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Packaging — Measurement results for the use of RFID on returnable transport items —

Part 1:
Metal returnable transport items

Emballages — Résultats de mesure pour l'utilisation d'étiquettes RFID sur les emballages de transport réutilisables —

Partie 1: Emballages de transport réutilisables en métal

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Foreword

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This document was prepared by Technical Committee ISO/TC 122, *Packaging*.

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Introduction

In recent years, the use of Radio Frequency Identification (RFID) in the supply chain has been seen as an ideal solution to the increasing demand for higher traceability and reduction of logistics costs and materials in supply chains around the world. In actual logistics and material handling, the introduction of returnable transport item (RTI) management with RFID makes it easy to establish remote bulk reading systems, which can significantly reduce management costs compared to management with conventional barcode systems.

Various RTIs, such as plate pallets and box pallets, are subject to RFID systems, but when RF tags are attached to metal RTIs, the RF tags can fail to operate because the reading distance becomes very short due to the inherent properties of the metal. Various RF tags can be used on metal, but the performance, durability and other properties of RF tags, the conditions for attachment and the conditions for using metal RTIs are not clear.

This document verifies the characteristics of RF tags attached to metal RTIs through experiments, and the results of these experiments will be useful for the actual use of RF tags on metal RTIs.

Packaging — Measurement results for the use of RFID on returnable transport items —

Part 1: Metal returnable transport items

1 Scope

This document summarizes measurement results for the use of RFID on metal returnable transport items (RTIs).

This document describes the following:

— types of metal RTIs,

— features, reliability of RFID used for metal RTIs, and

— measurement results for the use of RFID on metal RTIs.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 19762, *Information technology — Automatic identification and data capture (AIDC) techniques — Vocabulary*

ISO 445, *Pallets for materials handling — Vocabulary*

ISO 21067-1, *Packaging — Vocabulary — Part 1: General terms*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19762, ISO 445, ISO 21067-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
serial number
SN
codes, such as sequential numbers, used for uniqueness

Note 1 to entry: The structure of the serial number can be decided by the company that is under the control of the issuing agency. This is normally composed of an item number and its production number (serial number).

3.2 Abbreviated terms

EIRP	effective isotropic radiated power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
MB	memory bank
RF	radio frequency
RSSI	receiver signal strength indicator
SUS	stainless steel
UII	unique item identifier memory bank
USER	user memory bank

4 Characteristics of RFID for metal RTIs

4.1 General

In the automotive industry and other manufacturing industries, there is a need for metal RTI, and actual management systems using RFID have already been introduced in some manufacturing industries. However, insufficient results have been achieved due to a lack of experience and knowledge about the capabilities and performance of RFID and the effects of metals. In addition, many tests and examinations have been carried out toward the practical application of RFID. Annex B to Annex F present measurement results useful for the introduction of RFID, especially RF tags designed for metal RTIs. The concepts and data described in this document can be applied to other objects and materials.

The characteristic of RF tags attached on the “metal” and “durability test” has been confirmed in four validation studies in particular.

— communication distance: measurement of the RF tag’s communication performance (possible communication distance)

— communication time: measurement of the time it takes to write data to the RF tag

— durability test: verification of the durability of the RF tag

— field-application test: indication of the RFID implementation test points.

4.2 RF tag

The types of RF tags supported by the UHF band include passive tags, active tags and semi-active tags. This document covers inexpensive passive tags that do not need special maintenance such as battery replacement. When a RF tag is attached to a metal RTI as defined in this document, the communication performance of the RF tag is significantly degraded due to the following unfavourable effects:

— Radio interference is generated by reflected waves from the metal.

— Interfering with the magnetic field around the RF tag.

— Impedance at the IC’s connection is changed by the metal and the energy loss increases.

In these operating environments, standard RF tags such as general-purpose RF tags are completely unable to communicate.

To address this problem, RF tag manufacturers are currently developing RF tags that work on metal objects while keeping a high communication capability by using dedicated antennas. This document takes into account the usage operating conditions of metal RTIs and supports not only metal but also RF tags that can withstand a long-term use in outdoor environment.

In the evaluation, the position in Figure 2 and the vanning process of metal RTI in Figure 3 are assumed.

4.3 Communication distance

In the communication distance tests, the change in performance of the RF tag was examined by measuring the RF tag's reading and writing distances to see how the RF tag's performance changes according to the material or shape of the metal on which the RF tag is attached and the operating environment. Refer to Annex B and Annex C for the results of these tests.

The communication distance was evaluated using Tag A, Tag B, Tag C, Tag D, and Tag E, which are outdoor-resistant and are intended for use on metal. See Annex B and Annex C for the evaluation method and results.

From the above results, the communication distance can be summarized as follows:

a) Factors that largely change communication distance

   1) Writing distance in comparison to reading distance

   2) Difference in the operating frequency range

   3) Effects of the presence of metal objects

   4) Adhered reflecting tape

   5) Applications other than metal objects (resin, wood, cardboard, etc., including free air)

   6) Shielding with a metal plate or fine wire mesh panel

b) Factors that scarcely affect communication distance

   1) Metal type (ion, aluminium, stainless steel)

   2) Metal shape (large/medium/small size plate, square pipe)

   3) Installation method (double-sided adhesive tape, bolt, banding band)

   4) Changes in temperature and humidity

   5) Extraneous matters (water drops, glass, packing tape)

   6) Shielding with a loose wire mesh panel

4.4 Communication time

The time to read the UII and the USER data and to write data were measured regarding communication between the RF tag and the interrogator. Changes in the communication time as a result of fluctuations in the data volume were also examined for a single RF tag and multiple RF tags. Four different types of ISO/IEC 18000-63 RF tags (inlays) were tested. Refer to Table 1 for the details on these RF tags.

Table 1 — RF tags (inlays) subject to the test

Sample tag name	Tag X	Tag Y	Tag Z	Tag Y’
UII size bits	96/256	256	128	448
USER size bits	512/352	512	512	1 024
Antenna size mm	70 × 17	70 × 14	86 × 24	70 × 17

The communication time was evaluated using the RF tags Tag X, Tag Y, Tag Z and Tag Y’, each having the USER memory (see Table 1). Refer to Annex D for the evaluation method and the results. Tag X, tag Y, and tag Z are products from different manufacturers, while tag Y and tag Y' are products from the same manufacturer.

Figure D.5 to Figure D.7 show the results of reading the three different types of RF tags by using four antennas. The results indicate that reading the UII is much faster than reading the USER for the ISO/IEC 18000-63 tags. In the reading of the USER, no particular difference by the bit count is observed up to 15 RF tags. The time taken for reading remains almost the same for 32 bits and 128 bits. However, as the number of RF tags is increased to 30 RF tags, it takes more than 1 s longer if the number of bits is increased to 512 bits compared to 32 bits. It takes more time to write than to read, particularly for writing the Tag Y.

Figure D.8 to Figure D.10 show the results of writing three different types of RF tags by using four antennas. The results indicate that writing the UII is much faster than writing the USER regarding the ISO/IEC 18000-63 tags. It is assumed that writing to the USER is not intended for the Tag Y. For any other RF tags, a proportional relationship is observed between the number of bits to be written and the writing time. This also applies to the number of RF tags to be written and the writing time.

Figure D.11 and Figure D.12 show the results of measured time to read and write a 512-bit USER memory of the Tag X by using one antenna and four antennas. A proportional relationship is observed with the number of RF tags. As an interrogator is configured to establish communication by switching the antennas, the communication time is extended in proportion to the number of implemented RF tags. The number of antennas to be used depends on the actual operating conditions, including the direction and height of the antennas.

Figure D.13 and Figure D.14 show the results of comparing the time for reading and writing the Tag Y’ whose memory capacity is larger than that of the other RF tags. This was done under the condition of USER 512 bits for comparison. The results show that the reading speed of the Tag Y’ lies in the middle of the ranking and its writing speed is the fastest. It is presumed that the writing speed is the highest because the RF tag uses a new IC.

Based on the above results, the communication time can be summarized as follows:

a) Reading

1) UII reading is done at a much higher speed (inventory).

2) With an increase in the memory capacity and/or the number of RF tags, reading takes longer with a larger time variation.

3) In one case, reading five RF tags was faster than reading a single tag.

4) Speed of reading is in the order of Tag Z > Tag X > Tag Y’ > Tag Y from the fastest.

b) Writing

1) With an increase in the memory capacity and/or the number of RF tags, writing takes longer.

2) In one case, writing five RF tags was faster than writing a single RF tag.

3) Writing the RF tag Y was not completed under certain conditions.

4) Speed of writing is in the order of Tag Y’ > Tag Z > Tag X > Tag Y from the fastest.

4.5 Durability test

Table 2 lists the test standards applicable to Tag A intended for metal RTI applications. A durability test was performed according to ISO 18185-3, referring to the results of an evaluation test equivalent to a 10-year outdoor durability test.

Table 2 — RF tags (inlays) subject to the test

Item	Test condition	Standard used for testing
Low temperature	−40 °C	IEC 60068-2–1
High temperature	+85 °C	IEC 60068-2–2
Mechanical shock	30 G (11 ms)	IEC 60068-2–27
Random vibration	3 G (2 h, −40 °C and +85 °C)	IEC 60068-2–53
Humidity	Up to 95 %	IEC 60068-2–38
Rain/snow	1 m of salt water	IEC 60068-2–18
Salt fog	Salt fog	IEC 60068-2–11
Drop shock	3,3 m concrete	IEC 60068-2–31 and IEC 60068-2–32
Sand and dust	Sand and dust	IEC 60068-2–68

Two types of operating environment tests as shown in Table 3 and Table 4 were conducted. In the basic operating environment tests in Table 3, Tag A assessed with a high-temperature/high-humidity storage test, a low-temperature storage test, a high-temperature storage test, a heat cycle test, a heat shock test and a weatherproof test. The test results indicate that, in the high-temperature/high-humidity storage, high-temperature storage and heat cycle tests, Tag A failed to keep above the initial 90 % communication distance for the specified test time equivalent to 10 years.

Annex E shows the results of the high-temperature/high-humidity storage test. Annex E describes the reading ability of RF tags. Figure E.1 is a graphical representation of the RF tag's readability rate against its serviceable lifetime. In the high-temperature/high-humidity storage test, good results were achieved as shown in Figure E.2, while the RF tag's performance was degraded as shown in Figure E.3. It is assumed that the RF tag's reading distance becomes shorter as the contact resistance between the semiconductor and the antenna increases over time. As seen in Figure E.1, the test samples keeping more than 90 % of their initial functional ability end at 0 % after a test period equivalent to 32,5 years. In contrast, at an equivalent test time of 19,5 years, more than 80 % of the test samples keep more than 90 % of their initial functional ability.

Table 3 — Basic operating environment tests

No.	Test item	Test conditions	Result
01	High-temperature high-humidity storage	+85 °C and 85 % for 1 000 h	Passable
02	Low-temperature storage	−80 °C for 60 days	OK
03	High-temperature storage	100 °C for 3 500 h	Passable
04	Heat cycle	−40 °C to 100 °C, retained for 20 min. at each temperature for 630 cycles (1 cycle approx. 2 h)	Passable
05	Heat shock	−40 °C to 125 °C, retained for 20 min. at each temperature for 730 cycles	OK
06	Weatherproof	120 min., optical irradiation (incl. 18 min. shower) cycle for 3 000 h	Unknown

Key
OK No problem
Passable Unable to keep 90 % of the initial communication distance at a 10-year equivalent test time (communication enabled)

The test items for the operating environment tests are listed in Table 4. Good results were achieved in most of these tests, except the block shock test in which the resin housing was broken and the chemical-resistance test in which the inside of the RF tag's resin case was eroded by liquid.

Table 4 — Operating environment tests

No.	Test item	Test conditions	Result
07	Block shock test	ISO 8611-1:2011 block shock test was applied to the RF tags	Fail
08	Vibration test	3 G, single axis rebound random vibration for 3 h	OK
09	Shock test	100 G, sine half-wave for 6 ms Sample attached on a pallet was dropped	OK
10	Salt spray test	35 °C for 96 h	OK
11	Immunity test	50 V/m (electromagnetic field), 25 kV (static electricity)	OK
12	Chemical-resistance test	Sample was submerged in assumed chemical for 2 h	Passable

Key
OK No problem
Passable Can be partly eroded by chemicals
Fail Resin housing broke (communication enabled)

These test results suggest allowing enough time for the usage period of the RF tag to cover the degradation in communication distance observed in some of the tests. As the RF tags covered in this document are intended to be used with metal RTIs, the durability test was also conducted on the RF tags attached on metal objects. Note that a load stress caused by a difference in the heat expansion rate between the RF tag's resin housing and the metal is not applied to the RF tag in a single-unit RF tag test.

5 Evaluation of RFID for Metal RTIs

5.1 Reading RF tags on metal RTIs

A typical metal RTI as shown in Annex A is normally made in a box shape and carried in a shipping container in the global supply chain flow. Many metal RTIs are usually made in the size of one-eighth or one-tenth of the container in consideration of the loading efficiency of the container. Products or parts are put in the RTI at shipping (vanning) and the RTI is folded down into a smaller form to improve the loading efficiency at returning (devanning). The following points have been checked when selecting which type of RF tag to use for metal RTIs:

a) Shape of the metal to which the RF tag is attached

b) Conditions surrounding the metal

c) Power frequency and output of each home region

d) Need for USER

e) Need for writing

f) Orientation of RF tag

g) Weatherproof performance (product life of metal RTI)

When attaching RF tags to metal RTIs, an appropriate place and method have been chosen that will not largely affect the RF tag's communication performance, or a place and method where external impact force is minimized. As for the system structure, consideration is given to how to secure the time for communication (communication-enabled distance and communication time), in addition to the maximum number of RF tags, the number of antennas and the antenna angle.

The followings are the basic information for implementing RF tags on metal RTIs.

a) Metal RTI: maximum number of folded RTIs stacked up on one another (15 tiers in this example; see Figure 1 and Figure 3)

b) Operating frequency: 860 MHz to 960 MHz (920 MHz in this example)

c) Reading/writing: USER bank supported by ISO/IEC 18000-63 tag

d) Radio wave output: 4 W EIRP

e) Antenna type: linear polarized wave (oriented in RF tag's longer direction in this example), circular polarized wave

f) Antenna distance: antenna-to-RF tag distance (0,5 m and 1,8 m in this example)

g) Carrying speed: speed of moving forklift (1 km/h to 5 km/h in this example)

Key

1 metal RTI (folded form)

2 RF tag

Figure 1 — Metal RTI and RF tag

Annex G shows images of the verification tests. Since the write distance of RF tags is obviously shorter than the read distance, this clause focuses on the write capability. The write distance is calculated from the ratio of the distances for the mounting conditions. In Annex G, the layout of the antenna is adjusted to target the RF tag on the bottom layer because the RF tag mounted on the bottom layer had a significant decrease in communication distance due to the influence of the floor.

Figure 1 shows an RF tag attached on a folded metal RTI. Here, the RF tag is attached on a square-shaped pipe object. This position is disadvantageous in terms of the RF tag's communication distance, but potential effects from the external environment of the metal RTI can be avoided. Table 5 lists the distances selected from the verified data approximate to these conditions.

Table 5 — Reading distance supporting metal RTIs

RF tag position	Writable distance (m)	Comparison with base distance (%)
Attached on a stainless-steel plate (base)	6,247	100,0
Attached on a square pipe 40 sq.	5,569	89,1
In contact with metal at top side	3,958	63,4
50 mm in parallel from a wall (to be applied at the lowest tier)	4,163	66,6

The writable distance of an RF tag placed on a metal RTI at the lowest tier can be calculated as follows:

$$6,247\,(\text{base distance}) \times 0,891 \times 0,634 \times 0,666 = 2,350 \tag{1}$$

Considering that the RF tag's communication range to be a circle whose diameter is equal to the communication distance, the writable distance of the RF tag at the antenna position (1,8 m in distance) is calculated as below from the Pythagorean Theorem:

$$\sqrt{\left(\frac{2,350}{2}\right)^2 - \left(1,8 - \frac{2,350}{2}\right)^2} \times 2 = 1,99 \tag{2}$$

Since the actually confirmed distance 1,64 m is close to the value 1,99 m calculated from a single-unit test, the result of the single-unit test is confirmed to be practical as an objective guide.

The communication time was also evaluated. The time to write 15 tiers was calculated based on the results of a single-unit test. Refer to Table 6.

Table 6 — Communication time for writing

Item	Contents	Communication time (seconds)	Remarks
RTI's ID reading	UII read (inventory)	0,558	1
USER data identification	USER 32 bits read	0,159	2
All USER data reading	USER 512 bits read	0,196	2
Data rewriting	USER 512 bits write	3,664	2
Rewrite confirmation	USER 512 bits read	0,196	2
Total		4,773	3

NOTE 1 The number of antennas is adjusted to be equivalent to six antennas by increasing the test results on four antennas by half.

NOTE 2 In reading/writing the USER bank, communication was evaluated only on the specific antennas. The figures in this list indicate the test results for a single antenna.

NOTE 3 The actual communication time is "4,773 seconds + upper PC processing time x 'n' times"

Measurement was done by installing the gates in a distribution warehouse as illustrated in Annex F. With the functionality of the RF tags used for the test, writing was enabled if the received signal strength indicator (RSSI) value was not less than −60 dBm, and therefore the communication distance that achieves the RSSI value of higher than −60 dBm was measured and taken as the writable distance. Figure F.1 lists the communication distances at the lane near the antenna. The vertical line indicates 15 RTIs. The communication distances at the lane far from the antenna are given in Figure F.2.

The values calculated from a single-unit test are compared with the actual values as follows:

a) Communication distance at the lane near (0,5 m) the antenna
   Single unit equivalent value 1,92 m
   Actual measurement value 1,80 m (90 cm × 2)

b) Communication distance at the lane far from (1,8 m) the antenna
   Single unit equivalent value 1,99 m
   Actual measurement value 1,64 m (82 cm × 2)

For the communication time, a cycle of the time to rewrite the USER data on 15 tiers was measured using a metal RTI fixed within the range in which communication with all RF tags was enabled. The result was as follows.

Single unit equivalent value 4,8 seconds

Actual measurement value 6 to 7 seconds

From the above results, it is confirmed that the value calculated from a single-unit test are key for establishing the gates and applications. Table 7 and Table 8 list the respective times when the RF tag is passing through the gate at a speed of 5 km/h, 3 km/h and 1 km/h. Of the time range less than 6 seconds shown in grey, which is the cycle duration for rewriting the data on the 15 tiers, the interrogator fails in writing at a speed of 5 km/h and 3 km/h without exception. Even at the lane far from the antennas, the RF tag moving at a speed of 1 km/h failed to achieve twice the rewrite time and can end up failing to be written successfully depending on the timing of the communication cycle. With the existing RF tags, too much time is spent on rewriting RF tag data. This problem is a future challenge. A high level of traceability that covers the supply chain is possible at a lower cost just by writing a pass certificate in every RF tag without a need for networking in the supply chain. Faster writing speeds facilitate practical applications.

Table 7 — Pass-by time of communication-enabled distance (lane near the antenna)

No. of RTI tiers from the bottom	Writable distance (cm)	Pass-by time (seconds)		
		5 km/h	3 km/h	1 km/h
15	142	1,02 [a]	1,70 [a]	5,11 [a]
14	172	1,24 [a]	2,06 [a]	6,19
13	142	1,02 [a]	1,70 [a]	5,11 [a]
12	142	1,02 [a]	1,70 [a]	5,11 [a]
11	192	1,38 [a]	2,30 [a]	6,91
10	172	1,24 [a]	2,06 [a]	6,19
09	181	1,30 [a]	2,17 [a]	6,52
08	181	1,30 [a]	2,17 [a]	6,52
07	217	1,56 [a]	2,60 [a]	7,81
06	217	1,56 [a]	2,60 [a]	7,81
05	244	1,76 [a]	2,93 [a]	8,78
04	204	1,47 [a]	2,45 [a]	7,34
03	234	1,68 [a]	2,81 [a]	8,42
02	180	1,30 [a]	2,16 [a]	6,48
01	180	1,30 [a]	2,16 [a]	6,48
Maximum	244	1,76	2,93	8,78
Minimum	142	1,02	1,70	5,11

[a] Grey cells are the result for less than 6 seconds.

Table 8 — Pass-by time of communication-enabled distance (lane far from the antenna)

No. of RTI tiers from the bottom	Writable distance (cm)	Pass-by time (seconds)		
		5 km/h	3 km/h	1 km/h
15	310	2,23 [a]	3,72 [a]	11,16
14	374	2,69 [a]	4,49 [a]	13,46
13	288	2,07 [a]	3,46 [a]	10,37
12	258	1,86 [a]	3,10 [a]	9,28
11	494	3,56 [a]	5,93 [a]	17,78
10	542	3,90 [a]	6,50	19,51
09	498	3,59 [a]	5,98 [a]	17,93
08	504	3,63 [a]	6,05	18,14
07	542	3,90 [a]	6,50	19,51

[a] Grey cells are the result for less than 6 seconds.