ISSN 1816-6075 (Print), 1818-0523 (Online)
Journal of System and Management Sciences
Vol. 3 (2013) No. 3, pp. 34-41

Analysis and calculation of read distance in passive backscatter RFID systems

Yanghua Gao[1], Zhihua Zhang[1], Hailiang Lu[1], Huanwen Wang[1]
[1] Information Center, China Tobacco Zhejiang Industrial Co.Ltd, Hangzhou, China
{gaoyh, zzh, lhl.wanghw}@zjtobacco.com

Abstract: One of the obstacles to wide adapt passive RFID systems is the limited read distance or relatively high error rate due to radio interferences in the passive backscatter RFID systems. The most important tag performance characteristic is read distance at which RFID reader can detect the backscattered signal from the tag. The read distance in passive backscatter RFID systems depends on many factors; this paper presented an overview of passive backscatter RFID systems and the transmission model of these systems. We focus on presenting an overview of several antenna parameters impacting on read distance in the passive backscatter RFID system and obtaining the calculation formula of the read distance. The experimental verification shows the validity of the formula in the end.

Keywords: RFID, Transmission Model, Read Distance, Calculation Formula

1. Introduction

Radio Frequency Identification (RFID) is a kind of the contact-less automatic identification technology via radio frequency signal，which is one of the most developed rapidly technologies in automatic identification technology field. It uses radio frequency to identify the target and acquire data via non-contact radio communication. In recent years，with the growing application requirements for RFID, RFID technology，in particular，working at UHF and microwave bands develops very quickly. Meanwhile，with the operating frequency of RFID system increasing， for passive RFID systems working at the UHF and microwave bands and on the basis of backscattering modulation principle to work, it becomes very important to research on response model of electromagnetic field and calculation of the read distance.

Passive RFID systems and their communication have been researched in several publications [1]. These researches give more in-depth analysis towards the tags' performance. There also have been numerous publications on antennas for RFID tags. At the same time, there exist some papers on RCS of linear and non-linear laden antenna. However, very few papers provided an overview of response model of passive RFID systems [2-9]. This paper provides a calculation method for RCS which is very complex [7]. These investigations give academic analysis and measure on RCS of antenna for RFID tags with different load [2, 6]. But there exist no specific RCS calculation method for different laden antenna [2], meanwhile, there also have no simulation results [6]. In this paper, we attempted to fill existing gap. We reviewed passive RFID technology and the principle of the backscatter RFID system. The response model of passive backscatter RFID systems and the calculation of the read distance are analyzed and discussed.

2. Backscatter RFID System

The operation of a typical passive backscatter RFID system includes an RFID reader and a passive RFID tag，shown as Fig.1. A passive tag consists of an antenna and an application specific integrated circuit chip, both with complex impedance (Zin and ZL). The chip obtains power and data from the radio frequency (RF) signal transmitted by the RFID reader. The tag sends data back by switching its input impedance between two states (Zc1 and Zc2) and thus modulating the backscattered signal. At each impedance state, the tag presents a certain radar cross-section (RCS). One of the impedance states is generally high (RCS1) and another is low (RCS2) to provide a significant difference in the backscattered signal.

The variation of the chip impedance with power and frequency can drastically affect the performance of the tag. Thus, proper impedance match between the antenna and the chip is very important in passive RFID systems. It directly influences RFID system performance characteristics such as the reading ability. Usually, in order to maximize the reading ability, the antenna impedance is matched to the chip impedance at the minimum power level required for the chip to work.

Data exchange between reader and tag can employ various modulation and coding schemes. The signal transmitted on the uplink (reader to the tag) contains both continuous wave (CW) and modulated commands as shown in Fig.1. On the downlink (tag to the reader), the data is sent back during one of CW periods when the tag impedance modulates the backscattered signal [6]. A passive backscatter RFID system can be produced at a favorable price, but the read ability is strongly limited by the overall efficiency of the system. The antenna characteristics have a radical effect on the read ability of RFID systems. In the following paragraphs, we study the response model of passive backscatter RFID systems and the calculation of the read distance.

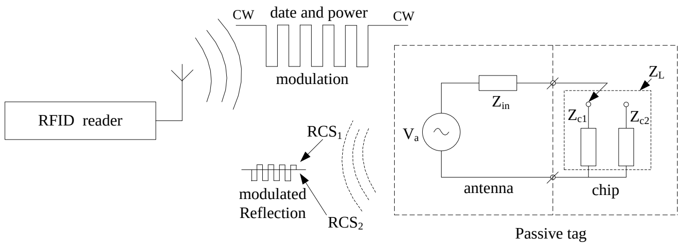

Fig.1 Passive backscatter RFID system

3. Analysis and Calculation

In passive backscatter RFID systems, the operational power required by the tag is transmitted from the reader. This calls attention to the total performance of the radio link between the reader and the tag.

The properties of the reader or the tag, such as transmitting power, antenna gain, operating frequency, radar cross-section, quality factor, effective aperture or scatter aperture, polarization, and receiver sensitivity, are considered as some primary factors affecting read distance.

3.1 Uplink Transmission Model

According to Friis transmission equations in free space, the received power at the read distance R can be calculated by formula as

$$P_r(R) = \frac{P_t G_t(\theta_t, \varphi_t) G_r(\theta_r, \varphi_r) \lambda^2}{(4\pi)^2 R^2 L} \tag{1}$$

Where λ is the wavelength, P_t is the power transmitted by the transmitter, $G_t(\theta_t, \varphi_t)$ is the gain of the transmitting antenna, $G_r(\theta_r, \varphi_r)$ is the gain of receiving antenna, Pr(R) is the receiving power of the receiver antenna, R is the distance between the receiver and transmitter, L is the system loss factor without the spread, when L = 1, it indicates that there is no loss in the system hardware.

In passive backscatter RFID systems, the uplink is the transmission from reader to the tag. The reader is transmitter, the tag is receiver. It supposes that the tag is on the direction of the maximum gain (G_t) of reader antenna gain and the direction of the maximum gain (G_r) of tag is same as reader antenna, at the same time, the polarization direction of reader antenna is same as the tag antenna, thus formula (1) can be showed

$$P_r(R) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 R^2} \tag{2}$$

The energy of the passive tag is completely provided by the reader antenna .

3.2 Downlink Transmission Model

According to radar transmission equations in free space, the intercepted power of the target is proportional to scattering area

$$P_i = \sigma S_i \tag{3}$$

Where Pi is the intercepted power of the target, σ is the Scattering area, Si is the incident power density of target.

When the incident power is uniformly diffused, thus

$$S_s = \frac{P_i}{4\pi R^2} \tag{4}$$

Where S_s is the power density of receiving antenna of radar from scattering. From (3) and (4)

$$\sigma = 4\pi R^2 \frac{S_s}{S_i} = 4\pi R^2 \left| \frac{E_s}{E_i} \right|^2 \tag{5}$$

Where E_i is the incident electric field intensity of target, E_s is scattering electric field intensity of radar antenna from target, and σ is the measure that target scatters electromagnetic-field at the direction of radar receiving antenna. Thus received power of radar can be expressed as

$$P_r = \frac{P_t G_t(\theta_t, \varphi_t) G_r(\theta_r, \varphi_r) \lambda^2 \sigma}{(4\pi)^3 R_1^2 R_2^2} \tag{6}$$

Where R_1 is the distance between transmission antenna and target, R_2 is the distance between receiving antenna and target (bistatic radar). $G_t(\theta_t, \varphi_t)$ is the gain of transmission radar, $G_t(\theta_t, \varphi_t)$ is the gain of receiving radar.

For monostatic radar, $G_t(\theta_t, \varphi_t)$, P_r can be defined as

$$P_r = \frac{P_t G_t(\theta_t, \varphi_t)^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{7}$$

In passive backscatter RFID systems, the reader generally only has a antenna, which equate to monostatic radar, and the electric field polarization of reader is the same as tag, so the intercepted power of the RFID reader is obtained as

$$P_r = \frac{P_t G_t^{\,2} \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{8}$$

Equation (8) is defined as RCS (radar cross-section) model.

3.3 Calculation of the read distance

According to uplink transmission model, the received power of tag can be taken into account by equation (2). Assuming that they started power of tag circuit is $P_{\min}$, when $P_r \ge P_{\min}$, the tag can be started. According to downlink transmission model, the receiving power of the reader antenna from the backscattering tag can be obtained, when $P_r'(R') \ge P'_{\min}$, where $P_r'(R')$ is the minimum received power requirement of the reader, $P'_{\min}$ is the started power of the reader, the reader can be started.

When
$$P_r = P_{\min} \tag{9}$$

Then
$$P_{\min} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 R^2} \tag{10}$$

The maximum read distance can be obtained as

$$R_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r}{P_{\min}}} \tag{11}$$

In free place

$$S_i = \frac{E^2}{2\mu_0} \tag{12}$$

Where $\mu_0 = 120\pi$

Then

$$R_{\max} = \frac{\sqrt{60 P_t G_t}}{E_0} \tag{13}$$

When

$$P_r'(R') = P'_{\min} \tag{14}$$

Then

$$P'_{\min} = \frac{P_t G_t^{\,2} \lambda^2 \sigma}{(4\pi)^3 R'^4} \tag{15}$$

The maximum read distance can be expressed as

$$R'_{\max} = \left[\frac{P_t G_t^{\,2} \lambda^2 \sigma}{(4\pi)^3 P'_{\min}} \right]^{\frac{1}{4}} \tag{16}$$

Considering downlink model in free place

$$R'_{\max} = \frac{\lambda}{4\pi} \left[\frac{P_t G_t^{\,2} G_r}{P'_{\min}} \right]^{\frac{1}{4}} \tag{17}$$

When the passive backscatter RFID system works, the maximum read distance of the system can be obtain as

$$R''_{\max} = \min\left\{ R_{\max}, R'_{\max} \right\} \tag{18}$$

4. Experimental Verification

In order to verify the calculation formula of read distance in backscatter systems, an experimental system is designed.

4.1 Experimental System

The experimental system is shown in Fig.2.

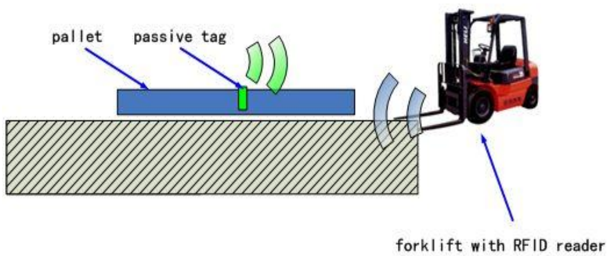

Fig.2 Experimental system based on RFID

The experimental system includes pallet with passive tag、pallet and forklift with RFID reader.

4.2 Verification

According to the parameters from manufacture, the maximum read distance can be calculated

$$R''_{\max} = 3.65m$$

The read times in 1 second are recorded when the read distance is different. The experimental results are shown in Table.1.

TABLE .1 READ DISTANCE EXPERIMENT

Read distance(m)	**Time(s)**	**Times**
1.2	1	12
2.2	1	10
3.5	1	2
4	1	0

When the read distance is 3.5 meter, the RFID reader can read the tag 2 times in 1 second, while the read times is 0 when read distance is 4 meter.
The experimental results show that the theory result accords with experimental results.

5. Conclusion

This paper presented an overview of passive backscatter RFID systems and the transmission model of passive backscatter RFID systems. Then the calculation formula of the read distance was obtained and discussed in the passive backscatter RFID system, and the experiment results showed the validity of the formula. The analysis of the read distance shows that antenna parameters affect read distance directly. Furthermore, the performance of a passive backscatter RFID system is highly depended on the antennae. Choosing the right antenna for the passive backscatter RFID system can increase the identifying reliability.

References

Rao, K. V. S., & Nikitin, P. V., & Lam, S. F. (2005). *IEEE Trans. Antennas Propag*, 53, 3870.

Nikitin, P. V., & Rao, K. V. S. (2006). *IEEE Antennas and Propagation Magazine*, 48, 212.

Yen, C. C., & Gutierrez, A. E., & Veeramani, D., & Wisconsin, D. U. (2007). *Madis on 2007 Antennas and Wireless Propag*. Letter, 6, 279.

Kwon, H., & Lee, B. *2005 Asia2Pacific Microwave Conference Proc*, 4, 1.

Liu, S. B., & Zhang, G. F., & Yuan, N. C. *2004 Acta Phys*. Sin. 53, 2633.

Penttila, K., & Keskilammi, M., & Sydanheimo, L., & Kivikoski. *2006 IEE Proc. Micro*. Antennas Propag, 153, 103.

Pozar, D. M. *1987 IEEE Trans*. *Antennas Propag*, 35, 613.

Tang, Z. J., & He, Y. G. *2009Acta Phys*. Sin, 7, 58.

Hu, S. M., & Chen, H. L., & Law, C. L., & Shen, Z. X., & Zhu, L., & Zhang, W. X., & Dou, W. B. *2007 IEEE Antennas and Wireless Propag*. Letter, 6, 70.