mutual inductance M between two parallel antennas is a function of the length of the cable wires and of the geometric mean distance between them. The mutual inductance of two antennas is calculated [2, 8].

EMBED Eqution.DSMT4 (6)

EMBED Visio. D awing.11

Fig. 3 Two overlapping loop antennas

Fig. 3 shows the two overlapping loop antennas. The distance d2 is the overlap ratio of the two antennas. According to the law of electromagnetic induction, when the electromagnetic flux of the no excitation antena in the two dash areas does not vary, induction current will not generate. The mutual inductance (M) between the two antennas will not exist.

Simulation to explain influence of the mutua inductance of the two antennas

As the spacing and overlapping area between the two antennas on the detection zone of the antenna with excitation, simulations in HFSS are carried out to determine the performance of the antenna by varying the spaig and measuring the gain total.

Fig. 4 Radiation pattern at 30cm space between the two antennas, one with excitation and the other not

Fig. 5 Radiation pattern at 3cm overlapping area between the two antennas

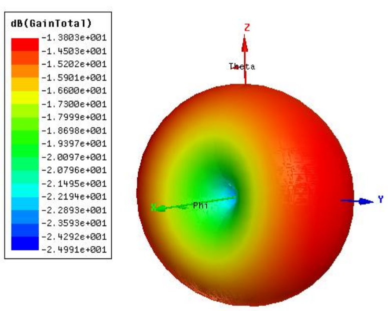


Fig. 6. Radiation pattern at 8cm overlapping area between the two antennas

Fig. 4 to 6 show the gain total by the antenna with excitation. Because of the influence of the mutual inductance between two antennas, the radiation pattern of the antenna with excitation will be varied by the space and overlapping area between the two antennas. If the spacing is kept beyond 30cm, the two antennas will not generate electromagnetic induction. If the overlapping area between the two antennas is 3cm, the gain total of the antenna varies due to the reduced energy absorbed by the other antenna. If the overlapping area between the two antennas is 8cm, the mutual inductance misses.

The communication system can be consisted of the two antennas. Now, define the coupling quotient b2/ɑ1 as the coupled signal received by the no excitation antenna when a unit signal is incident to the reader antenna, which is equal to S_{21} when considering the two antennas as a two-port network. Fig.7 shows the equal circuit model.

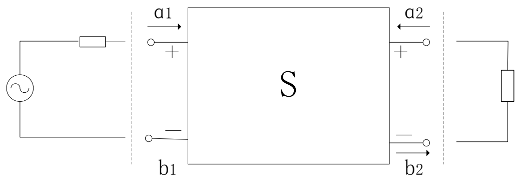


Fig. 7. Equivalent two-port network

According to the theory of two-port network, the coupling

$$\text{coefficient } C = \left|\frac{b_2}{a_1}\right|^2 = 10\lg\left(\left|S_{21}\right|^2\right) \quad (7)$$

Fig. 8 shows the coupling coefficient of the two antennas in the HFSS simulation by assuming the two antennas are perfectly matched. Also the antennas are designed in HF bands.

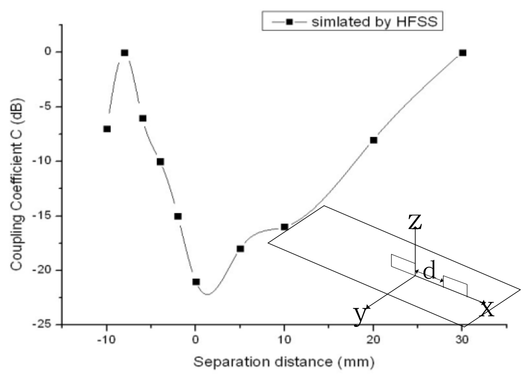
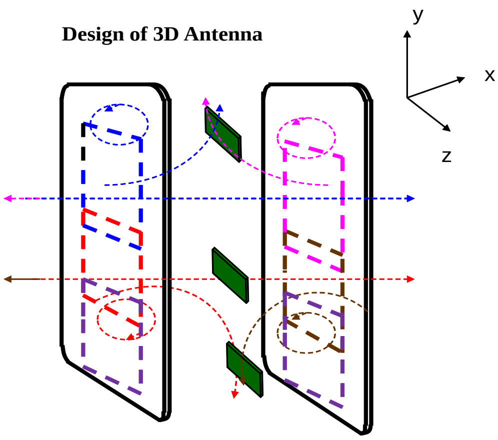


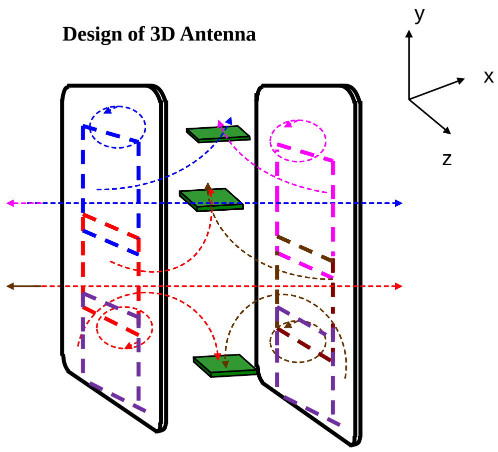
Fig. 8. C between the two antennas (the left antenna has excitation and the right one has no excitation. They are all in 50ohms matched.)

B. *Three Overlapping Loop Antennas with Switching Techniques*

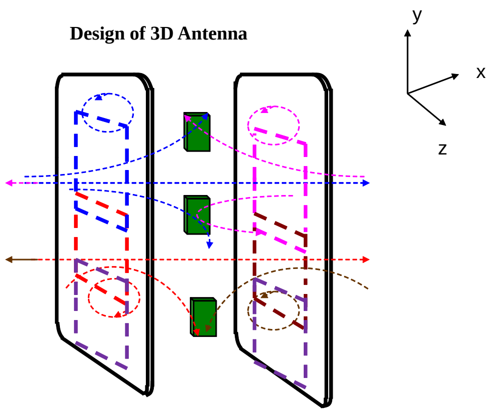
Three overlapping loop antennas can be designed to possess null field in different positions with the others to cover the filed in whole volume of the pass-through gates. Fig. 9 shows the RFID 3D access control gates. The tags can be rotated around ±40 ºeither side of its optimal position and will still be read. So, three overlapping loop antennas with switching techniques for the library anti-theft system can generate 3D electromagnetic field in the whole pass-through gate as shown in Fig.10. The electromagnetic field energy can activate the tags in books from all the orientations.



(a)The tags can be activated in X-axis



(b) The tags can be activated in Y-axis



(c) The tags can be activated in Z-axis

Fig. 9. The design of 3D RFID antennas for access control gates

For the application of anti-theft system, the orientation of tag in book can be varied in different directions. Thus the reader has to communicate with the tag in various orientations. The switching technique is the circuit that is used to swap between six antennas connected with RFID reader. When first antenna is switched "on" and the others are "off". The timing "on" and "off" depends on the reading time of RFID reader. We use one-way switch to connect between the six antennas of the two gates. The microcontroller is used to cycle the switch "on" and "off".

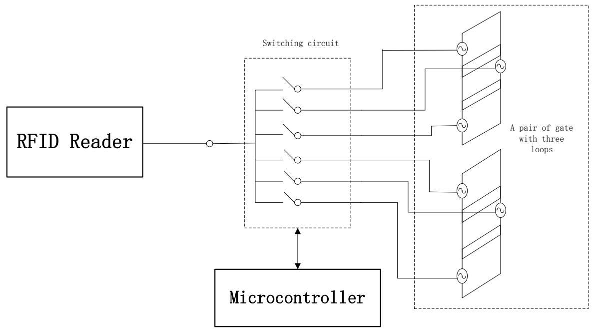


Fig. 10. The diagram of switching techniques

III. Mesured Results

The measurement set up is carried out in the case that the three overlapping loop antennas has the same dimension using the switching techniques installed as the walk-through gate configuration in Fig.11. The rectangle loop antennas are constructed by using the cable wire BVR24. The tag under test is the ISO15693 card. The method to measure the percentage of volume is shown in Fig.12.

(a) Theantenna construction in wood structure

(b) The antenna prototype in organic glass.

Fig. 11. Fabricated two sets of three Overlapping loop antennas in the walk-through gate arrangement for 3D RFID anti-theft system.

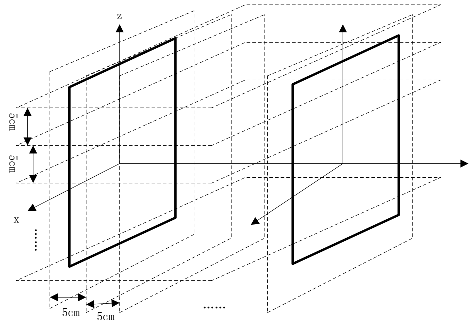


Fig. 12. Measurement of the percentage of volume between two gates

From top to bottom, from left to right, we take a tag pass through the gate every 5 square centimeters. The measured percentages of volume are 100%. The measure result proves that the three overlapping loop antennas can detect the tags from any orientation.

IV. Conclusions

By analysis of the antenna couple theory, we can easily find the two overlapping antennas can generate non-coupling electromagnetic field. So every antenna can performance well and be not influenced with each other. Based on the simulation and the experiment results, the electromagnetic field generating by the structure of the three overlapping antenna can fill the whole pass-through gate. This antenna can be efficiently used in RFID system at 13.56MHz for access control gate.

References

[1] D. Senić, D. Poljak, and A. Šarolić, "Electromagnetic field exposure of 13.56 MHz RFID loop antenna," *Telecommunications and Computer Networks (SoftCOM)*, 2010 International Conference on Software, pp.23-25, 2010.

[2] W. Liu, L. Q. Wong, and M. M. Wong, "Simulation and design for 3D RFID application," *in Proc. IEEE International Conference on Emerging Technologies and Factory Automation*, pp.1326-1331, 2008.

[3] S. F. Pichorim and P. J. Abatti, "Design of coils for millimeter and submillmeter sizes biotelemetry," *IEEE Trans. Biomed. Eng.*, vol. 51,no.8, pp.1487-1489, 2004.

[4] S. Kawdungta, P. Wounchoum, C. Phongcharoenpanich, and Danai Torrungrueng, "Improvement of Communication Performance for Trapezoidal Dual Loop Antennas by Switching Techniques," *Asia-Pacific Microwave Conference*, pp.1-4, 2007.

[5] C. Steve, Q. Chen, and V. Thomas, "Optimization of inductive RFID technology," *2001 IEEE International Symposium on Electronics and the Environment*, pp. 82-87, 2001.

[6] H.-S. Kim, D.-H. Won, and B.-J. Jang, "Simple design method of wireless power transfer system using 13.56MHz loop antennas," *IEEE International Symposium on Industrial Electronics (ISIE)*, pp. 1058-1063, 2010.

[7] C. Mansap, P. Wounchoum, C. Phongcharoenpanich, and D. Torrungrueng, "Trapezoidal Dual Loop Antenna for Radio Frequency Identification," *Asia-Pacific Microwave Conference*, pp.1478-1481, 2006.

[8] R. F. Harrington and J. Mautz, "Electromagnetic behaviour of circular wire loops with arbitrary excitation and loading," in *Proceedings of the Institution of Electrical Engineers*, vol.115, pp.68-77, 1968.

Guang-jun Xie received the B.S. degree and the M.S. degree from Hefei University of Technology, in 1992 and 1995, respectively. He received the Ph.D. degree from University of Science and Technology of China in 2002. He is now a Professor of Hefei University of Technology, and his research interests include IC design, computational intelligence.