Calculation of RFID Antenna Characteristic Parameters under the Condition of Near-field Coupling

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Abstract— Passive near-field coupling antenna is widely used in RFID system. Antenna design is the key part of RFID system. In this paper, we present a fundamental method to design the RFID antenna, in which we mainly focus on some important physical parameters, such as magnetic field intensity, optimal radius of the antenna, turning and estimating inductance of the conductor loop.

1. INTRODUCTION

RFID technology and its three major components have experienced huge progress in these years [1]. This technology has proliferated in almost all sectors of modern society. Healthcare, public transportation, social security is only a small number of the application fields.

Antenna characterization parameters such as gain, radiation pattern, radiation power efficiency and beam width, are normally used in antenna design. So it is important to reinforce those parameters in the mathematical way.

2. MAIN PHYSICAL PARAMETERS UNDER THE CONDITION OF NEAR-FIELD COUPLING

2.1. Calculation of the Magnetic Field Intensity

The distance that a RFID antenna can work effectively is closely related to the magnetic field intensity which is generated by the coil current [2].

The magnetic field intensity of a circular coil can be calculated by

$$H = \frac{I \cdot N \cdot R^2}{2\left(R^2 + x^2\right)^3} \tag{1}$$

in which H is the intensity of magnetic field, I is the intensity of electric current, N is turns of the coil, R is radius of the antenna, x is the distance away from the circular coil.

The magnetic field intensity of a rectangular conductor loop whose side length is ab can be calculated by

$$H = \frac{I \cdot N \cdot ab}{4\pi\sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2 + x^2}} \cdot \left[\frac{1}{\left(\frac{a}{2}\right)^2 + x^2} + \frac{1}{\left(\frac{b}{2}\right)^2 + x^2}\right] \tag{2}$$

Conclusions can be made from these two equations, when x is small ($x < R$), H is steady and at a high level, a bigger antenna can still get a high H even x is large in the number ($x > R$) while a smaller one can't.

2.2. The Optimal Radius of the Antenna

Assuming x is a constant and I is unchanged in the coil of antenna, if we change the radius of the antenna, then we can get the maximum H according to the relationship between x and R. As we all know, different x has its own optimal radius of the antenna, to get this R, we can use maximum H to be the solution.

First, derivation for R

$$\frac{d}{dR}H(R) = \frac{2NR^2}{\sqrt{\left(R^2 + x^2\right)^3}} - \frac{3INR^3}{\left(R^2 + x^2\right) \cdot \sqrt{\left(R^2 + x^2\right)^3}} \tag{3}$$

Then let the equation be 0, we can get

$$R = \pm\sqrt{2}x \tag{4}$$

Discard the negative one, finally we got the optimal radius of the transmitting antenna according to the distance between Reader and Tag.

2.3. Turning

RFID system can be considered as a R-L-R series circuit, in which R is the resistance of coils and L is the inductance of the antenna. In the process of turning, the capacitance of coils can be discarded because of little impact on this process, so another capacitance should be added in order to obtain the maximum electric current for the antenna [3]. The extra capacitance can be determined by

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

in which f is the operating frequency.

2.4. Estimating Inductance

If without impedance analyzer, we can use an estimating equation to get the value of L. Assuming the ratio of the diameter d of the conductor to the diameter D of the conductor loop is very small ($d/D < 0.001$), then the inductance of the loop can be determined by [4].

$$L = N^2 \mu_0 R \cdot \ln(2R/d) \tag{6}$$

in which N is turns of the coil, R is radius of the antenna, μ_0 is the magnetic permeability of free space.

N can also be estimated by (7), and in practical application, these two equations can be used as a complementary to solve more problems.

$$N = (\text{approx})^{1.9} \sqrt{\frac{L}{2A\ln(A/D)}} \tag{7}$$

in which A is area surrounded by the antenna coil.

The results from these two equations are not extremely accurate, but still can be trustful.

2.5. Quality Factor of the Antenna

As we all know, quality factor Q has an impact on energy transfer efficiency and frequency selection. Although a higher Q can enlarge the transmitting energy from the antenna, the bandpass characteristic of the Reader will be affected. So when adjusting Q, we should consider a compromise. Conventionally, we put a resistance in a R-L-C equivalent circuit to adjust Q, like (8)

$$Q = \omega L/(R + R_1) \tag{8}$$

So if we want to achieve the optimal result, the number of R_1 should be carefully chosen based on the actual demand.

2.6. Near-field Coupling

All the equations mentioned above should be used under the condition of

$$d \ll R \quad \text{and} \quad x < \lambda/2\pi.$$

When not meeting these two conditions, near-field coupling loses its effect and goes to the long-range electromagnetic field. As we all know, the initial magnetic field in a conductor loop begins from the antenna, during the transmission of the electromagnetic field, if x is bigger than $\lambda/2\pi$, then the electromagnetic field will be transmitted like without the antenna, similar to the process of electromagnetic waves going into free space.

3. SIMULATION

It is important to run a simulation of Equation (1) to clearly see the interconnection between distance x and the intensity of magnetic field H.

In order to see the result clearly, we assume I and N are constant numbers.

In Fig. 1, the downward trend is inversely proportional to the size of R.

It is also important to run the simulation of Equations (3) and (4) to see the interconnection between optimal radius of R and distance x like Fig. 2, and we assume I and N are constants.

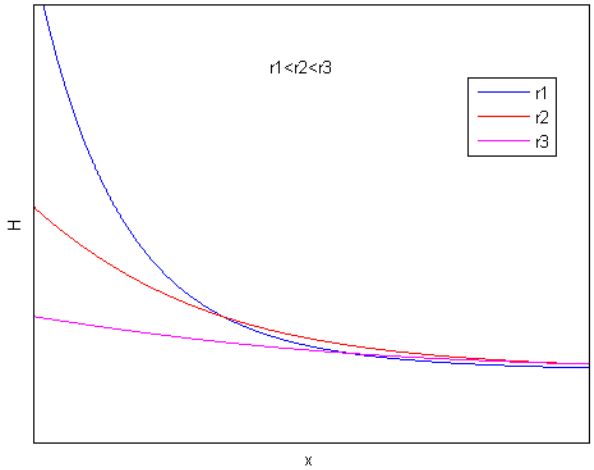

Figure 1: Interconnection between x and H.

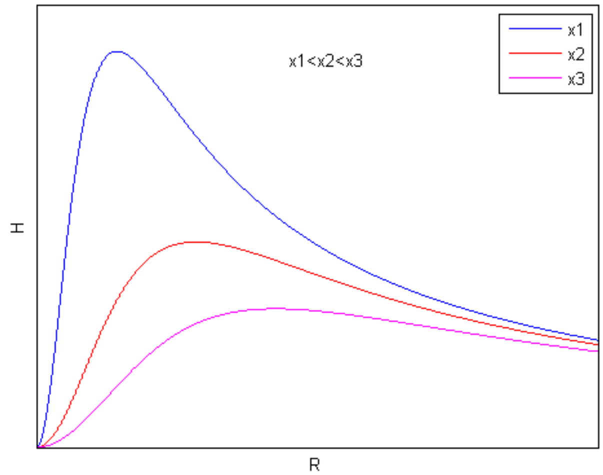

Figure 2: Interconnection between R and H.

4. CONCLUSION

This paper gives a fundamental method to design a RFID antenna which mostly concerns about important physical parameters like magnetic field intensity, optimal radius of the antenna, turning and estimating inductance of the conductor loop in mathematical way.

In the practical designing, more things should be considered based on the materials you have. But the essential still remains the same in this paper.

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