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Design of Antennas for RFID Application

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1. Introduction

As a vital and integrated part of the radio-frequency identification (RFID) system, RFID antennas have been received much attention over years, and their design is very urgent and significant. In fact, the development of RFID antenna is of theoretical significance and practical value for the RFID system. In this chapter, the RFID technology is briefly introduced, and the operating principle of the RFID system is described. The antenna in RFID system is discussed, and the designing principle of the antennas for RFID applications is presented. Some commonly used antennas in the RFID system are also displayed.

2. RFID technology and antennas

As an automatic identification technique without touching, RFID technology uses radio waves carrying information stored about the identified object or commands to identify object via space coupling, such as inductive coupling or electromagnetic wave propagation. For the details about the RFID technology, refer to some web sites such as www.rfidchina.org, www.rfidinfo.com.cn, www.rfidofchina.com, www.cnrfid.net, www.superrfid.net/china/, www.rfidworld.com.cn, and www.kingant.com.

As a vital device for transmitting the RF power from the radio transceiver to the open space in the form of electromagnetic wave, or receiving it from space and transferring it to the next circuit, antenna is always the key part of the RF system, and its performance greatly affects the performance of the whole system. Thus design of antennas for the RFID system is very important. In the RFID system, according to their functions in the system, the antennas can be divided into two parts: tag antenna and reader antenna. The present RFID systems are applied at LF, HF (13.56MHz), UHF and microwave bands, and the antenna design is focused on these frequency bands. In fact, the system working at LF and HF bands is based on the magnetic field coupling between the tag coil and reader coil, whose operating principle is identical with that of the transformer. There is no radiation and wave transmission, and the antenna in the system is just a coil. The antenna discussed here is limited to the system that operates at UHF band, or microwave bands. Based on the different operating principles at different bands, design of the antennas in the system will be discussed at following sections.

Source: Development and Implementation of RFID Technology, Book edited by: Cristina TURCU,
ISBN 978-3-902613-54-7, pp. 554, February 2009, I-Tech, Vienna, Austria

2.1 Antennas in the RFID system

According to the different functions in the RFID system, the RFID antennas can be divided into two classes: the tag antenna and the reader antenna. The tag antenna not only transmits the wave carrying the information stored in the tag, but also needs to catch the wave from the reader to supply energy for the tag operation. Since the tag should be attached to the identified object, the size of the tag must be small enough, and the antenna should be small in size. In most cases, the tag antenna should have omnidirectional radiation or hemispherical coverage. Generally the impedance of the tag chip is not 50 ohm, and the antenna should realize the conjugate match with the tag chip directly, in order to supply the maximum power to the tag chip. In common applications, the tag antenna should be low-cost and easy to fabricate for mass production.

The reader antenna transmits the electromagnetic energy to activate or awaken the tag, realizes the data transfer and sends the instructions to the tag. Meanwhile, the reader antenna receives information from the tag. Generally the position or the orientation of the identified object is random, and the manner for attaching the tag to the identified object is unfixed. Thus the reader antenna should be a circularly polarized antenna, in order to avoid the polarization loss when the orientation of the identified object is changed. Meanwhile, the reader antenna should have low profile and realize miniaturization, some of which should operate at more than one band. In some special cases, multiple antenna technology or smart antenna arrays for beam scanning will be employed.

In passive RFID system, the energy for maintaining the tag operation comes from the electromagnetic wave transmitted by the reader antenna. Here the passive system is mainly discussed to show the impact of the antenna parameters on the system performance (Keskilammi, Sydanheimo & Kivikoski, 2003).

To double the reading range, the transmitted power, the antenna gain, or the sensitivity of the receiver should increase at least 12dB. First, the impact of the antenna gain on thte system performance is described. When the transmitted power is fixed, the maximum reading range of the RFID system is mainly limited by the antenna gain and the operating frequency. By the RF link analysis, the electromagnetic wave transmitted by the reader antenna radiates to the tag through the space loss, and then reversely propagates back to the reader, carrying the information stored in the tag. Suppose that the RF energy caught by the tag can be re-radiated into the space totally. Let the power transmitted by the reader be $P_{transmitted}^{reader}$, and the gain of the reader antenna be G_{reader}. The power density at distance R where the tag is placed can be expressed as

$$S_1 = \frac{G_{reader} P_{transmitted}^{reader}}{4\pi R^2} \tag{1}$$

The power received by the tag is calculated by

$$P_{received}^{tag} = S_1 A_{tag} , \tag{2}$$

where

$$A_{tag} = \frac{G_{tag} \lambda^2}{4\pi} \tag{3}$$

Then, we have

$$P_{received}^{tag} = (\frac{\lambda}{4\pi R})^2 G_{reader} G_{tag} P_{transmitted}^{reader} . \tag{4}$$

The power density of the return wave from the tag at the position of the reader is

$$S_2 = \frac{G_{tag} P_{received}^{tag}}{4\pi R^2} \tag{5}$$

Thus the power received by the reader is

$$P_{back}^{reader} = S_2 A_{reader} = S_2 G_{reader} \frac{\lambda^2}{4\pi} \tag{6}$$

That is

$$P_{back}^{reader} = (\frac{\lambda}{4\pi R})^4 G_{reader}^2 G_{tag}^2 P_{transmitted}^{reader} \tag{7}$$

where G_{reader} stands for the gain of the reader antenna, A_{reader} the equivalent aperture of the reader antenna, G_{tag} the gain of the tag antenna, and A_{tag} the equivalent aperture of the tag antenna.

Define the equivalent transmitted power as

$$P_{(EIRP)} = G_{reader} P_{transmitted} \tag{8}$$

Then

$$P_{back}^{reader} = (\frac{\lambda}{4\pi R})^4 G_{tag}^2 G_{reader} (P_{(EIRP)}) . \tag{9}$$

Denote by $P_{sensitivity}^{reader}$ the threshold power of the sensitivity. Then the maximum reading range is expressed as

$$R = \frac{\lambda}{4\pi} \sqrt[4]{\frac{P_{transmitted}^{reader} G_{reader}^2 G_{tag}^2}{P_{sensitivity}^{reader}}} \tag{10}$$

Now we analyze the RFID system by using the radar principle. Suppose that the back-scattering section of the tag, including the antenna and the chip, is σ^{tag} , then the back-scattering power of the tag is

$$P_{BS} = S_1 \sigma^{tag} = \frac{G_{reader} P_{transmitted}^{reader} \sigma^{tag}}{4\pi R^2} \tag{11}$$

The power density of the back scattering wave at the position of the reader is

$$S_2 = \frac{P_{BS}}{4\pi R^2} = \frac{G_{reader} P^{reader}_{transmitted} \sigma^{tag}}{(4\pi)^2 R^4} \tag{12}$$

So we have

$$P^{reader}_{back} = S_2 A_{reader} = S_2 G_{reader} \frac{\lambda^2}{4\pi} = \frac{P^{reader}_{transmitted} G^2_{reader} \sigma^{tag} \lambda^2}{(4\pi)^3 R^4} . \tag{13}$$

By adjusting the tag chip impedance according to the stored data in tag, σ^{tag} will be changed, and then the return wave coming from the tag and received by the reader will be changed such that the amplitude modulation and demodulation can be realized. In this manner, the tag information can be read, and the object detected by the tag can be identified. Generally, the operating frequencies of the normal RFID system based on the back-scattering include: 915MHz, 2.45GHz, and 5.8GHz, the corresponding wavelengths are 0.328m, 0.122m, and 0.051m. Obviously, the maximum reading range is directly proportional to the wavelength. In fact, for the same distance the space loss at higher frequency is greater than that at lower frequency. The space loss *SL* is defined as

$$SL = \left(\frac{4\pi R}{\lambda} \right)^2 . \tag{14}$$

Commonly, the size of the antenna is relevant to its working frequency. For lower frequency, the antenna will be larger, and the size of the tag will increase. When the antenna size is fixed, the higher gain will be achieved for higher frequency. In most cases, the antenna size is a bottleneck for tag miniaturization. In order to appropriately choose the operating frequency for the RFID system, we should consider simultaneously many factors such as the space loss, the antenna gain, and the size of the tag.

There also exists another loss, called the polarization loss, which is caused by the polarization mismatch between the incoming wave and the antenna, or between the transmitting antenna and the receiving antenna. The polarization mismatch will make the antenna lose the ability to receive all the power of the wave.

Suppose $\vec{E}_i = \hat{\rho}_w E_i$ is the incoming wave, $\vec{E}_a = \hat{\rho}_a$ is the polarization orientation of the receiving antenna, and $\hat{\rho}_o$ is the vector that is orthogonal to the polarization vector of the receiving antenna. The polarization factor *PLF* is defined as

$$PLF = \left| \hat{\rho}_w \cdot \hat{\rho}_a \right|^2 = \left| \cos \varphi_p \right|^2 \text{, or } PLF(dB) = 10 \lg PLF \tag{15}$$

Then, the power received by the antenna is denoted by

$$P_r = P_{\max} \cdot PLF \text{ , or } P_r(dB) = P_{\max}(dB) + PLF(dB) \tag{16}$$

where $P_{\max}$ stands for the power of the incoming wave, or the maximum power received by the antenna when the polarizations are matched, $\hat{\rho}_a$ the unit polarization vector of the receiving antenna, and $\hat{\rho}_w$ the unit vector of the incoming wave.
Assume that the incoming wave is circularly polarized. Then the unit vector $\hat{\rho}_w$ can be expressed as

$$\hat{\rho}_w = \frac{\sqrt{2}}{2}(\hat{\rho}_a \pm j\hat{\rho}_o) \tag{17}$$

$PLF = 1/2$, and $PLF(dB) = -3dB$.

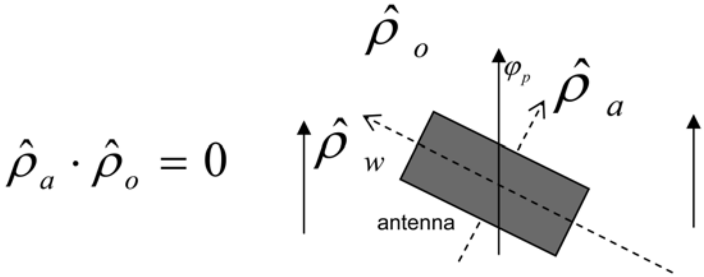


Fig. 1. Polarizations of the antenna and the wave

As shown in Fig. 1, the polarization mismatch between the antenna and the wave reduces the received power, and deteriorates the system performance. Thus choosing a suitable polarization is also an important step for designing the antenna.

2.2 Development of antennas in the RFID system

Potential applications of the RFID technology inspired the development of various antennas for the RFID systems. Lots of antennas with high performance for various requirements have been fabricated. As an identification system with huge market and potentials, RFID system requires the RFID antenna to meet some particular specifications. Design of the RFID antennas faces many challenges, such as the antenna structure, the antenna size, the operating mode, the bandwidth, the radiation pattern, the polarization, mutual coupling between multiple antennas, and the antenna scattering. In the present RFID system, the reader antenna is designed to be a circularly polarized antenna. Patch and spiral antennas are typical reader antennas. In some special cases, linearly polarized antennas can also be used. In the tag, the eroded or printed antennas are commonly used, and the dipole is the typical tag antenna structure. Some circularly polarized antennas for the tag may be required in some special applications.
In recent years, theory for matching the antenna with the tag chip is discussed, which guides the design of the tag antenna and the analysis of the tag configuration. Several tag antennas in common use are designed with simple impedance transformation for matching the chip with special impedance, especially for UHF band application. In the microwave band, some tag antennas are also designed to integrate with the already existing specific circuits with 50 ohm impedance.

Schemes for designing the circularly polarized reader antenna are also presented in some literature. Based on two ports for the dual circular polarization, the aperture-coupled patch antenna integrated with the microstrip branch line coupler is preferred. Some modifications are performed to achieve the wide band, or meet the practical requirements. The system, in which multiple reader antennas are used, is also discussed.

In the design of antenna for the RFID system, some other problems, such as the environmental effects on RFID tag antennas, especially surrounded by metallic objects, should be considered. Designing the RFID tag antenna, which is mounted on the metallic objects, also faces a challenge. The inverted-F antenna and its modifications are usually used in the tag for identifying the metallic objects, and other antenna structures can also be referred in designing antenna mounted on metallic surfaces. The electromagnetic scattering of the tag antenna is also introduced and discussed, and relative calculations have been performed.

2.3 Antenna design software for RFID application

Efficient numerical methods promote the antenna design. Modern antenna design becomes a manipulation of accurate computing based on relative theory and a design under the theory instruction or according to the calculated results. The antenna design method based on numerical methods has been applied to design antennas for various systems. Familiar numerical methods include Method of Moment (MoM), Finite Element Method (FEM), and Finite Difference Time Domain (FDTD). There already exist several design tools based on these methods, which are of different characteristic and are widely used. Fig. 2 shows some familiar methods and the design tools. These design tools can be chosen for different problems in designing antennas. The MoM can be used to calculate the antenna performance quickly and accurately, especially for some large antenna structures. Some optimization methods, such as the optimization tool used in Zeland IE3D, can be embedded into the analysis method to make the antenna achieve the excellent performance. The FEM and FDTD methods can be used directly to analyze the antenna performance. However, the FEM method gets more accurate results than the FDTD method. The FDTD method can be used to analyze some larger antenna structures, solve the wide band problems in time domain, and give a dynamic demo about the electromagnetic field distribution and radiation. Some tools such as HFSS, which are widely used to deign antenna for the RFID system, add the ability of automatically meshing to facilitate the user and improve the precision.

These design tools should be chosen properly for designing antenna, since they have different characteristics. Some tools can be used to analyze some types of antenna suitably but lose the ability for solving other antennas or affording the large memory requirement. In designing antenna, the antenna concept based on the electromagnetic theory should be mixed with the manipulating software skilfully, and the antenna prototype of the design scheme chosen for the system requirement is more important than the skill in applying the software. After the antenna scheme is decided, being familiar with the software and the relative numerical methods will help the designer to design antenna properly, and adjust the structure parameters to optimize its performance. To succeed in designing antenna, it is of great importance to apply software under the guidance of antenna principle and electromagnetic theory. Although the function of the software for designing antenna is more powerful, the basic theory and concept is also absolutely necessary. Both the antenna theory and the design software promote the design of antennas in the RFID system.

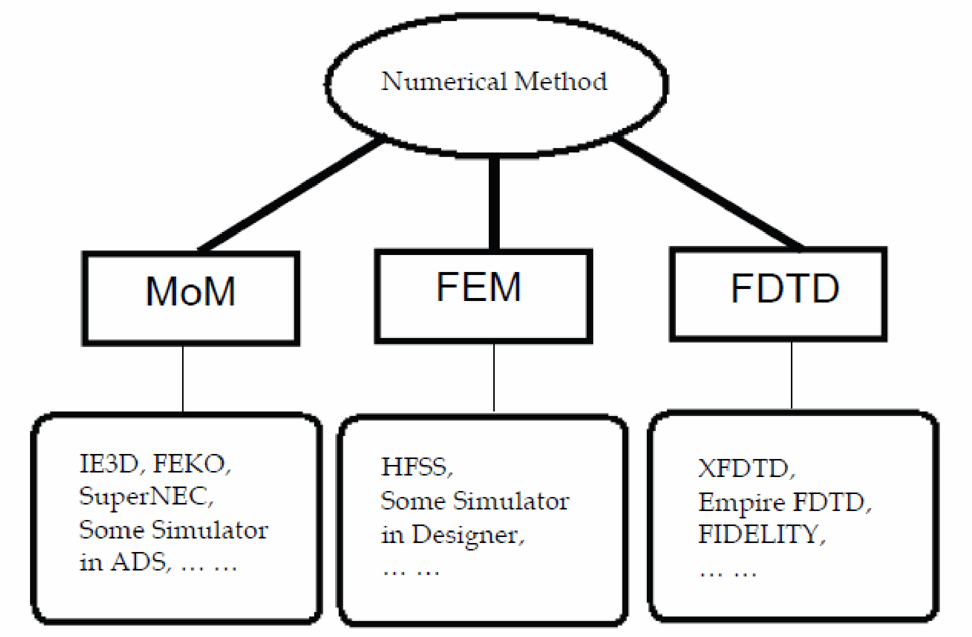


Fig. 2. Numerical methods and software

3. Power transmission between tag chip & antenna

Generally, the RFID system mainly consists of reader and tag. The tag design is the most important loop in the RFID application, and also the most difficult part in the function realization. Performance of the tag usually decides the performance of the whole system. The tag is composed of the tag antenna and the chip, between which good connection and power transmission directly impact on the system configuration, the relative function realization and also the system performance. Thus, it is necessary to analyze the connection of the tag antenna to the RFID tag chip, and to discuss the impedance match problem.

3.1 Theory of impedance match

The most important factor in the tag is the reading range, which is the maximum distance between the reader and the tag such that the reader can detect the backscattering signal from the tag. Compared with the tag, the reader is always of high sensitivity, and the reading range is mainly limited by the performance of the tag. Especially for the passive tag, both the energy for maintaining or arousing the tag and the power of signal retransmitted by the tag are from the RF energy, which is transmitted by the reader and caught by the tag. The impedance match between the antenna and the chip has a direct influence on whether the tag circuit can operate well and the chip is able to retransmit enough energy to implement the backscattering communication, and limits the reading range.

To maximize the power transfer between the antenna and the chip, the impedance of the chip connected to the antenna should be conjugate to the antenna impedance. When the working frequency comes into the microwave band, the impedance match problem becomes more serious. Ordinarily, the impedance of the antenna prototype designed for the tag is 50 ohm or 75 ohm, while the chip impedance may be a random value, or vary with frequency, and have a difference when the driving power is changed. It is extremely crucial to achieve suitable impedance match between the antenna and the chip. New integrated circuit chip design and development need large investment and long research period, however, designing antenna to match the existing chip is more convenient and practical. Due to the requirements such as easy manufacture, low cost and small size, adding the matching network is infeasible. To solve this problem, the antenna should be able to match the chip directly by adjusting its structure. How to design an antenna to match a chip of arbitrary impedance is an inevitable mission in designing antenna for the RFID system (Nikitin et al., 2005; Rao, Nikitin & Lam, 2005a).

By analyzing the tag, its equivalent circuit is shown in Fig. 3. Denote by Z_a the antenna impedance, and $Z_a = R_a + jX_a$, by Z_c the chip impedance, and $Z_c = R_c + jX_c$.

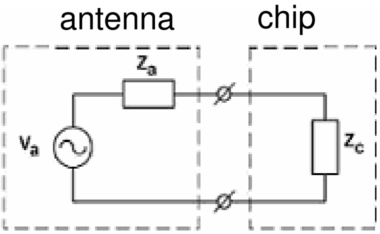


Fig. 3. Equivalent circuit of the tag

Define the complex power reflection coefficient s as

$$s = \frac{Z_a - Z_c^*}{Z_a + Z_c} \tag{18}$$

Then the power reflection coefficient is calculated by

$$|s|^2 = \left|\frac{Z_a - Z_c^*}{Z_a + Z_c}\right|^2 = \left|\frac{(R_a - R_c) + j(X_a + X_c)}{(R_a + R_c) + j(X_a + X_c)}\right|^2$$

$$= \left|\frac{\left[R_a + j(X_a + X_c)\right] - R_c}{\left[R_a + j(X_a + X_c)\right] + R_c}\right|^2 = \left|\frac{\left(\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c}\right) - 1}{\left(\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c}\right) + 1}\right|^2 \tag{19}$$

Let

$$\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c} = r + jy = \overline{Z}_a \tag{20}$$

be the antenna impedance normalized to the real part of the chip impedance, then

$$|s|^2 = \left|\frac{\overline{Z}_a - 1}{\overline{Z}_a + 1}\right|^2 \text{, or } |s| = \left|\frac{\overline{Z}_a - 1}{\overline{Z}_a + 1}\right|. \tag{21}$$

On the basis of the transformation, the traditional Smith Chart can be used to describe the impedance match between the antenna and the chip. $\overline{Z}_a$ can be marked according to its real part and imaginary part on Smith Chart like the traditional normalized impedance. The distance between the point of each $\overline{Z}_a$ and the centre point of Smith Chart expresses the magnitude of the complex power reflection coefficient *s*, while the trace of impedance points, which have a constant distance to the centre point, forms the concentric circle, which is called as the equivalent power reflection circle. The centre point of Smith Chart is the perfect impedance match point, while the most outer circle denotes the complete mismatch case, i.e. $|s| = 1$.

The power transmission coefficient (Rao, Nikitin & Lam, 2005b) can also be defined as τ, and $P_c = P_a\tau$, where P_a stands for the power from reader caught by tag antenna, P_c the power transmitted from the tag antenna to the tag chip. It follows from Fig. 3 that

$$\tau = \frac{4R_cR_a}{|Z_a + Z_c|^2}, 0 \le \tau \le 1 \tag{22}$$

$$\tau + |s|^2 = 1 \tag{23}$$

Let $x_a = \frac{X_a}{R_c}$, $r_a = \frac{R_a}{R_c}$, $Q_c = \frac{X_c}{R_c}$, then equation of the circle with constant power transmission coefficient is expressed as follows.

$$[r_a - (\frac{2}{\tau} - 1)]^2 + [x_a + Q_c]^2 = \frac{4}{\tau^2}(1 - \tau) \tag{24}$$

From equation (24), the impedance chart with the constant power transmission coefficient is draw, as shown in Fig. 4.

In Fig. 4, the x axis expresses the normalized real part $r_a = R_a / R_c$, and y axis the normalized imaginary part $x_a = X_a / R_c$. The circles with constant power transmission coefficients τ =1, 0.75, 0.5, 0.25 are draw in Fig. 4. The x axis is called as the resonant line with $X_a = -X_c$, while the y axis is called as the complete mismatch line. When τ's decrease, the radius of the circles with constant power transmission coefficient increase. While $\tau \to 0$, the circle with constant power transmission coefficient approaches to its tangent, that is the y axis, on which the impedance point cannot achieve the power transmission.

When the chip and the antenna are resonant, $X_a = -X_c$, and $x_a = -Q_c$, then equation (24) becomes

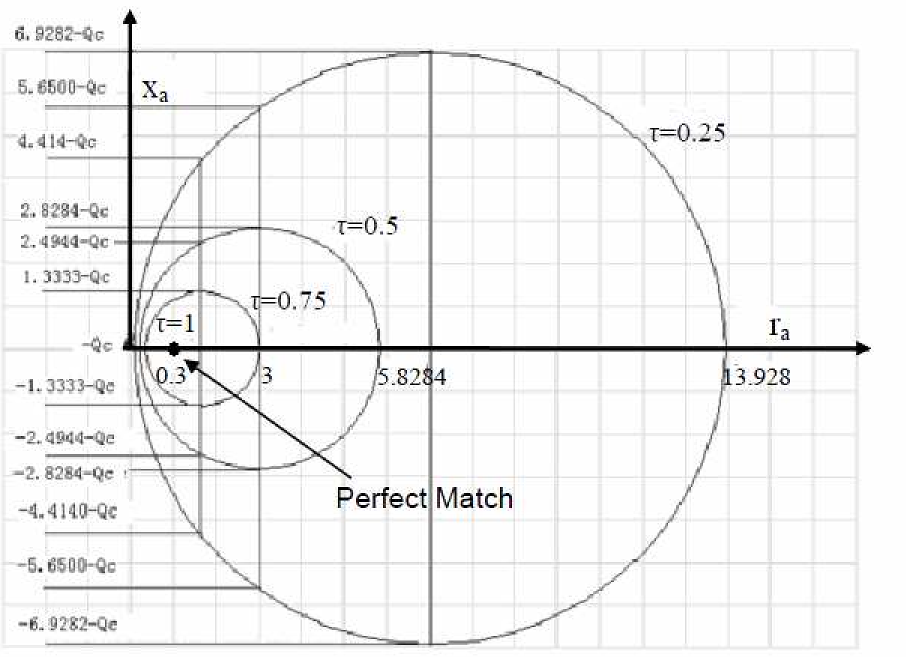


Fig. 4. The impedance chart with the constant power transmission coefficient

$$[r_a - (\frac{2}{\tau} - 1)]^2 = \frac{4}{\tau^2}(1-\tau) \tag{25}$$

$$[\tau r_a - (2-\tau)]^2 = 4(1-\tau) \tag{26}$$

Making the derivative for the both sides of equation (26), we have

$$2[\tau r_a - (2-\tau)](\tau + r_a\frac{d\tau}{dr_a} + \frac{d\tau}{dr_a}) = -4\frac{d\tau}{dr_a} \tag{27}$$

$$\frac{d\tau}{dr_a} = \frac{[(r_a+1)\tau - 2]\tau}{2r_a} \tag{28}$$

Obviously $\tau = 1$ means perfect match, and $\frac{d\tau}{dr_a} = 0$. $\tau = 0$ means complete mismatch, and $\frac{d\tau}{dr_a} = 0$. Thus either the perfect match or the complete mismatch is a steady point of τ with r_a, i.e. $\frac{d\tau}{dr_a} = 0$.

For the fixed $\frac{R_a}{R_c}$ and $\frac{X_a}{X_c}$,

$$\tau = \frac{4\frac{R_a}{R_c}}{|1+\frac{R_a}{R_c}+jQ_c(1+\frac{X_a}{X_c})|} = \frac{4\frac{R_a}{R_c}}{(1+\frac{R_a}{R_c})^2+Q_c^{\ 2}(1+\frac{X_a}{X_c})^2} \tag{29}$$

$$\frac{d\tau}{dQ_c} = -8Q_c(1+\frac{X_a}{X_c})^2\frac{R_a}{R_c}[(1+\frac{R_a}{R_c})^2+Q_c^{\ 2}(1+\frac{X_a}{X_c})^2]^{-2} \tag{30}$$

When the chip impedance is capacitive, i.e. $Q_c < 0$, it follows from (13) that $\frac{d\tau}{dQ_c} > 0$. While the chip impedance is inductive, i.e. $Q_c > 0$, $\frac{d\tau}{dQ_c} < 0$. When $Q_c = 0$, i.e. $X_c = 0$ and meanwhile $X_a = 0$, we have

$$\tau = \frac{4R_cR_a}{(R_c+R_a)^2} \tag{31}$$

The curve of τ versus *Qc* is shown in Fig.5. From this figure, we can see that for the fixed $\frac{R_a}{R_c}$ and $\frac{X_a}{X_c}$, *Qc* should be as small as possible from the power transmission point of view, when the tag antenna is connected to the tag chip.

For the tag antenna, the impedance chart can be used to guide the design or to describe the tag antenna. The chart is theoretically important and very useful for other applications.

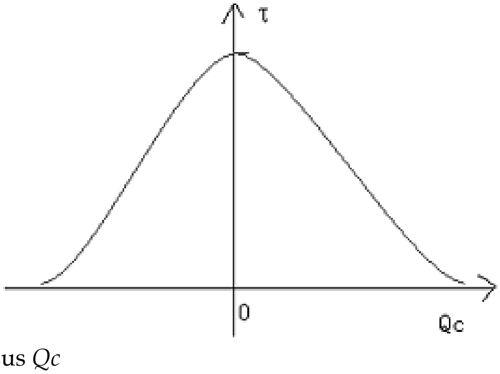


Fig. 5. Curve of τ versus *Qc*

3.2 Impedance design for the tag antenna

Aforementioned results indicate that the maximum power transmission can be realized only if the antenna impedance is equal to the conjugate value of the chip impedance. While the chip impedance is not normal 50 ohm or 75ohm, the structure of the tag antenna should be carefully chosen. In this section, a symmetrical inverted-F metallic strip with simple structure shown in Fig. 6 is proposed.

The antenna has the ability to realize several impedances. For UHF band application, the impedance of the antenna in four cases with different structure parameters is analyzed at 912MHz, whose real part is approximately 22ohm, 50ohm, 75ohm, 100ohm respectively. The simulated results for these four cases are shown in Fig. 7.

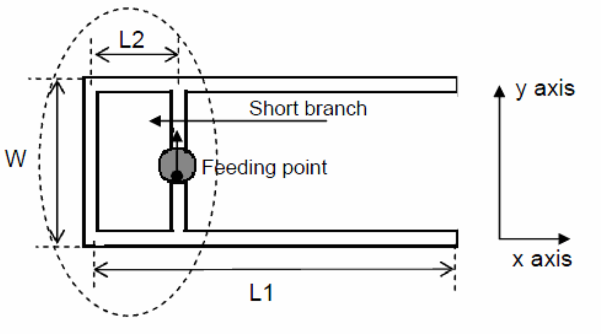
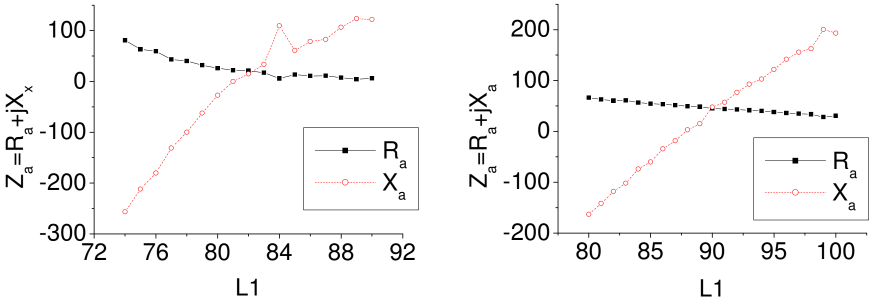
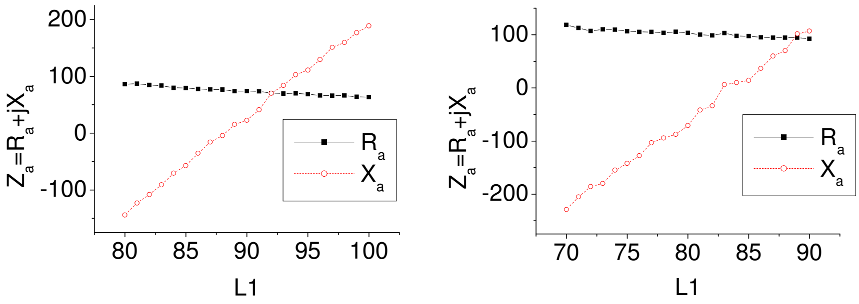


Fig. 6. The symmetrical inverted-F Antenna



(A) W=30mm, L2=10mm (B) W=50mm, L2=25mm



(C) W=64mm, L2=32mm (D) W=73mm, L2=32mm

Fig. 7. Impedance results of the antenna in different cases

Fig. 7 shows that the symmetrical inverted-F metallic strip can realize several impedance values by adjusting its short branch. A lot of familiar types of tag antennas are the modifications or transformations of this structure (Dobkin & Weigand, 2005).
Fig. 8 shows the evolvement of several tag antennas. Antenna B has less influence on its performance than antenna A, when the antenna is curved (Tikhov & Won, 2004). Antennas C and D are fed by an inductively coupled loop (Son & Pyo, 2005).

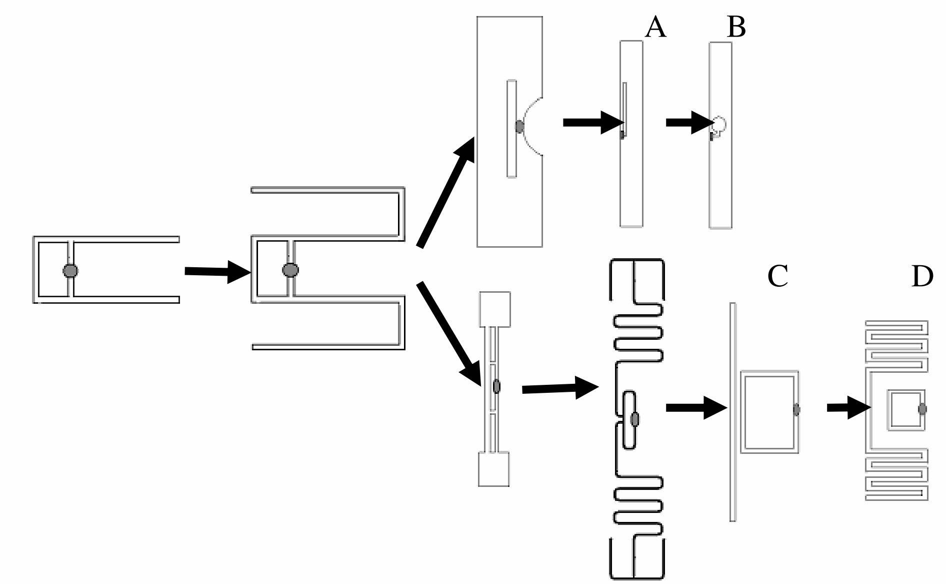


Fig. 8. Evolvement of the tag antennas

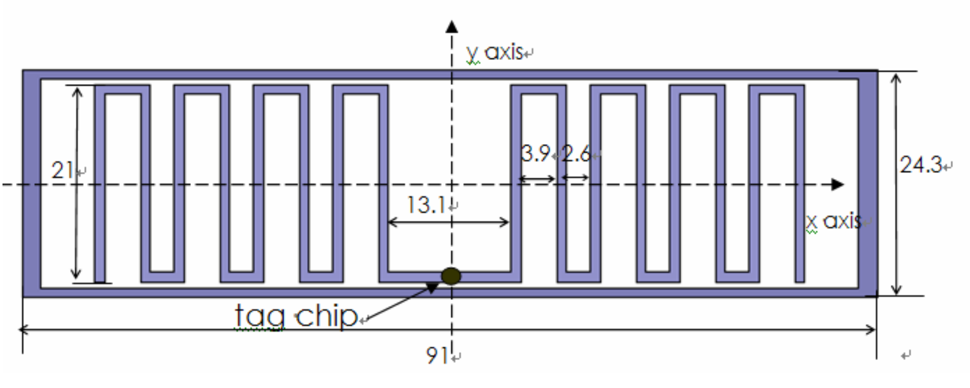


Fig. 9. Geometry of a meandered dipole antenna surrounded by the rectangular loop (dimensions in mm)

In our application, an UHF band tag chip with 43-j800 ohm impedance is used, and a tag antenna connected to this chip should match the tag chip. Meanwhile the tag antenna should be small in size and easily fabricated. In Fig. 9, a meandered dipole antenna is designed, and a pair of symmetrical meandered metallic strips surrounded by a rectangular loop is fed. The higher real part of the impedance can be realized by the meandered dipole, while its high imaginary part can be supplied by the coupling between rectangular loop and symmetrical meandered dipole. In this way, a tag antenna with higher absolute value impedance and higher Q value is designed and connected to the chip, to ensure the good power transmission. The gap of the feeding point is 0.1mm, the width of the metallic meandered strip and the horizontal part of the rectangular loop is 1mm, and the width of its vertical part is 2mm. The tag antenna has a thickness of 0.018mm.

The tag antenna is analyzed by the HFSS software, the performance of the antenna, including its impedance and radiation patterns, is calculated. The simulated results are shown in Table 1 and Fig. 10. These results show that the antenna with small size can be used as a tag antenna for the UHF band RFID chip application.

Freq(MHz)	Antenna impedance (ohm)	Power reflection coefficient $\left\|s\right\|^2$	Power transmission coefficient τ
900	36.6+j695.2	0.6365	0.3635
901	37.1+j701.6	0.6036	0.3964
902	37.7+j708.0	0.5670	0.4330
903	38.3+j714.5	0.5268	0.4732
904	38.9+j721.0	0.4833	0.5167
905	39.5+j727.7	0.4354	0.5646
906	40.1+j734.5	0.3840	0.6160
907	40.7+j741.4	0.3294	0.6706
908	41.3+j748.4	0.2728	0.7272
909	42.0+j755.5	0.2152	0.7848
910	42.7+j762.7	0.1593	0.8407
911	43.4+j770.0	0.1076	0.8924
912	44.1+j777.4	0.0632	0.9368
913	44.8+j785.0	0.0288	0.9712
914	45.5+j792.7	0.0076	0.9924
915	46.3+j800.5	0.0014	0.9986
916	47.1+j808.4	0.0107	0.9893
917	47.9+j816.4	0.0343	0.9657
918	48.7+j824.6	0.0707	0.9293
919	49.6+j832.9	0.1166	0.8834
920	50.4+j841.4	0.1695	0.8305
921	51.3+j850.0	0.2255	0.7745
922	52.2+j858.7	0.2822	0.7178
923	53.2+j867.6	0.3381	0.6619
924	54.1+j876.7	0.3923	0.6077
925	55.1+j885.9	0.4426	0.5574
926	56.1+j895.2	0.4890	0.5110
927	57.2+j904.8	0.5320	0.4680
928	58.3+j914.5	0.5710	0.4290
929	59.4+j924.4	0.6065	0.3935
930	60.5+j934.5	0.6387	0.3613

Table 1. The impedance and power reflection coefficient, power transmission coefficient for Tag antenna（chip impedance: 43-j800ohm）

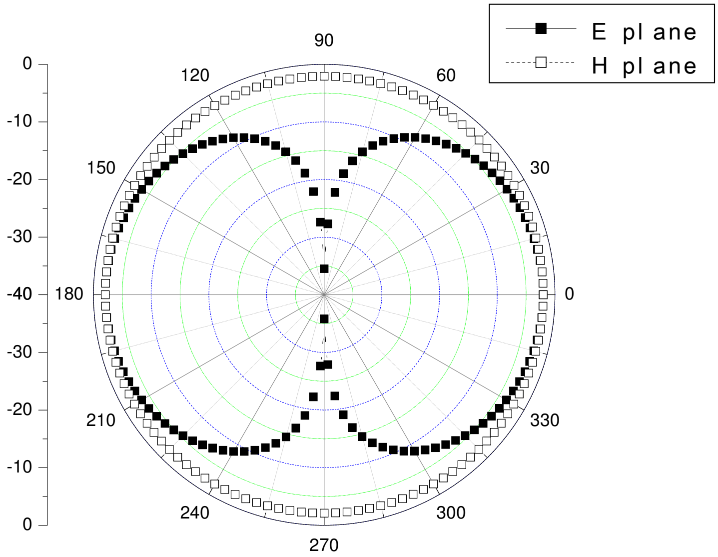


Fig. 10. Radiation pattern of the meandered dipole antenna

3.3 Tag antenna mountable on metallic objects

Since the RFID technology is applied in wide fields, RFID systems frequently appear in the metallic environment, and the effect of the metallic objects should be considered in designing the antenna (Penttilä et al, 2006). RFID antennas in microwave band have a defect of standing wave nulls under the impact of metallic environment. To solve the problem brought by the metallic objects, some special tag antennas should be designed. These antennas usually have a metallic ground. Some metallic objects, which make the performance of the RFID antenna worse, are modified to be as an extended part of the antenna to improve its performance. Some existing problems should be discussed.

When the traditional dipole antenna is attached to an extremely large metallic plane, its radiation will be damaged. In general, the tag antenna with a hemispherical coverage is required. In practical application, a tag antenna with low profile is frequently used, and its vertical current is limited. In Fig. 11, when a normal dipole antenna approaches closely the metallic surface, an inductive current in opposite direction is excited, and the radiation induced by the current will eliminate the radiation of the dipole, resulting in that the tag cannot be detected or read. As a class of antennas, the microstrip antenna may be a good choice for being mounted on the metallic surfaces and identifying the metallic objects. For ordinary tag chip, a balun or other circuit is needed to feed the antenna. Here, based on the dipole antenna, two design schemes for the metallic surfaces are proposed. One is a modification to the Yagi antenna, and the other is a dipole Antenna backed by an EBG structure. A substrate with high dielectric coefficient is sandwiched between the dipole and the metallic surface, its thickness will reverse the orientation of the inductive current, and the radiation is strengthened. An EBG structure can depress the primary inductive current, the radiation of the dipole will be available, and the metallic surface of the identified object is also the ground of the EBG structure.

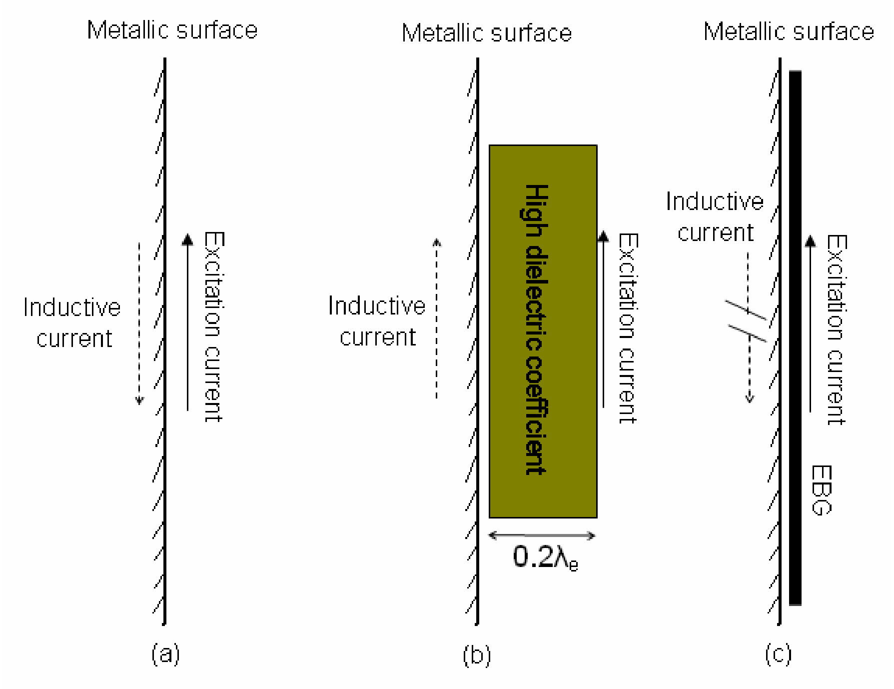


Fig. 11. Design scheme for the tag antenna on metallic surfaces
(a) Excitation current nearby the metallic surface; (b) Scheme based on the Yagi antenna
(c) Scheme based on the EBG structure

According to the introduced schemes, three tag antennas are designed for three tag chips with impedances 15-j20 ohm (chip 1), 6.7-j197ohm (chip 2), and 43-j800 ohm (chip 3), respectively. The tag antenna based on the Yagi antenna is shown in Fig. 12, and the geometry of the active dipole (Qing & Yang, 2004a) is also given in Fig. 13. In Fig.12, the active dipole is attached on the substrate with the relative dielectric coefficient εr=10.2. The width of the metallic strip is 0.8mm.

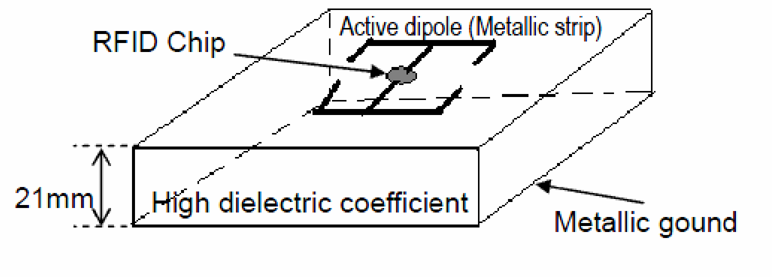


Fig. 12. The tag antenna for chip 1 based on the Yagi antenna

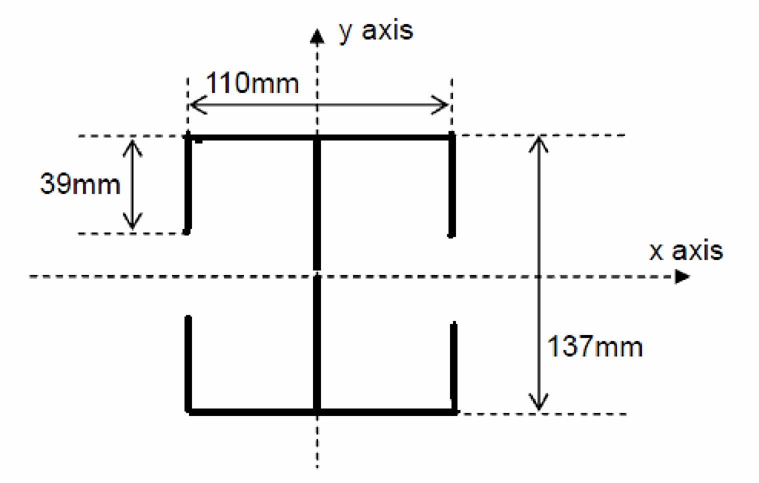


Fig. 13. Geometry of the active dipole (dimensions in mm)

The antenna shown in Fig. 12 is analyzed by the HFSS software. The calculated antenna impedance matches the chip impedance 15-j20 ohm in UHF band. Radiation patterns of the tag antenna are also calculated and shown in Fig. 14.

To design the antenna for chip 2 with 6.7-j197 ohm impedance, the structure parameters are adjusted. The designed dipole is shown in Fig. 15, and its simulated radiation patterns are presented in Fig. 16.

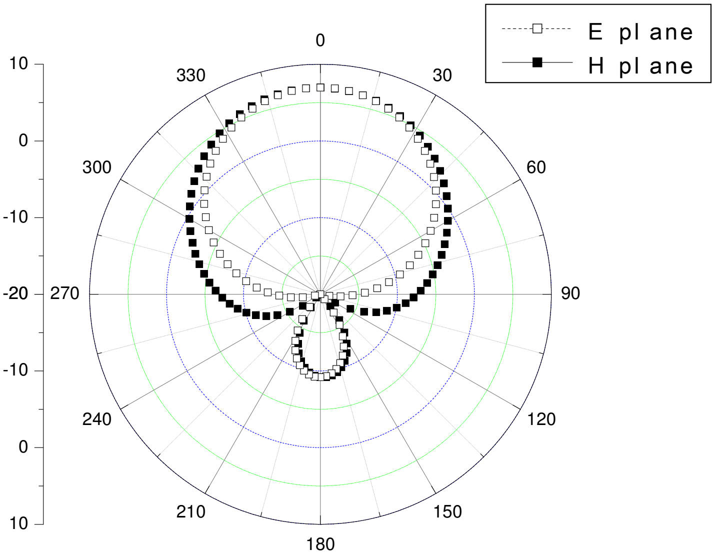


Fig. 14. Radiation patterns of the tag antenna for chip 1