RFID Antenna Performance Evaluation for Library Inventory Management

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Abstract: Three types of printed radio-frequency-identification (RFID) antennas with the characteristics of high gain, wide beam wave, and omnidirectional beam wave are constructed and evaluated in this study. The objective is to find out their best reading rates for providing effective wireless communications among RFID antenna readers during the library book inventory process. Three kinds of antenna readers have been fabricated on the printed circuit board (PCB) with the operating frequency at 915 MHz, which are tested by using vector network analyses device named Agilent PNA N5230A and simulated by using antenna design kit named ANSOFT HFSS. The fabricated antenna readers are embedded into different locations of bookshelves at the library of Cheng Shiu University in Taiwan. According to the experimental results, the designed prototypes of the antenna readers has the characteristics of the directional radiation pattern, wide beam wave, simple shape, good gain, low cost and easy to be integrated to the bookshelf. They can benefit administrating librarians with the capabilities of decreasing the library inventory processing time and reducing the possibility of the books being misplaced.

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1. Introduction

Traditionally library inventory works not only include books' check-in/out but also include keeping the resources at actual locations [1]. In the past decade, barcode labels and electromagnetic (EM) strips are two common technologies used to support the identification and anti-theft capabilities in the library inventory system. However, the barcode labels could be only stuck on the book with one time, manually scanned, and easily damaged; the EM strips don't support resource identification capability [2]. In recent years, in order to overcome the weaknesses mentioned above, radio frequency identification (RFID) wireless communication technology has replaced the barcode label and magnetic strip with the identification and anti-theft detection capabilities in the library inventory management [3-4]. Such technology utilizes magnetic coupling or electromagnetic field in the electromagnetic radio frequency spectrum. Compared with using barcodes in the library inventory management, a RFID tag could be read more than ten-thousand times, could support high information contents, and would provide more convenient and efficient advantages on check-out and return processes [5].

Generally a typical RFID system consists of antennas, readers, and tags. The reader would send the wireless radio signal which would be then received by the antenna. When the tag senses the radio signal, it returns the electromagnetic wave back to the reader [6].

Several literatures have been proposed for the smart shelf application in library, including utilizing mobile robot to improve inventory management [7], applying micro-strip lines to enhance energy leaking and improving tag detecting capability [8]. However, these methods are not good for the needs of real time and low cost. As for the use of RFID technology in the bookshelf applications, Kim and Choi [9] proposed a wideband rectangular loop tag antenna for ultra-high frequency radio frequency identification library management systems. The size of the tag antenna is 35 mm × 90 mm, which had a wide impedance bandwidth of 170 MHz less than -10 dB. Lau et al. [10] proposed a small wideband circularly polarized patch antenna printed on the low-cost FR-4 material for radio-frequency-identification smart bookshelves in libraries. The proposed antenna operated at a center frequency of 0.915 GHz and the wave-beam width is 115 °. Qing et al. [11] constructed an antenna prototype, which is printed onto a piece of FR4 substrate, with good impedance matching and uniform magnetic field distribution over the entire UHF RFID band of 840-960 MHz.

In the reviewing some references applying UHF RFID Antenna in the library inventory managements, Kim et al. [12] designed a loop antenna for UHF band RFID tag used for a library management system. To achieve the wide-band characteristic, both vertical sides of a loop antenna are widened. Lukas et al. [13] and Kaiwen et al. [14] proposed UHF omnidirectional RFID antenna researches to increase the wireless identification and tracking capabilities for the item-level RFID application. Both literatures presented the designs of UHF RFID tag antennas which supported omnidirectional reading pattern and provided great potential for item-level RFID applications in libraries for tracking the books. Pitukwerakul et al. [15] proposed the channel modeling of wooden and metal book shelves for predicting received power and performance system. The channels were measured at frequency of 2.45 GHz. The microstrip antennas were used as both transmitter (Tx) and receiver (Rx) antennas. Vertical-vertical (V-V) and horizontal-horizontal (H-H) polarizations are considered. The results exhibited wooden book shelves of V-V polarization and metal book shelves of H-H polarization are appropriate to use for RFID library management system.

Golding and Tennant [16] investigated the factors that may affect the reading rate of an inventory reader in a library. The investigated factors were read distance, tag location, number of sweeps and sweep direction. Wang [17] studied the RFID-based methodology and approaches that support library services and management, including sensor gate control, circulation, inventory, searches and utilization statistics. The study also discussed barriers, challenges and future work about RFID applications in libraries and concluded that RFID-based technology would improve digital archives and digital humanities in library systems. Zhang and Shi [18] and Bin Abdullah, et al. [19] are two literatures related to self services of library management systems. Zhang and Shi strongly pointed out that the necessity of the new RFID technology of self-service book borrowing and returning system in library, which would replace the barcode technology and accelerate the library's self-service process. Bin Abdullah, et al. developed an integrated the RFID system with graphical user interface (GUI) at the host PC. The study aims to develop an automatic library shelf management system to assist the librarians for more efficient shelf management to find any misplaced books on the library shelf.

In addition, in the reviewing some other RFID related literatures [20-22], two comments were made: (1) such intelligent plan may not meet the library demand because the system have to consider library internal disturbances such as metal, motion communication electric wave, and wireless network electric wave, which could affect the RFID operation; (2) the proposed inventory system have to be convenient to all readers. As mentioned above and driven by the advanced ubiquitous computing technology, in this study, the authors proposes Three types of printed radio-frequency-identification (RFID) antennas with the characteristics of high gain, wide beam wave, and omnidirectional beam wave are constructed and evaluated in this study. The objective is to find out their best reading rates for providing effective wireless communications among RFID antenna readers during the library book inventory process.

In the following, Section 2 describes the proposed optimal library inventory system based on EMID technology. The experimental results are shown in Section 3. Finally, the conclusions and Discussions are summarized in Section 4.

2. RFID Antenna Design

Figure 1 illustrates the structure of the RFID based library inventory system which includes four parts: RFID antennas, bookshelves, readers/writers, and the computer terminal. As illustrated in Figure 1, the library computer terminal through readers/writers obtains RFID antennas' signals of the bookshelf. The database of the computer will then authenticate the location of the book automatically.

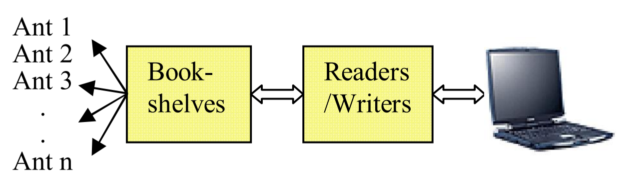


Figure 1. Structure of RFID-based library inventory system.

Figure 2 is the picture of a bookshelf with the width and height of 90 and 19 cm, respectively. Three places, labeled as A, B and C, are tested to find the optimal antenna location in this study. The place A is located on the left hand side of the bookshelf; the place B is located on the middle of the bookshelf; the place C is located either on the 30 cm from the distance of left and right hand sides of the bookshelf. Figure 3 shows the example of antennas' locations in a multi-layer bookshelf. Considering the bookshelf structure, the books are vertically set in the shelf, and the antennas are also set vertically to the shelf and parallel to each other in order to obtain the optimal reading rates of the antenna.

In the following, three types of RFID antennas, including the pictures of geometry planes and prototypes, are introduced.

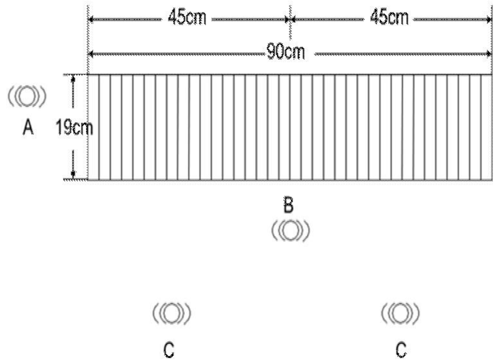
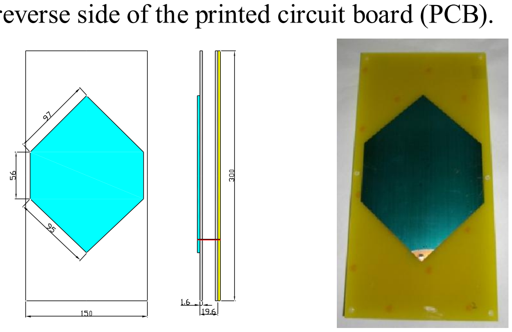


Figure 2. Antenna locations on the one layer bookshelf.

Figure 3. An antenna on location B of a bookshelf.

2.1. Type 1 - High Gain Antenna

The geometry plane and the prototype of the proposed high gain antenna are shown in Figure 4. The antenna consists of a polygon patch and rectangle ground substrates. The antenna is printed on a 150 mm × 300 mm dielectric substrate; the dielectric substrate (FR4) has a thickness of 1.6 mm with the coefficient constant of 4.4. The total high is 18.2 mm with two-layer FR4 board. The lengths of the patch side edge are 95mm, 56mm, and 97 mm, respectively. The ground plane width and length is 150mm and 300 mm. The detecting point is located at the radio frequency (RF) circuitry which is on the reverse side of the printed circuit board (PCB).

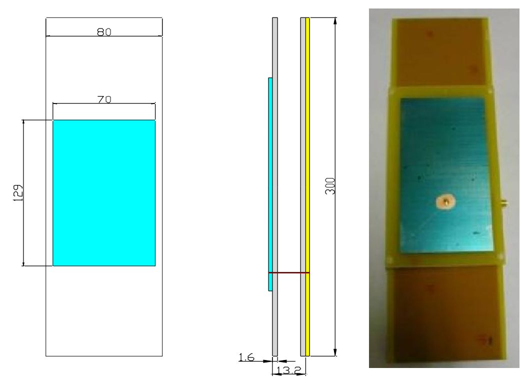


(a) (b)

Figure 4. (a) geometry ; (b) prototype of Type 1 antenna (unit: mm).

2.2. Type 2 – Wide Beam Antenna

The geometry plane and the prototype of the proposed the wide-beam antenna are illustrated in Figure 5. The antenna consists of a rectangle patch and ground substrates. The antenna is printed on an 80 mm × 150 mm dielectric substrate; the dielectric substrate (FR4) has a thickness of 1.6 mm a with the coefficient constant of 4.4. The total high is 13.2 mm with two-layer FR4 board. The length and width of the patch substrate are 129mm and 70mm, respectively. The width and length of the ground substrate is 80mm and 150 mm, respectively. The detecting point is located at the radio frequency (RF) circuitry which is on the reverse side of the printed circuit board (PCB).



(a) (b)

Figure 5. (a) geometry; (b) prototype of Type 2 antenna (unit: mm).

2.3. Type 3 – Omnidirectional Beam Antenna

The geometry plane and the prototype of the proposed omnidirectional beam antenna are shown in Figure 6. The antenna consists of an upside down triangle patch and rectangle ground substrates. The antenna is printed on a 65 mm × 1500 mm dielectric substrate; the dielectric substrate (FR4) has a thickness of 1.6 mm with the coefficient constant of 4.4. By starting from the top view, the lengths of each side of upside down triangle patch are 41 mm, 14mm, 42 mm, 14 mm, and 3 mm, respectively, with two-layer FR4 board. The width and length of the ground substrate board are 65 mm and 150 mm. The detecting point is located at the center area of the upside down triangle printed patch.

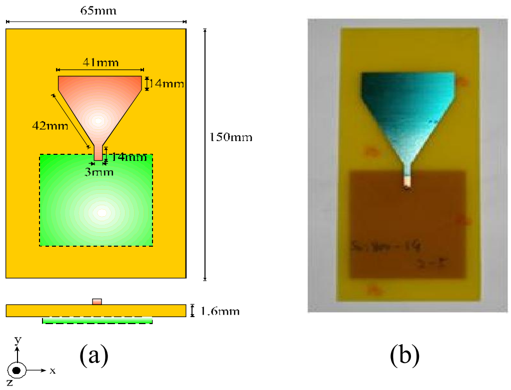


Figure 6. (a) geometry ; (b) prototype of Type 3 antenna (unit: mm).

3. Experimental Results

Three kinds of antenna readers have been fabricated on the printed circuit board (PCB) with the operating frequency at 915 MHz. In this paper, three performances, including the radiation, return losses, and peak gain, are tested by using vector network analyses device named Agilent PNA N5230A and simulated by using antenna design kit named ANSOFT HFSS. Figure 7 shows three types of the proposed antennas' radiation patterns which are in YZ and XZ planes with the operating frequency at 915 MHz. As shown in Figure 7(a), the wave-beam width for the type 1 antenna at the half power is around 100 degree and at the power greater than 0dB is 156 degree; Figure 7(b) shows that the wave-beam width for the type 2 antenna at the half power is around 120 degree and at the power greater than 0dB is 180 degree; as shown in Figure 7(c), the wave-beam width of type 3 antenna is omnidirectional and the wave-beam for the power greater than 0dB is 360 degree. Conclusively, type 3 antenna has the widest wave beam compared with the other two antennas. However, type 1 and type 2 antennas still have enough wide wave-beam performance for the library inventory application.

Figure 8 shows the measured -10 dB return losses of the proposed antennas which are operated at the frequency between 885MHz and 942 MHz for type 1 antenna, between 885MHz and 942 MHz for type 2 antenna and between 795MHz and 1.05 GHz for type 3 antenna respectively. This indicates that three antenna are all suitable for the ultra high frequency (UHF) RFID application. Figure 9 shows the measured peak gain of three types of antennas. As shown in Figure 9(a), the measured gain of the type 1 antenna is between 6.93dB and 7.92dB at the operating frequency from 885 to 942MHz. Figure 9(b) illustrates the measured gain of the type 2 antenna is between 5.61dB and 5.78dB at the operating frequency from 885 to 945MHz. As for the type 3 antenna, the measured gain is between 2.41dB and 2.52dB at the operating frequency from 885 to 945MHz. According to the experimental results, the peak gain for the proposed antennas is 8.2dB, 6.13dB, and 3.01dB at 920MHz operating frequency, respectively. Conclusively, the type 1 antenna has the highest peak gain whereas type 3 antenna has the lowest peak gain.

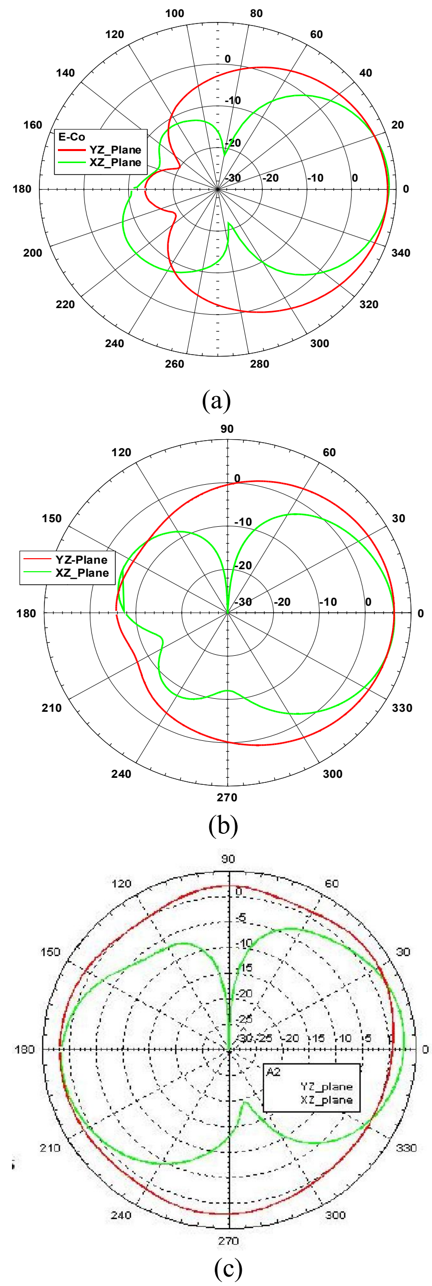
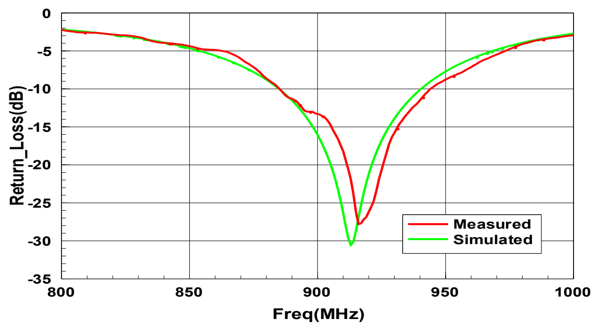
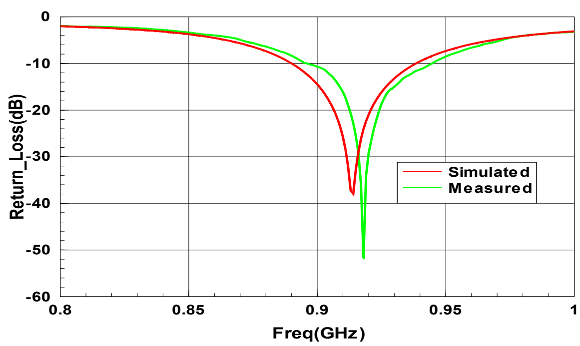


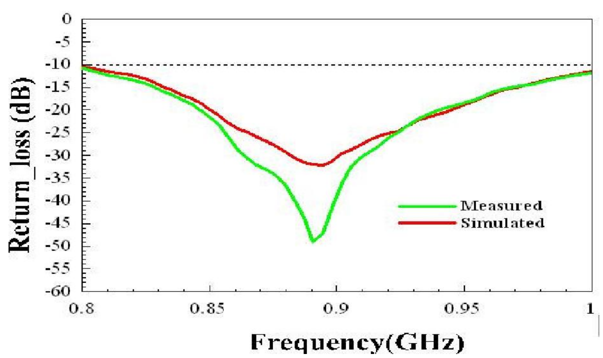
Figure 7. Measured radiation patterns for XZ and YZ plane at 915MHz; (a) type 1 antenna; (b) type 3 antenna; (c) type 3 antenna.



(a)

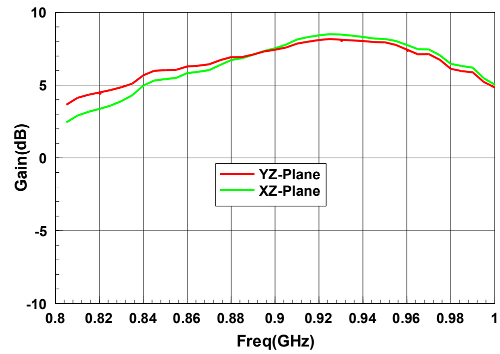


(b)

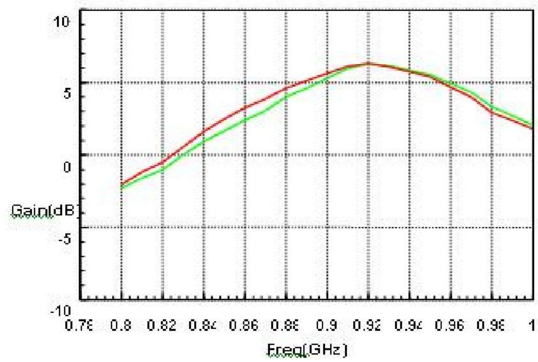


(c)

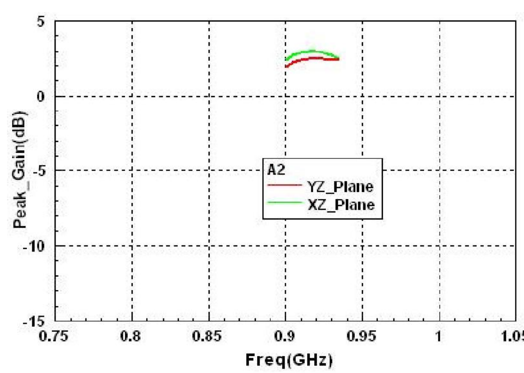
Figure 8. Measured return losses; (a) type 1 antenna; (b) type 2 antenna; (c) type 3 antenna.



(a)



(b)



(c)

Figure 10. Measured total field of maximum gain; (a) type 1 antenna; (a) type 2 antenna; (a) type 3 antenna.

Table 1. Reading rate for different RFID tag locations

Tag Quantity	Location	Reading Time(ms)	Reading Rate (%)
30 (Type 1 Antenna)	A	15	50%
	B	20	66%
	C	30	100%
30 (Type 2 Antenna)	A	20	66%
	B	30	100%
	C	30	100%
30 (Type 3 Antenna)	A	23	77%
	B	30	100%
	C	30	100%

Table 1 shows the reading rates of the proposed antennas located at A, B, and C places as illustrated in Figure 2. From Table 1, the reading rates of 30 type 1 antennas at the location A, B, and C are 50%, 66%, and 100%, respectively. This implies that the location C gets better reading rate. The reading rates for 30 type 2 antennas at the location A, B, and C are 66%, 100%, and 100%, respectively. This implies that either the location B or C gets better reading rate. As for type 3 antenna, the reading rates are 77%, 100%, and 100%, respectively. This also implies that either the location B or C gets better reading rate. Conclusively, the performance of the antennas at location A tells that the antenna readers are generally hard to identify the responding signals. As for the location B which is in the back of the bookshelf, the wave-beam width of the antenna readers has to have enough good wave-beam width to cover the one layer of the bookshelf. According to the experimental results, the location C gets the best reading rates for the proposed antenna because there are two antennas at left and right side of the bookshelf individually.

4. Conclusions and Discussions

This paper has presented three kinds of UHF antennas specifically for RFID-based book inventory applications. The main contribution of the proposed system is to improve traditional labor-based library inventory methodology for administrating librarians with the capabilities of decreasing the library inventory processing time and reducing the possibility of the books being misplaced. Compared to the exiting methods, the proposed system supports three distinctive advantages: (1) The proposed antennas in the plane form are printed on PCB with the characteristic of easily being integrated into the bookshelf. (2) The prototype antenna has characteristics of the directional radiation pattern; wave-beam width, simple shape, good gain characteristic and low fabricate cost. (3) The performance of the proposed antennas are suitable for RFID based book inventory application.

This work can be practically implemented at the library of Cheng Shiu University in Taiwan for the book inventory management application

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