Container Electronic Tag Test System Design and Experimental Method Research

Shibo Xu, Wensheng Cao*, Jichun Li, Bencheng Luo, Jing Wang, Yongming Zhang

***Abstract*—Although several RFID standards for container logistics exist, few address the specific challenges of testing RFID tags in real-world environments where containers are subjected to metallic interference, varying temperatures, and humidity levels. Previous research has primarily focused on RFID tag performance in laboratory settings or general supply chain applications. However, comprehensive test systems tailored to evaluate the performance of RFID tags in diverse and extreme logistical conditions, such as those encountered during container transportation, are lacking. This study addresses this gap by proposing a container electronic tag testing system that combines advanced radio frequency analysis with edge computing and real-time field tests. Our approach provides a novel solution for evaluating RFID tag performance under a wide range of environmental factors, offering significant improvements in the efficiency and accuracy of container tracking in real-world logistics.**

***Keywords*—RFID, container logistics, edge computing, signal reliability, tag testing system, automated tracking**

I. Introduction

Containers are the main transportation equipment for international logistics. The vast majority of international goods are transported via containers, with more than 50 million TEU (Twenty-foot Equivalent Unit) s circulated around the world each year. Before a container leaves the production line and reaches the hands of a customer, it must go through transportation, temporary storage and other links. At the same time, as a transportation carrier, the container must also pass through customers, ports, yards, logistics centers, LCL warehouses, land transportation, shipping and other links. During this process, the information collection of the container needs to be collected dozens of times. In the face of such a large-scale, international cargo circulation carrier, container supply chain management, information collection, tracking and monitoring were mostly completed manually in the past, resulting in poor timeliness and accuracy of container transportation data collection. With the development of technology, data collection of container transportation has gradually transitioned from manual collection to automatic identification and collection. RFID technology, with its own advantages and characteristics, has become the first choice for rapid identification and tracking of containers. It effectively solves the problem of automatic identification and data collection of containers. Its technical characteristics are reflected in the following aspects: First, it provides a non-visual contact data transmission mechanism, allowing efficient wireless identification under obstructed line of sight or multi-angle conditions; Second, RFID tags have large data storage capabilities, support fast batch reading functions, and maintain data stability and reliability even in extreme logistics environments; In addition, RFID technology realizes real-time monitoring and data update of container status, enhances the security and transparency of the logistics process, and its highly automated characteristics and compatibility with global standards provide convenience for cross-border container management.

A comprehensive literature review reveals that prior studies have predominantly focused on single-metric or single-environment (laboratory-only or field-only) UHF RFID tag testing, and none have established an integrated evaluation framework tailored to container logistics under concurrent metallic interference, and multipath fading. This paper presents threefold integrated innovations: (1) A cyber-physical test architecture based on the NI PXIe-8840 controller and Virtex-6 FPGA that co-integrates RF vector transceivers, carrier-suppression filters, edge computing units, and a full protocol stack, enabling one-click replicability between anechoic-chamber and gate-like scenarios; (2) The introduction of a programmable turntable and 3-D antenna array within an 800 MHz-3 GHz, −30 dB reflectivity anechoic chamber, which for the first time quantifies the metallic-container effect on tag sensitivity (≈6 dB degradation) and backscatter power (resonant amplification of 23 dB at 840 MHz); (3) A joint "sensitivity-backscatter-installation angle" test sequence coupled with an automated report generation workflow, thereby bridging the methodological gap left by ISO 18186 and ISO 17363. Collectively, these contributions constitute the first comprehensive performance-assessment ecosystem for container-centric RFID tags, substantially enhancing testing efficiency and reliability in complex metallic logistics environments.

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II. BACKGROUND OF PREVIOUS RESEARCH

In order to better realize the application of RFID technology in containers, several technical standards related to container RFID have been proposed, such as ISO 18186: This is an international standard initiated and led by Chinese experts, "ISO 18186: Cargo Container-RFID Freight Label System", which is specifically for the RFID freight label system of containers; ISO 17363:2013 RFID Supply Chain Applications of RFID - Freight Containers, which defines the use of read/write radio frequency identification technology (RFID) cargo shipment-specific labels related to container freight for the purpose of supply chain management, commonly known as "manifest labels"; and a series of standards developed by the EPCglobal organization involving the application of RFID technology in supply chain management, including container logistics. The establishment of these standards has played a good role in regulating the manufacture and use of container electronic tags. Global container electronic tag manufacturers product container electronic tags according to standards, but these standards rarely mention the testing of container electronic tags, and do not propose testing equipment and methods for container electronic tags.

Gao and Huang (2020) developed an open testing platform for UHF RFID to analyze tag communication characteristics in transportation environments, laying a foundation for testing various types of tags under different logistics conditions. Amini et al. (2019) introduced a deep learning-assisted detection technique that enhances the robustness of tag identification in chipless RFID systems within IoT environments, significantly improving detection accuracy and stability, especially in complex environments. Lopez and Smith (2021) examined the read reliability of RFID tags in multipath interference environments, analyzing how different materials affect tag signal integrity, which supports improved tag read accuracy in practical applications. Chen et al. (2017) conducted a comparative study of RFID technologies for container identification, exploring the suitability and performance of different RFID systems for container applications, providing technical references for enhancing logistics efficiency. Patel and Chauhan (2018) investigated testing methodologies for RFID tags, particularly for logistics applications, to ensure reliable performance across various logistics conditions. Ye et al. (2016) explored RFID tag signal performance in different container environments, analyzing how environmental factors impact signal transmission quality, offering insights into improving tag read rates within containers. Jones and Davis (2015) focused on the reliability testing of UHF RFID tags in maritime logistics, aiming to extend tag lifespan and performance in challenging marine environments. Kim and Park (2014) proposed a non-destructive testing method for RFID tags in harsh industrial settings, targeting improved durability and stability of tags used in industrial environments. Yang and Lee (2013) researched and tested RFID tags suitable for high-speed container tracking, enhancing tag stability and reliability in high-speed, dynamic settings.

These studies provide valuable insights for this project on RFID tag testing, though a comprehensive performance test specific to electronic container tags has yet to be conducted. In order to make up for the shortcomings in the field of container electronic tag testing, research and testing of container electronic tag testing systems are carried out. The paper will introduce in detail the design of the container electronic tag system and the test verification of subsequent experiments, which makes up for the shortcomings in the testing of container electronic tags. Container electronic tags that have been verified as qualified by this test system and test method can have stable and efficient reading efficiency according to feedback from actual applications, and there will no longer be incidents of port congestion due to the inability to read container electronic tags normally.

III. MATERIALS AND METHODS

A. Test-Bed Hardware

The container electronic tag test system is designed using National Instruments (NI) simulated virtual instruments at its core, with LabVIEW software programming facilitating system control. The hardware consists of several key components, the system schematic diagram is shown in Fig. 1.

- Main Controller: The NI PXIe-8840 embedded controller, powered by an Intel Core i7 processor, serves as the system's control unit. This unit is responsible for generating and analyzing baseband signals, managing protocol states, and controlling signal transceivers.
- Carrier Suppression Module: Equipped with a high-performance carrier suppression filter, this module eliminates carrier components from the RF input signal, ensuring signal clarity and accurate data processing.
- RF Transceiver Module: The NI PXIe-5640R dual-channel RF vector signal generator integrates both signal generation and analysis functions, enabling precise RF testing. It includes a signal conditioning circuit, filter circuit, and orthogonal demodulation circuit for enhancing signal clarity and efficiency. The RF signal path utilizes Huber+Suhner Sucoflex 106PE coaxial cables with a documented loss of less than 0.5 dB/m at 2.5 GHz. For power sensitivity measurements, a sweep step size of 0.5 dB was employed to ensure high resolution.
- Power Amplifier Module: The NI PXIe-5652A vector signal transceiver boosts the output RF power up to +30 dBm, providing high linearity and enabling effective testing of RFID systems under various conditions.

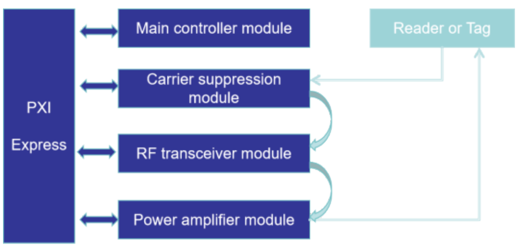

Fig.1. Test system hardware schematic diagram

This configuration enables the testing of both electronic tags and readers. When testing tags, the system simulates the reader's operation, transmitting command signals and collecting the response signals from the tags. Conversely, when testing readers, the system mimics the tag's operation by receiving the command signals from the reader and sending appropriate responses. The hardware system also uses the Xilinx Virtex-6 FPGA programming interface to meet the real-time requirements of the electronic tag communication protocol, and is equipped with a PXI Express instrument bus control interface. The hardware architecture includes two elements: modular instruments and open high-speed buses. Each modular instrument exchanges data and commands through the PXI Express open high-speed bus. The RF modules transmit clock signals and RF signals through RF cables, and provide RF signal interfaces with the electronic tags under test. The baseband output module is specifically composed of an analog-to-digital conversion circuit, a filter circuit, and a signal conditioning circuit, and the baseband input module is specifically composed of a signal conditioning circuit, a filter circuit, and an analog-to-digital conversion circuit.

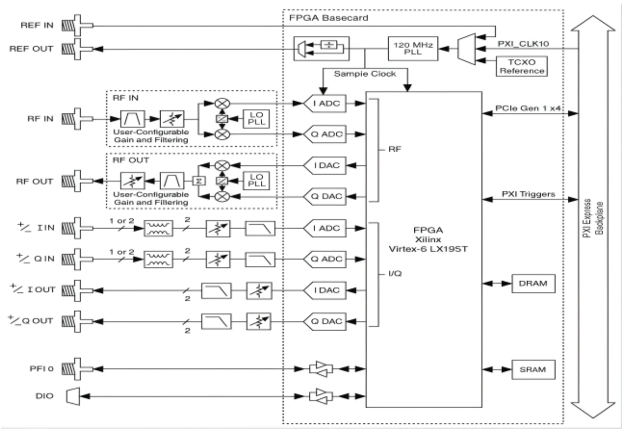

Fig.2. RFID radio frequency communication principle diagram

Both the RF module and the baseband module are connected to the FPGA coprocessor, and the generation and analysis of RFID electronic tag signals are realized through digital signal processing. The RFID RF communication schematic diagram is shown in Fig. 2

The RF communication test system has developed professional test software based on the hardware architecture. It uses the LabVIEW graphical programming tool to form a combination of manual test interface and Test Stand textual automatic test sequence. The graphical manual test interface can set various test parameters and read various test results one by one through manual control. The textual automatic test sequence can automatically complete various tests through simple configuration and generate test reports. Among them, the core code of the test software runs on the FPGA, has a dual security mechanism of user authority restriction and hardware encryption, supports manual testing, built-in time domain waveform analysis, joint time-frequency analysis, amplitude analysis, phase analysis, IQ complex signal analysis and other functions, can set FPGA resources, center frequency, reference level, trigger mode, gain, reference time and other parameters, supports fast measurement mode and maximum acquisition control, can measure random numbers, time slots, inventory, collision and other statistical parameters, supports data interleaving storage, can export data during operation, supports .iq, .stm and other data formats, built-in complete RFID protocol stack, supports one-click automatic testing, configures automatic test management software, and can automatically generate XML format test reports. The performance test of container electronic tags is used to scan the working power of the tag at different frequencies, test the minimum working power at which the tag can successfully return the response signal, and obtain the performance parameters of the tag at different frequencies, such as sensitivity, recognition distance, radar scattering cross-sectional area change rate and scattering power.

B. Anechoic Chamber

To create a controlled test environment, the RFID test system is housed in a radio wave anechoic chamber designed to shield external electromagnetic interference. The chamber is constructed using shielded steel plates and SA-300 foam pyramid absorbent material, which achieves a reflectivity of up to -30dB at vertical incidence at a frequency of 1 GHz, with a characterized reflectivity curve that meets an average of -25 dB across the 800 MHz to 3 GHz band. Antenna model: Laird S9025PCB (5 dBi, circular polarization). All tests were conducted under controlled ambient conditions of 23°C ± 2°C and relative humidity of 45% ± 5%. A sample size of n=25 identical container electronic tags from the same production batch was used for all statistical measurements to ensure result reliability. This setup allows for accurate testing of container electronic tags in an isolated environment. Inside the chamber, four test antenna brackets are strategically positioned to simulate different real-world conditions. The antennas operate in both dual-antenna mode and single-antenna mode to cover a wide range of testing scenarios. The test frequency range spans from 800 MHz to 3000 MHz, fully covering the frequency bands used by container RFID tags. A programmable turntable with a rotation accuracy of 1 degree is incorporated to allow precise adjustments to the tag's orientation, simulating realistic conditions during testing. The test system framework in the laboratory is shown in Fig. 3. The container electronic tag test system consists of system unit, radio frequency unit, power amplifier unit, cabinet, and accessories. It can generate command signals that comply with the container electronic tag protocol standard and analyze the response signals returned by the container electronic tag under test.

There are four sets of test antenna brackets, as shown in Fig. 4. The test antenna adopts a combination of dual antenna mode and single antenna mode. Two test antennas are installed on the antenna bracket in the horizontal direction, and one test antenna can be installed on each of the antenna brackets in the other three directions. The test platform uses a disc-shaped foam platform for placing the device under test. The disc has an angle scale for adjusting the angle between the device under test and the test antenna. The test frequency range is between 800MHz and 3000MHz, covering the entire frequency band of the entire container electronic tag. The shielding effectiveness is 80dB. It has a built-in single-axis programmable turntable with a rotation accuracy of 1.0 degree, which supports electronic tag directionality testing. It has a built-in 5 antenna groups, circular polarization, antenna gain of 5dBi, axial ratio of 1.0dB, 3dB lobe width of 50 degrees, and standing wave ratio of 1.5:1. It has a built-in height-adjustable device under test placement platform, which supports electronic tag testing and experimental testing of installing electronic tags on container panels.

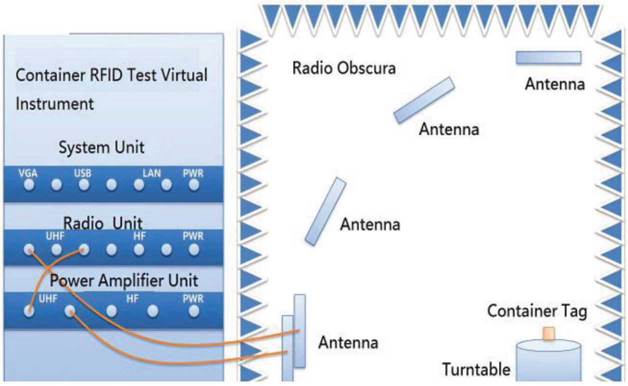

Fig.3. Test system framework in the laboratory

Fig.4. Radio darkroom

C. Gate Setup

For field testing, the container electronic tags were evaluated under real-world conditions in an outdoor setting, mimicking the environment at container gates. The test setup at the gate involved the use of a reader connected to an antenna mounted 5 meters above ground level, replicating the typical height and angle of real-world container handling. The antenna installation positions were carefully selected to cover all likely orientations of containers passing through the gate.

RF cables were employed to connect the reader to the antenna, with careful attention to ensure consistency with the indoor test setup. Sensitivity tests were first conducted in the field to assess the container electronic tags' performance in this more variable environment. The field test results were then compared with the laboratory data to ensure consistency across different environments. The actual test environment of the container electronic tag at the gate is shown in Fig. 5. The test equipment plays the role of a reader at this time and is directly connected to the reader antenna. The antenna is installed on the import and export rack with a height of 5M according to the actual environment of the gate.

Fig.5. Gate test environment

D. Experimental Procedure

The following experimental steps were followed for both laboratory and field tests:

- Sensitivity Testing: The container electronic tags were tested for sensitivity in both the anechoic chamber and the gate setup. The performance of the tags was measured at different frequencies (940 MHz and 920 MHz), with a focus on assessing the activation sensitivity.
- Backscatter Power Testing: In addition to sensitivity testing, the backscatter power of the tags was measured. These tests were conducted both in the laboratory and field environments to compare how the tags' performance varied under different conditions (e.g., air vs. container surface).
- Installation Angle Evaluation: Tags were installed at various angles on the container surface (e.g., horizontally, vertically, and at 45-degree angles) to determine the optimal installation orientation for best reading performance.

IV. Results and Analysis

A. Laboratory results and analysis

Firstly, the container electronic tags are tested in the air, then installed the electronic tags on the container sheet and put them in the anechoic chamber for testing. In actual applications, the sensitivity design of the electronic tags is crucial to its performance, so tests are conducted on the sensitivity of the tags in the air and on the container sheet for comparative analysis. The test results are shown in Fig. 6. The red curve represents the sensitivity curve of the tested container electronic tags in the air. The data shows that the best performance frequency of the electronic tags in the air is at 940MHz, with an activation sensitivity of -19dBm; at 920MHz, the activation sensitivity is -18dBm.

The blue curve represents the sensitivity curve of the tested container electronic tag on the container plate. The data shows that its best performance frequency is at 940MHz, with an activation sensitivity of -14.5dBm; the activation sensitivity at 920MHz is -13dBm. Comparing the two, it can be seen that the activation sensitivity of the container electronic tag in the air and on the container plate differs by about 6dB.

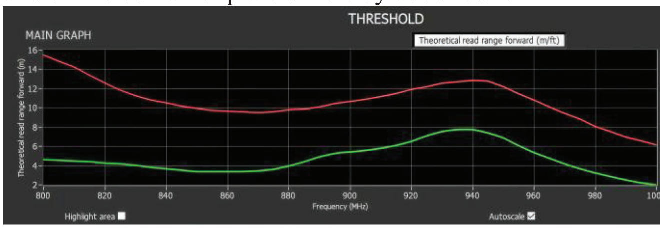

Fig.6. Sensitivity curve of container electronic tag in air and container plate

According to the forward theory reading distance equation (4.1)

$$R_{max} = \sqrt{\frac{P_{max,EIRP}}{P_{tag}}} \times \frac{C}{4\pi f} \quad (4.1)$$

$$P_{tag}=10^{P(dBm)/10} \times 10^{-3} \quad (4.2)$$

Where， $P_{max,EIRP}$=3.28W， $c = 3 * 10^{8}$m/s, f represents the frequency of RFID, P_{tag} is calculated according to equation (4.2), and the corresponding forward theoretical reading distance curve is shown in Fig. 7. The performance of container electronic tags in the air is better than that on the metal plate. In the forward theoretical reading distance (calculated at +35dBm transmission power), the user tag can read 13m@940MHz and 12m@920MHz in the air, while it can read 8m@940MHz and 6.5m@920MHz on the metal plate.

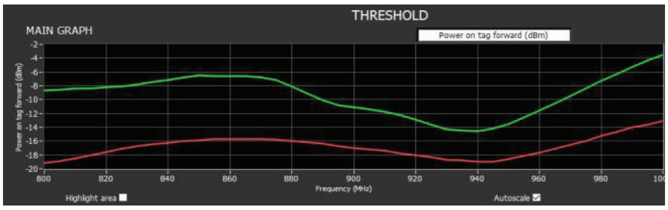

Fig.7. The forward theoretical reading distance curve of container electronic tags

In the performance test of container electronic tags, in addition to the sensitivity test, the backscatter power of the electronic tags is also a very important indicator. The test results are shown in the Fig. 8:

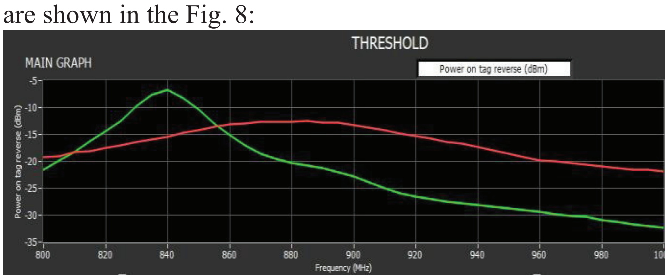

Fig. 8. Backscatter power curve of container electronic tag in air and container plate electronic tags

The red curve represents the backscatter power curve of the tested container electronic tag in the air. The data shows that the backscatter power of the electronic tag reaches a maximum value of -12.5dBm at 880MHz, -15dBm at 920MHz, and -18dBm at 940MHz. The blue curve represents the backscatter power curve of the tested container electronic tag on the container plate. The data shows that the backscatter power of the electronic tag reaches a maximum value of -5dBm at 840MHz, -27dBm at 920MHz, and -28dBm at 940MHz. Normally, at the same frequency, the backscatter power in the air is higher than the power on the container sheet. However, in this test, it is obvious that at the 840MHz frequency, the backscatter signal of the container sheet is much higher than the backscatter power in the air. The reason for this is that the surface of the container sheet may resonate with the antenna of the RFID tag at this frequency, resulting in signal enhancement. This resonance phenomenon can increase the electromagnetic field strength received by the tag, thereby increasing the backscatter signal. This discovery provides us with some inspiration when designing electronic tags. By designing the antenna and circuit of the tag and continuously conducting actual tests, the container electronic tag can resonate with the container sheet at the 920MHz frequency, enhance the reading distance of the tag, and transform the adverse effects of metal electromagnetic wave reflection into a favorable direction.

At the same time, according to the reverse theory reading distance equation (4.3)：

$$R_{max,BS} = \sqrt{\frac{P_{tag,BS}}{P_{EIRP,BS,lim\ it}}} \times \frac{C}{4\pi f} \quad (4.3)$$

Where， P_($_{EIRP}$ (Effective Isotropic Radiated Power), $_{BS}$ (Backscatter), $_{lim\ it}$)=-74dBm， c=3*10^8m/s, f represents the frequency of RFID, and is calculated according to formula (3), the reverse theoretical reading distance curve of the electronic tag is shown in Fig. 9:

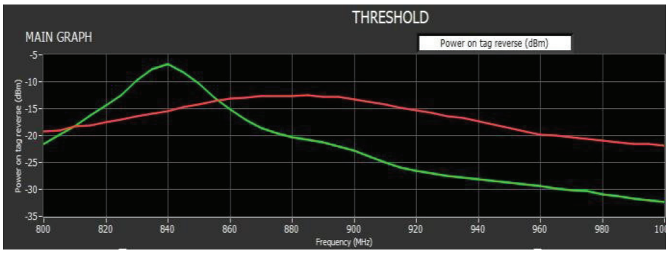

Fig.9. The reverse theoretical reading distance curve of the electronic tag

The reverse theoretical reading distance of container electronic tags in the air (calculated with -74dBm receiving sensitivity) is 31m@880MHz, 22m@920MHz and 18m@940MHz. The reverse theoretical reading distance on the metal plate is 65m@840MHz, 6m@920MHz and 5m@920MHz. We found that at 920MHz, the reverse theoretical reading distance is less than the forward theoretical reading distance of` 6.5m, which will result in the situation that the tag can be activated but the reader cannot demodulate. These issues need to be considered when designing the tag, and the performance needs to be redesigned to ensure the most ideal reverse reading distance at 920MHz. The principle of magnetic field resonance mentioned above can be referred to improve the reverse theoretical reading distance. There are other test indicators for the performance test of container electronic tags, which are not listed here one by one. Because the above test of electronic tag sensitivity and backscattering power indicators can basically make an accurate judgment on whether the performance of container electronic tags can be applied to container transportation. After the laboratory test is completed, we will conduct actual working condition tests on the container electronic tags at the off-site gate and further perform performance tests on the electronic tags.

B. Outdoor test results and analysis

Due to the distance in the outdoor field, the RF cable between the device and the antenna is not the same as the RF cable in the laboratory. Therefore, in order to ensure the difference with the laboratory test, we first conducted a sensitivity test of the container electronic tag. The test results are shown in Fig. 10 and 11. By comparing the actual outdoor scene and the laboratory test, the sensitivity of the container electronic tag is close, and the performance difference at the 920MHz frequency point is 1.5dBm. Analysis shows that the main reason for the slight difference in performance is related to the RF cable. The indoor laboratory test uses a 1.8M RF cable, while the RF cable used outdoors is longer than the RF cable in the laboratory, and the manufacturer is also different, so the deviation is within the normal range. Through the above experiments, it can be confirmed that the test conditions of the outdoor site can fully meet the conditions of the actual test, and the container electronic tag can be further installed on the container for testing.

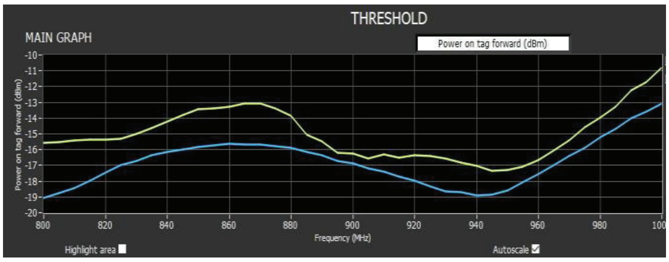

Fig.10. Sensitivity curve of container electronic tags in off-site air

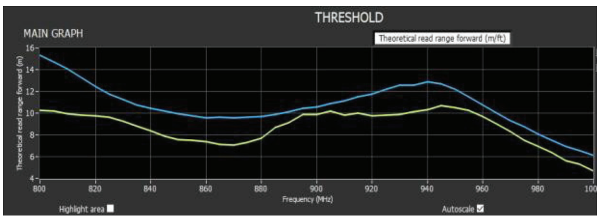

Fig. 11. Theoretical forward distance curve of container electronic tags

C. Container electronic tag gate test results and analysis

The test environment is set up. The installation position of the reader/writer of the test equipment is shown in Fig. 5. The position relationship between the container with the container electronic tag and the antenna is shown in Fig. 12. The antenna height is 5M and the container height is about 2.4M.

Fig. 12. The testing distance between container and test antenna

After determining the distance, we installed the container electronic tag at the upper part of the container surface and carried out the reading experiment at different installation angles. The different installation angles are shown in Fig. 13. This test method can more accurately measure the actual performance of the container electronic tag and obtain the best installation angle.

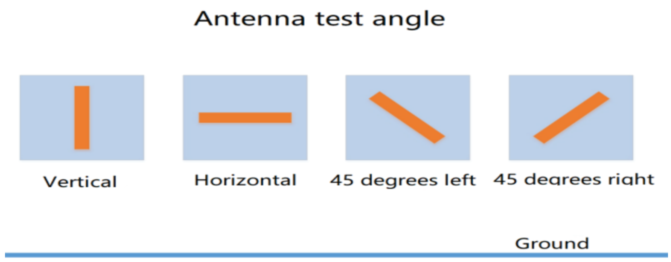

Fig.13. Schematic diagram of the installation angle of the container electronic tag

The actual test method is shown in Table 1. The position relationship between the container and the antenna is mainly distributed in three directions: directly below the antenna, one meter to the left of the antenna, and one meter to the right of the antenna. These three position relationships cover the main positions of the container when passing through the gate. The specific test conditions are shown in Table 1. Mark with a check (√) for successful reading, and with an (×) for failure to read.

Table 1. Tag orientation and Read success

Distance		Verticality	Horizontality	45 degrees left	45 degrees right
Immediately beneath the antenna	1 M	√	√	√	√
	2 M	√	√	√	√
	3 M	√	√	√	√
	4 M	√	√	√	√
	5 M	√	√	√	√
	6 M	√	√	√	√
	7 M	×	√	×	×
	8 M	×	×	×	×
To 1M left Immediately beneath the antenna	1 M	×	×	×	×
	2 M	×	√	×	×
	3 M	√	√	√	√
	4 M	√	√	√	√
	5 M	×	√	×	×
	6 M	×	×	×	×
To 1M right Immediately beneath the antenna	1 M	×	×	×	×
	2 M	×	√	×	×
	3 M	√	√	√	√
	4 M	√	√	√	√
	5 M	×	×	√	×
	6 M	×	×	×	×

From the table above, we can see that the probability of successful reading is the highest when placed horizontally, and the reading range is also the largest. Therefore, it is more appropriate to install the container electronic tag horizontally on the container. The electronic tag can be read normally most of the time when the horizontal distance is 6m, but it cannot be read at some angles within 6m. This is mainly related to the antenna designed for the container electronic tag. The strength of the reverse signal received from the tag during the application test is between -56dBm and -71dBm. Through the above tests, we found that the reading distance of the container electronic tag submitted for inspection is short. Although it can basically meet the needs of automatic container identification, the performance still needs to be further improved and optimized. It is necessary to readjust and optimize the design of the electronic tag so that it can be read smoothly within a range of at least 8 meters directly below the antenna, 1 meter to the left and 1 meter to the right on both sides, and can be read smoothly within a range of 6 meters from the reader. Only when the container electronic tag meets this requirement can a 99.99% reading success rate be ensured when passing through the gate.

V. Discussion

In this section, we interpret the results, and analyze potential limitations of the study.

Sensitivity

The sensitivity values obtained in both laboratory and field tests demonstrate the significant impact of environmental conditions on the performance of RFID tags. Specifically, the difference in sensitivity between the air and container plate environments reflects the well-documented issue of metal interference in RFID systems. Previous studies have highlighted that metal surfaces can significantly reduce the sensitivity of RFID tags by absorbing and reflecting signals, resulting in shorter read ranges. This effect was particularly evident when the tags were placed on the metal container plate, where sensitivity decreased by approximately 6 dB compared to the air environment. Our findings are consistent with this body of research, emphasizing the need for specialized antenna designs or frequency adjustments to mitigate the effects of metal interference in container logistics applications.

Installation Angle

Regarding the installation angle of RFID tags, our results align with existing research suggesting that horizontal installation maximizes reading success in logistics environments. Our tests demonstrated that horizontal placement of RFID tags on the container surface yielded the highest read success rates, confirming the results of these previous studies. In contrast, vertical or angled installations resulted in shorter read distances and lower success rates. This finding is crucial for optimizing container tracking systems, as it suggests that standardizing the orientation of RFID tags can improve the efficiency of automatic identification systems at container gates, minimizing misreads and delays in logistics operations.

Limitations and Future Work

While our study provides valuable insights into the performance of RFID tags under various conditions, it has some limitations. First, the testing was conducted under controlled laboratory conditions and at a single field site, which may not fully represent the diversity of real-world environments in container logistics. Future research should expand the testing to include a wider range of environmental factors, such as varying humidity, temperature, and movement, all of which can influence RFID tag performance. Additionally, while we have demonstrated the impact of metal interference, further investigation is needed into optimizing tag and antenna designs to better handle metallic environments. This could involve exploring new materials, frequencies, or hybrid systems that combine RFID with other sensor technologies for improved reliability.

VI. Conclusion

Experiments have proved that the container electronic tag test system designed can well complete the test of container electronic tags, and can be used as the mainstream instrument for container electronic tag testing. The test results can be used as the basis for evaluating the performance of container electronic tags. This experimental test equipment and test method have been used in the container intelligent transportation industry laboratory, and container electronic tag testing work has been carried out externally.

The container electronic tag test method proposed in this article can test the performance of container electronic tags and provide an effective evaluation tool for the design and manufacture of container electronic tags. The container electronic tags tested by this system can meet the requirements of improving the efficiency and reliability of container logistics. At the same time, the following suggestions are put forward for the design of the container electronic tag system under test for reference by the designers of container electronic tags:

1. Adjust the sensitivity design of the container electronic tag so that its activation sensitivity at 920MHz-925MHz is the lowest, which helps to improve the reading efficiency of the electronic tag.

2. Although the reading performance of the container electronic tag on the container plate is weaker than the reading efficiency in the air, the surface of the container plate can resonate with the antenna of the RFID tag at the frequency of 920MHz-925MHz through design, generating signal enhancement and increasing backscattering power, which helps to improve the reading efficiency of the electronic tag.

3. The selection of the container electronic tag antenna needs to select an antenna with a wide radiation range, because when the container passes through the gate, it is difficult to ensure that the container is in the best reading position, and it should be able to be stably identified within a range of 1 meter to the left and right of the center.

4. When improving the efficiency of container electronic tag reading, in addition to paying attention to the electronic tag itself, we must also pay attention to the receiving sensitivity of the reader. During the test, we found that the reverse signal strength of the tag is often between -56dBm and -71dBm, which requires the sensitivity of the reader to be lower than -71dBm. In order to ensure that the reader can normally and stably receive the return information of the tag, the reader's receiving

sensitivity needs to be higher than the actual test result by more than +3dB. Therefore, in practical applications, it is best to choose a reader with a receiving sensitivity lower than -74dBm.

5. The installation angle of the container electronic tag on the container should be placed horizontally as much as possible, and at the top of the container. Experiments have shown that this position has the best reading effect.

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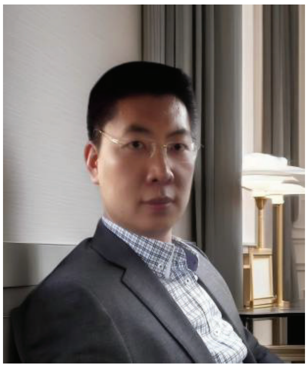

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