Long Range Yagi-Uda UHF RFID Tag Antennas with Very Small Back-lobe

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Abstract
A Yagi-Uda UHF RFID tag antenna with a long reading range has been designed. According to ISO-18000, the ERIP of a reader and reader antenna is limited as 6dB. Therefore, the gain of a tag antenna should be large to extend the reading range of a tag antenna. A Yagi-Uda antenna has been applied to a RFID tag antenna, and high gain and long reading range have been achieved. The different sizes antenna types of Yagi-Uda RFID tag antennas have been optimized to achieve the small size with very low back-lobe patterns. The patterns, reading range and sizes of the different types of Yagi-Uda UHF RFID tag antennas are compared.

1. Introduction

An RFID system consists of a transponder (tag), a reader, and a computer connected to the reader. The reader has one or multiple antennas, and the tag has an antenna and an RFID IC chip. In the RFID system, the reader transmits the modulated signal to the tag antenna. The passive tag receives all the required energy from the carrier signal of the reader. Then, the signal of the tag is transmitted back to reader antenna based on the backscattering method [1-4].

The different types of RFID tag antennas are developed [5-16]. The applications of the RFID are library, airport luggage, logistics, auto document tracking, auto toll collection and etc [5]. In a large warehouse, a reader can read and locate the products and parts. To recognize the current locations of products and parts in the large warehouse with a scanning phased array reader antenna, the long reading range tag antenna is required. The long reading range tag antenna is also useful for auto toll collection at the highway tollgate. To achieve the long reading range, the high gain tag antenna is required since the EIRP (emitted isotropic radiated power) of the reader and reader antenna is limited as 6dB by ISO (International standard organization). To make a high forward gain of tag antenna, the directivity of main-lobe must be high and FBR (Front-to-back ratio) should be large.

According to ISO-18000, the frequency band of the UHF RFID is 860~960 MHz, and the frequency bands of corresponding countries are following: Europe 865~868 MHz, America and Canada 902~928 MHz, Korea 908.5~914 MHz and Japan 950~956 MHz.

In this paper, various Yagi-Uda type UHF tag antennas, resonated at 915MHz, are introduced to extend the reading range, and increase the gain and FBR of the tag antennas. The designs have better FBR than a conventional Yagi-Uda tag antenna design.

2. Design of the Yagi-Uda UHF RFID Antenn

The Yagi-Uda antenna is practical for the frequency range of HF (3-30MHz), VHF (30-300MHz), and UHF (300-1000MHz) bands. It consists of one or multiple directors, a reflector and a driven element. For the RFID applications, a RFID chip is connected at the feeding point of the driven element of the Yagi-Uda antenna. The beam pattern of the Yagi-Uda tag antenna will be end-fire, and the FBR of the Yagi-Uda tag antenna will be high. The chip impedance of the RFID chip has real number of resistive loss and negative imaginary value due to the parasitic capacitance of the RFID chip. Therefore, the impedance of the Yagi-Uda will be conjugate of the chip impedance.

Alien RFID chip has been used. As shown in Fig. 1, the first antenna design (called Tag Ant1) is designed based on the 5 elements conventional Yagi-Uda antenna, resonated at 915MHz. The width of each element is fixed as 2mm for all elements. Since the conventional design has similar value of spacing among the directors, one space variable, d_direct is only assigned as shown in Figure 1. The optimized parameters of the conventional Yagi-Uda, lengths of elements and space of among the elements, are shown in Table 1.

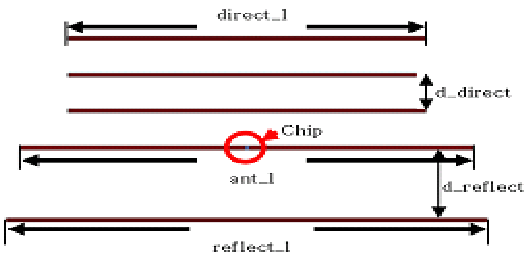

Figure 1. Structure of Tag Ant1

TABLE 1: OPTIMIZED PARAMETERS OF TAG ANT1

Parameter	direct_l	ant_l	reflect_l
Value(mm)	151	191	203
Parameter	d_direct	d_reflect	
Value(mm)	20	40	

Figure 2 shows the simulated pattern of the Tag Ant1. The gain is 4.296dB. The back-lobe has 2.616dB, and HPBW(Half Power Beam Width) is 27 . Therefore, the FBR is about 1.64. The measured reading range at the main lobe is 6.3m.

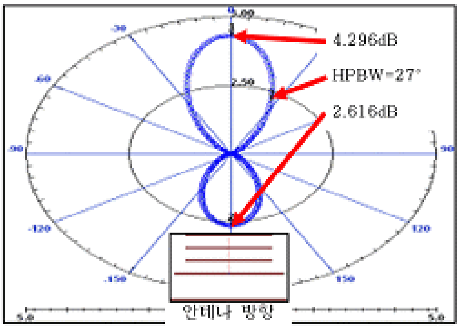

Figure 2. Beam pattern of Tag Ant1

To have a better FBR of the pattern, all parameters are further optimized. As shown in Figure 3, the widths of three director elements are optimized as 5, 10 and 15 mm. The widths of the driven and reflector elements are 2mm each. The spaces of elements are optimized. Table 2 shows the optimized parameters of each element. The widths of directors are gradually smaller from the 1st director.

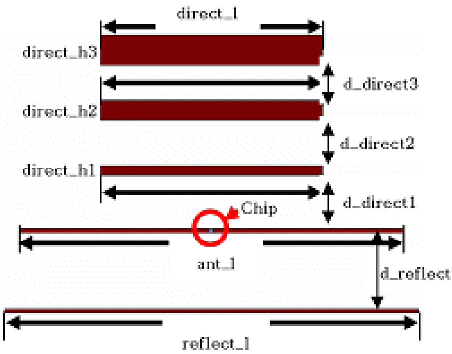

Figure 3. Structure of Tag Ant2

TABLE 2 : OPTIMIZED PARAMETERS OF TAG ANT2

Parameter	direct_l	ant_l	reflect_l
Value(mm)	100	172	187
Parameter	D_direct1	d_direct2	d_direct3
Value(mm)	27	22	18
Parameter	direct_h1	direct_h2	direct_h3
Value(mm)	5	10	15
Parameter	D_reflect		
Value(mm)	40		

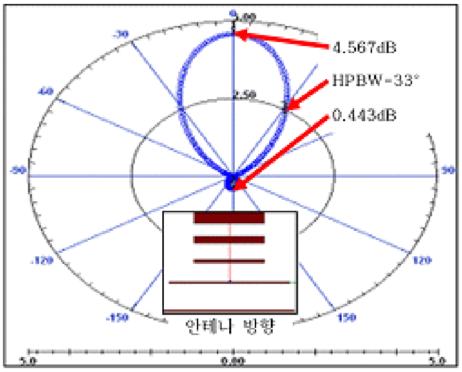

Figure 4. Beam pattern of Tag Ant2

Figure 4 shows the beam pattern of the Tag Ant2. The gain of main-lobe is 4.567dB, which is 0.271 dB higher than the first design. The back-lobe is 0.443dB which is 2.2dB smaller than the first design. The HPBW is 33 , 6 wider than the first design. Therefore, FBR is improved from 1.64 to 10.3, which is about 7 times higher. The reading range is improved from 6.3m to 8m.

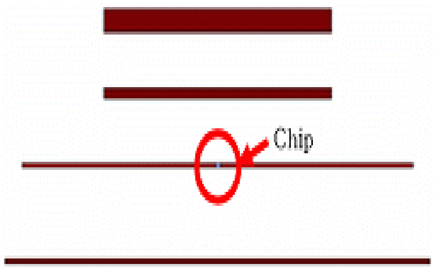

Figure 5. Structure of Tag Ant3

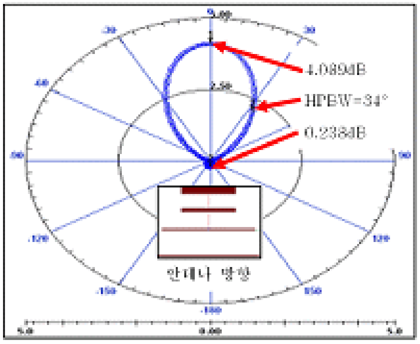

Figure 6. Beam pattern of Tag Ant3

The third design shown in Figure 5, the size of tag antenna has been reduced by removing the first director. The gain is reduced to 4.089dB, which is 0.48dB smaller than the second design while the reading range is only 20cm reduced. Figure 6 shows the pattern of the third design. The main-lobe has 4.089dB, and the back-lobe has 0.238dB. HPBW is 34 . The FBR is 17.18. Tag Ant3 is 24% smaller than the second design and FBR is increased from 10.3 of the second design to 17.18.

3. FABRICATION AND MEASUREMENT

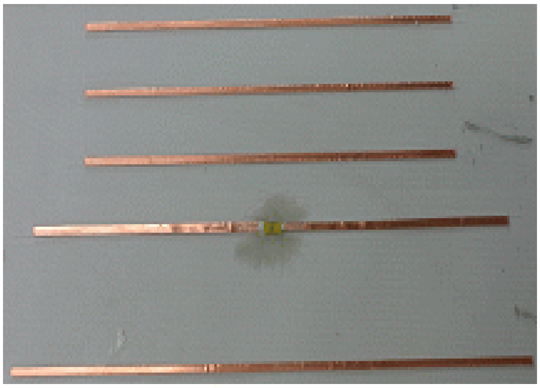

Figure 7. Fabricated Tag Ant1

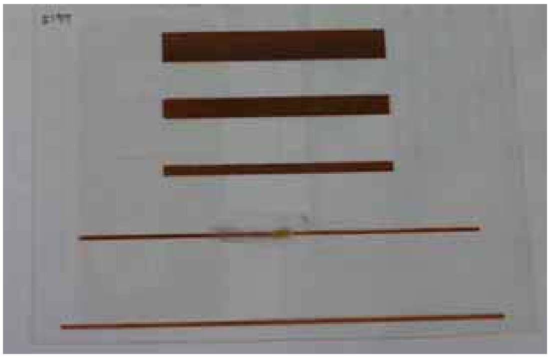

Figure 8. Fabricated Tag Ant2

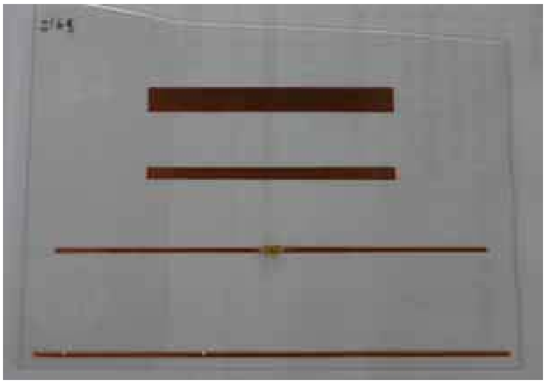

Figure 9. Fabricated Tag Ant3

Figures 7 ~ 9 show the fabricated tag antennas. The patterns and the reading ranges of the second and the third designs are measured with ALR9800 reader and ALR-9610-AL antenna manufactured by Alien Co.

4. CALCULATIONS AND MEASUREMENTS COMPARISON

Friis Transmission formula is used to calculate the reading range of a RFID system. The simulation results are compared with the measurement results. Figure 10 shows a RFID transmission system and energy flow.

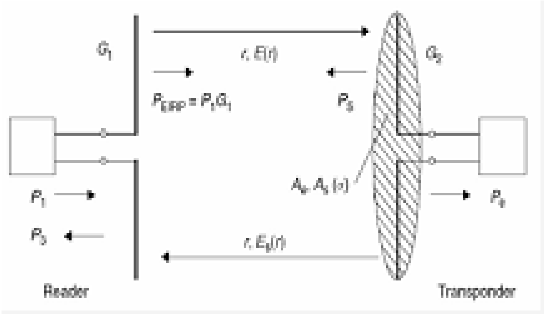

Figure 10. RFID Transmission System

$$r_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{G_1 P_1 G_2 \tau}{P_{th}}} \qquad (1)$$

$$\tau = \frac{4 R_c R_a}{\left|Z_c + Z_a\right|},\ 0 \le \tau \le 1 \qquad (2)$$

Maximum reading range of a tag is defined with the Equation (1), and the matching coefficient between the tag chip and tag antenna is also shown as equation (2) [12] .

G_1 : gain of the reader antenna,
P_1 : power of the reader,
G_2 : gain of the tag antenna,
P_{th} : the accomplishment power of the chip.

Za : the impedance of tag antenna,
Ra : the real value of impedance for the RFID chip,
Zc is the chip impedance,
Rc : the real value of impedance for a tag antenna.

The Rc, Ra, Zc, and Za are the results of the simulation or measurements. The calculated results are compared with the measured results in Table 3.

The measurements of beam pattern of the second and third design are sown in Figure 11. The back lobes of the patterns are larger than the simulated results. Table 3 shows comparison of results of three designs. The third design is 10.5% larger than the first design, and has 10 times higher FBR as shown in Table 3. The reading range is also improved from 6.3m to 7.8m.

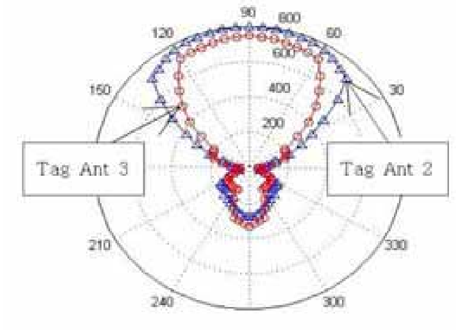

Fig. 11 : Beam pattern of Tag Ant2 and Tag Ant3

TABLE 3:COPARISION OF 3 TAG ANTENNAS

		Ant 1	Ant 2	Ant 3
VSWR		1.4	1.78	1.98
dB	main-lobe	4.296	4.567	4.080
	back-lobe	2.616	0.443	0.238
FBR		1.62	10.3	17.18
HPBW		27	33	34
Range	calculation	6.6m	6.8m	6.4m
	measure	6.3m	8m	7.8m
	difference	0.3m	1.2m	1.4m
area(Cm^2)		180	266	199

5. CONCLUSION

Three different long range Yagi-Uda UHF RFID tag antennas have been designed and tested. The performance of 5-elements conventional Yagi-Uda RFID tag antenna is compared with the optimized Yagi-Uda RFID tag antenna designs. The longest reading range is achieved as 8m as shown in Table 3. The reading range is extended from 6.3m of the first design to 8m by improving FBR of the pattern. The FBR is improved, and the size of the tag antenna is smaller than conventional Yagi-Uda design. Tag Ant3 is 24% smaller than the optimized Tag Ant2 and the difference of reading range is only 0.2m.

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