Design and Simulation of 13.56MHz RFID Reader Antenna

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Abstract: Since RFID technology is developed, 13.56 MHz RFID system with its excellent performance is widely applied. 13.56MHz RFID system is a passive system. So the performance of the antenna directly affects the performance of the RFID system. The paper simply introduces the basic principle of 13.56MHz RFID system antenna. And by using HFSS, the paper can get some circuit parameters of the antenna, including the equivalent inductance, loss resistance and so on. Moreover, the paper analyze the relationship between the equivalent inductance and the wire width of the antenna and trace spacing. And the paper introduce the design and simulation of matching circuit.

Keywords: 13.56MHz RFID; Design of antenna; HFSS

1 Introduction

RFID(Radio Frequency Identification) is a kind of automatic identification technology that use radio frequency signal to transfer data between a reader and a remotely located device. The most basic RFID system consists of three parts, the tag, the reader and the data processing center. According to the power supply mode of the tag, RFID system have three basic types, active system, passive system and semi-passive system. Because of using 13.56MHz electromagnetic wave has not special restrictions in the world, 13.56MHz RFID system has wide application. Such as the second generation ID card of China, campus one-card-through, door access system and so on. Now 13.56MHz RFID system is a passive system, its operation mode is inductance coupled. Energy exchanges and information transfer between reader and tag can be done through electromagnetic coupling between the antenna coil. RFID system's antenna consists of reader's antenna and tag's antenna. To improve the performance of RFID system, two aspects including improving performance of reader's antenna and improving performance of tag's antenna can be considers. However, in order to maintain the advantages of tag, such as low cost, small size, long life and so on, the performance of tag's antenna is hardly improved. So the main way that improving performance of RFID system is to improve the performance of reader's antenna. At present, the main factors that affect the performance of reader's antenna length of antenna, thickness of wire, number of turns in the antenna coil, quality factor Q and impedance match, etc.

2 Basic theory of 13.56MHZ antenna

Because of wavelength of 13.56MHZ electromagnetic (22.12m) is far longer than read range of reader (maximum is 1m) , and 13.56MHz RFID system is passive system, operation mode of 13.56 RFID system is only inductance coupled. This mode is similar with working node of transformer. They follow the basic Faraday's law of electromagnetic induction. Therefore, the paper will introduce following basic aspects about the basic theory of 13.56MHz antenna.

1. Ampere's law

Now the most common shape of 13.56MHz antenna coil are rectangular, square and circular. So the loop antenna is the equivalent of loop coil. Its work model is shown in Figure 1.

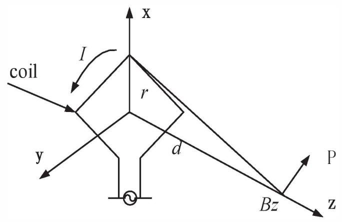

Figure 1 Antenna normal direction of magnetic induction intensity

When reader is working, the magnetic field produced by loop antenna coil is given by:

$$B_z = \frac{\mu_0 I N r^2}{2(r^2 + d^2)^{3/2}} \tag{1}$$

$$B_z = \frac{\mu_0 I N r^2}{2d^3} \qquad d^2 >> r^2 \tag{2}$$

Where I is current through the coil, r is radius of loop, d is distance from the center of loop, μ_0 is permeability of free space.

Equation(1) shows that magnetic field is proportional to the number of turns of antenna coil and current. So, an increase of the number of turns of antenna and improving reader's power can effectively improve the reader range. When $d^2 >> r^2$, equation(2) shows that increasing the radius of antenna coil can improve the reader range.

2. Faraday's law of electromagnetic induction

Because 13.56MHz RFID system's operation mode is inductance coupled, when tag's antenna close to reader's antenna, the magnetic field produced by the reader antenna will pass through the closed the tag antenna. According to Faraday's law of electromagnetic induction, tag's antenna will produce induced voltage (V). When V reaches tag's working minimum voltage, tag will start working. Then tag sends a corresponding signal to the reader according to tag used protocol, reader begin to identify tag.

Figure 2 shows a simple working model of 13.56MHz

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RFID system's antenna. When the magnetic flux density generated by the reader antenna coil is B, the area of the coil is S, the magnetic flux through the plane of antenna coil is

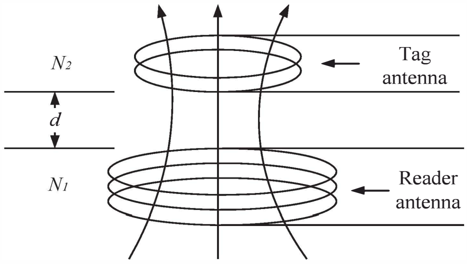


Figure 2 The working model of 13.56MHz RFID system's antenna

$$\Psi = \int B \cdot dS \tag{3}$$

So the induced voltage (V) of tag's antenna is

$$V = -N_2 \frac{d\Psi}{dt} \tag{4}$$

Using Equations (1) and (3), Equation (4) can be rewritten as:

$$\begin{aligned} V &= -N_2 \frac{d}{dt}\left[\int \frac{\mu_0 i_1 N_1 r_1^2}{2(r_1^2+d^2)^{3/2}} \cdot dS\right] \\ &= -\left[\frac{\mu_0 N_1 N_2 r_1^2 (\pi r_2^2)}{2(r_1^2+d^2)^{3/2}}\right]\frac{di_1}{dt} \\ &= -M\frac{di_1}{dt} \end{aligned} \tag{5}$$

Where M is the mutual inductance, r_1, r_2, respectively reader antenna's radius and tag antenna's radius, N_1, N_2, respectively the number of turns of reader's antenna and tag's antenna. Equation (5) shows that structure of antenna, material and size of antenna can affect the induced voltage, and V decays with $1/r^3$.Therefore, when tag is gradually close to the reader, V will also become larger.

3. The optimum loop radius

Equation(1) shows a relationship between the read range versus optimum coil diameter when B_z is maximum. The optimum coil diameter is found as:

$$r = \sqrt{2}d \tag{6}$$

Equation(6) shows that the optimum reader's antenna's radius, r, is equal to 1.414times the demanded read range d.

3 Design of antenna

3.1 Equivalent circuit

Figure 3 shows the equivalent circuit of antenna coil.

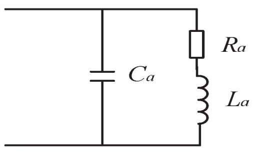


Figure 3 equivalent circuit of antenna coil

Where L_a is the inductance of the antenna coil, R_a is loss resistance of coil, C_a is external tuning capacitor. In order to produced maximum magnetic flux density by reader's antenna, the current must be maximum through the coil. There are two different resonant circuits: parallel and series. The series resonant circuit has a minimum impedance at the resonance frequency. As a result, maximum current is available in the circuit. Because of its simplicity and the availability of the high current into the antenna element, the series resonant circuit is often used for a proximity reader. So the match circuit is the series resonant circuit in this design.

When the circuit is the tuned resonant circuit, the tuned resonant frequency is:

$$f = \frac{1}{2\pi\sqrt{L_a C_a}} \tag{7}$$

When the structure of antenna is rectangle or circular, La can be approximately expressed as:

$$L_a(\mu H) = 0.002 \times l_1 \times \left[\ln\left(\frac{l_1}{d_1}\right) - K\right] \times N^{1.8} \tag{8}$$

Where, l_1 and d_1 is length and radius of wire in cm, respectively. K = 1.47 when the structure of antenna is rectangle. When the resonance frequency is tuned to the reader's operating frequency 13.56MHz,Equation (7) (8) shows that increasing the size of antenna and the numbers of turns of coil will make the equivalent inductance of the antenna increase. However, too large value of inductance will make the tuning capacitor C_a become too small. So the equivalent inductance of the antenna is usually designed in 1~2uH.

3.2 Quality factor

Quality factor Q is a ratio between resonant circuit stored energy and the loss per cycle. It is a quality indicator. In the reader antenna circuit, the resonant frequency f = 13.56MHz, Q can be expressed as

$$Q = \frac{2\pi f L_a}{R_a} \tag{9}$$

Q can also be expressed as :

$$Q = \frac{f}{BW} \tag{10}$$

Equation(9)and(10) shows that the higher the value of Q, the more energy the antenna output. However, too large value of Q will narrow bandwidth of the reader. It is not conducive to identify tag for reader. Q is generally 6~15 at 13.56MHz system. Q is calculated in when the system use different protocol. This can improve the performance of the reader's antenna.

4 Simulation of antenna and analysis

This simulation of antenna uses three dimensional full wave electromagnetic simulation software HFSS developed by Ansoft from USA. According to the method of antenna, in order to access to the actual production, the material of circuit board of model is epoxy woven glass fabric laminates, FR-4, that has higher mechanical properties and dielectric properties. The material of antenna is copper foil that has good conductivity. Wire's thickness is 0.035mm. The initial width of wire is 0.5mm. N=4 is appropriate according Equation(8). If the reader range, d, is 50mm, the radius of antenna coil should be 1.414 times d, r = 70mm. However, in consider of practical application, it well make the reader have large volume. So in this simulation, the radius is set to 54mm.

The solution frequency is 13.56MHz. The mode of sweep type is fast mode. Figure 4 shows relationship between the equivalent inductance and the frequency.

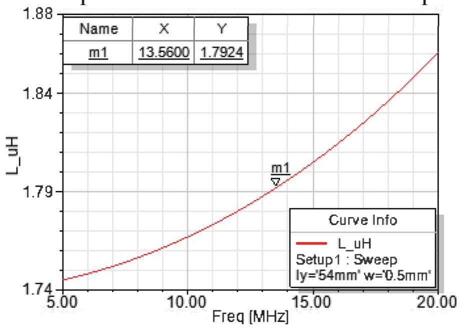
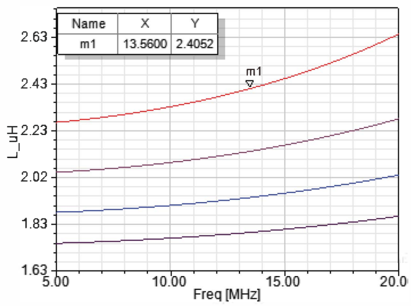


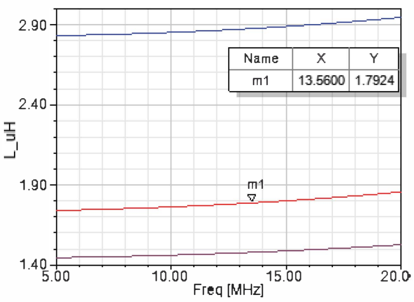
Figure 4 The relationship between the equivalent inductance and the frequency

Figure 4 shows that the equivalent inductance of antenna is 1.7924uH in 13.56MHz.

Figure 5 shows the relationship between L_a and width of wire and trace width.



(a)

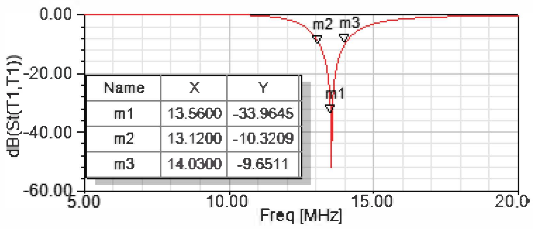


(b)

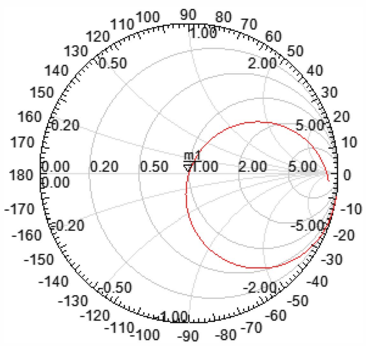
Figure 5 (a) The relationship between L_a and trace width **(b)** The relationship between L_a and width of wire

In Figure 5(a) the trace width increases from top to bottom. In (b) the width of wire decreases from top to bottom on edge extraction. So the wider trace width, the narrower the width of wire, the larger the value of L_a.

It is convenient for the design of antenna's match circuit to use HFSS. Q=10 is necessary for designing a match circuit. Using HFSS's data analysis tool, the antenna's loss resistance R_a can be got, R_a=0.2ohm. Besides, the paper can gets the self-resonant frequency and impedance through analysis the result of HFSS simulation by frequency sweeping. So the series resonance resistance can be obtain by calculating. Then using Smith chart, the match circuit cap C_s and C_p can be got. Figure 6 (a)shows the return loss(RL), and (b) shows the Smith char.



(a)



(b)

Figure 6 (a) RL **(b)** Smith char

Figure 6 shows that the performance of match circuit is good. The simulation

5 Conclusions

The paper introduce a design method of 13.56MHz reader's antenna according to the basic law of antenna., analysis some factors that can effect the equivalent inductance of reader's antenna . Meanwhile, a model of antenna is created by using HFSS. The match circuit that has good performance is designed by using some HFSS's data analysis tool. The simulation has a good reference value for the actual production of 13.56MHz RFID antenna.

References

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