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Information technology — Radio frequency identification for item management — Methods for localization of RFID tags

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Foreword

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Technology progress continuously achieves longer read ranges for RFID and in particular UHF RFID. With increasing communication ranges, the actual possible location of a tag around an interrogator gets larger and larger and there is often demand for more precise details on the tag location around the interrogator.

This document addresses tag localization by additionally superimposing a wideband localization signal to the communication between interrogator and tag.

In order to ensure interoperable systems, this document addresses the physical layer, logical layer and details on systems.

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Information technology — Radio frequency identification for item management — Methods for localization of RFID tags

1 Scope

This document defines how to use the RFID air interface standards of the ISO/IEC 18000 series that are based on backscatter technology for localization of RFID tags, specifically tags which are ISO/IEC 18000-4, ISO/IEC 18000-61, ISO/IEC 18000-62, ISO/IEC 18000-63 and ISO/IEC 18000-64 compliant.

This document specifies the physical and logical requirements for localization. The system comprises interrogators, also known as readers, and tags, also known as labels. An interrogator receives information from a tag by transmitting a modulated RF signal to the tag and the tag responds by modulating the reflection coefficient of its antenna, thereby backscattering an information signal to the interrogator. The modulated RF signal for data exchange is based on the relevant part of the ISO/IEC 18000 series and, in addition, there is a superimposed modulated RF signal with the same or different carrier frequency intended for localization. This document describes the signals required for localization, the method to derive localization information from the signals received by the interrogator and the requirements onto tags and interrogators.

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 18000-63, *Information technology — Radio frequency identification for item management — Part 63: Parameters for air interface communications at 860 MHz to 960 MHz Type C*

ISO/IEC 18047-6, *Information technology — Radio frequency identification device conformance test methods — Part 6: Test methods for air interface communications at 860 MHz to 960 MHz*

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

3 Terms and definitions

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

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

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

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

3.1
information-bit
single bit of information sent from the tag to the interrogator

Note 1 to entry: Depending on the selected modulation of the backscatter link, an information-bit is represented by multiple modulation-bits.

3.2
modulation-bit
smallest unit in a binary modulated backscatter communication

Note 1 to entry: Depending on the type of modulation, an information-bit is represented by multiple modulation-bits.

Note 2 to entry: In case of ISO/IEC 18000-63 modulations, each modulation bit has the length of Tpri/2.

3.3
Query
command from interrogator-to-tag

Note 1 to entry: This term is explained in more detail in ISO/IEC 18000-63.

4 Conformance

4.1 Claiming conformance

An interrogator or tag shall comply with all relevant clauses of this document, except those marked as "optional".

4.2 Interrogator conformance and obligations

An interrogator shall implement the mandatory commands defined in this document and conform to ISO/IEC 18000-63.

An interrogator may implement any subset of the optional commands defined in this document.

The interrogator shall not

— implement any command that conflicts with this document, or

— require the use of an optional, proprietary or custom command to meet the requirements of this document.

4.3 Tag conformance and obligations

A tag shall implement the mandatory commands defined in this document for the supported types and conform to ISO/IEC 18000-63.

A tag may implement any subset of the optional commands defined in this document.

A tag shall not

— implement any command that conflicts with this document, or

— require the use of an optional, proprietary or custom command to meet the requirements of this document.

5 Symbols and abbreviated terms

The main symbols and abbreviated terms used in this document are detailed in ISO/IEC 19762. Symbols, abbreviated terms and notation specific to this document are as follows:

BLF	backscatter-link frequency
CW	continuous wave
$\Delta s_{avg}(\tau)$	difference waveform between the averaged waveforms $\Delta s_{avg,1}(\tau) - \Delta s_{avg,0}(\tau)$. This waveform serves as the basis for calculation the ToF between interrogator and tag
$\overline{\Delta \mathrm{IQ}}$	averaged delta voltage between the tag's two different modulation states (complex valued)
Δ_{RCS}	delta radar cross section
DUT	device under test
FT	frequency tolerance (of the backscatter link)
$\mathrm{G}_{0\mathrm{r}}$	gain of the receiving antenna
$\mathrm{G}_{0\mathrm{t}}$	gain of the transmitting antenna
I	in-phase component (real-part of complex value)
$\overline{IQ_{k,m}}$	average IQ voltage during modulation state *m* and bit number *k*
k	index of the backscatter modulation-bits, $k = 0, 1, 2\ldots$
$P_{\mathrm{I,min}}$	minimum power allowing the DUT tag activation
Q	quadrature-phase component (imaginary-part of complex value)
R=>T	interrogator-to-tag
RCS	radar cross section of tag
RX	receive(d)
$s_{avg,0}(\tau)$	averaged waveform of the RX waveforms, realigned in time, $s'_{\mathrm{RX},k}(\tau)$ of "0"-modulation-bits
$s_{avg,1}(\tau)$	averaged waveform of the RX waveforms, realigned in time, $s'_{\mathrm{RX},k}(\tau)$ of "1"-modulation-bits
$S_{\mathrm{RRSEQ}}(\tau)$	cyclic ranging signal in time-domain (one period)
$s_{\mathrm{leakage,RX},k}(\tau)$	part of the RX-signal due to leakage and reflections with the length of one period of the ranging signal, received in time-slot *k*
$s'_{\mathrm{leakage,RX},k}(\tau)$	part of the RX-signal due to leakage and reflections cyclically rotated
$s_{\mathrm{tag.RX},k}(\tau)$	part of the RX-signal from the active tag with the length of one period of the ranging signal, received in time-slot *k*
$s'_{\mathrm{tag,RX},k}(\tau)$	part of the RX-signal from the active tag cyclically rotated
$s_{\mathrm{RX},k}(\tau)$	RX-signal with the length of one period of the ranging signal, received in time-slot *k*
$s'_{\mathrm{RX},k}(\tau)$	RX-signal cyclically rotated
t_{RSEQ}	length of a single period of the ranging signal
T_k	*k*-th time-segments of the tag's backscattered modulation-bits
T=>R	tag-to-interrogator

ToF time of flight

τ time within a signal of the length of a ranging signal's single period $0 \le \tau < t_{RSEQ}$

TX transmit(ted)

6 Ranging requirements

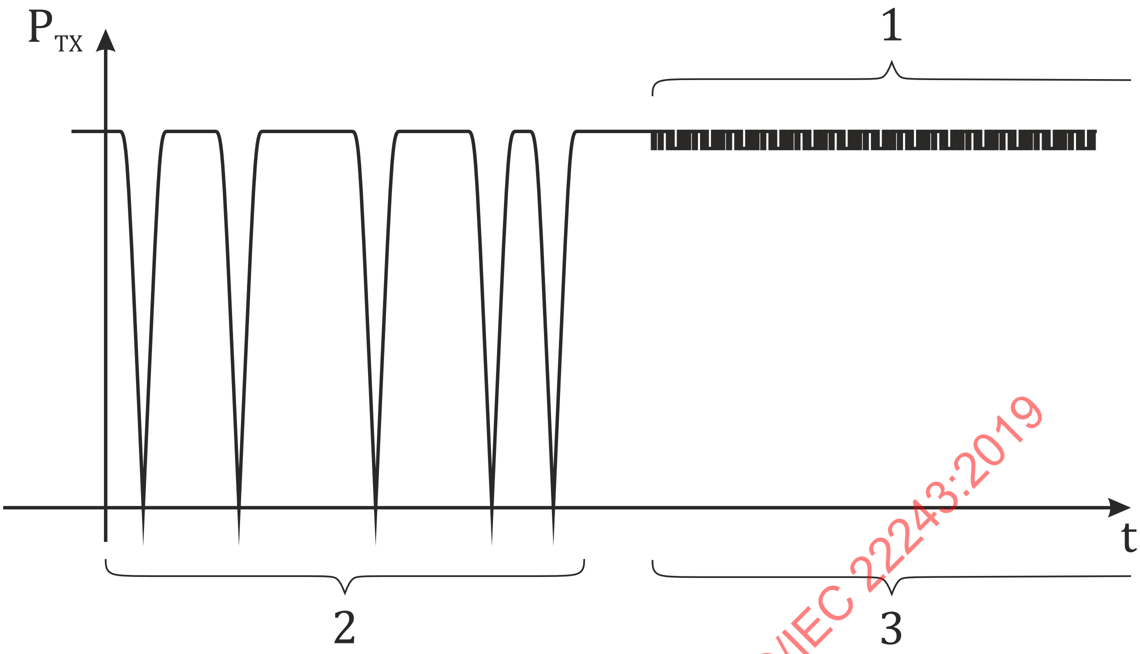
6.1 Overview of the ranging method

The ranging principle is intended to be used in backscatter-based RFID systems. It uses a wideband-signal, superimposed onto the interrogator's signal during tag-to-interrogator (also known as reader) (T=>R) communication. The interrogator uses signal processing on the received signal to determine the distance between tag and interrogator when interrogating the tag. The tag may implement commands and/or operational modes, enhancing the accuracy of the ranging. Ranging in general works with regular tags as e.g. tags compliant to ISO/IEC 18000-63, however some tag designs can have limitations in range and accuracy. The requirements within this document ensure a certain minimum ranging performance for different tag- and interrogator vendors.

6.2 Description of operating procedure

The ranging is based on ToF measurements of the round-trip time from interrogator to tag and back to interrogator. As typical RFID tags work with rather low link data rates (e.g. up to 640 kBits/s for ISO/IEC 18000-63 tags) and allow timing variations of several microseconds, ToF cannot be used directly. Using a wideband interrogator signal and measuring the delay of the received echo does not give usable results either, as the echo is dominated by multiple other contributions (e.g. antenna coupling, other tags).

Figure 1 shows an example for the ranging signal, being transmitted after a ISO/IEC 18000-63 Query command during the time a response from the tag is expected.



Key

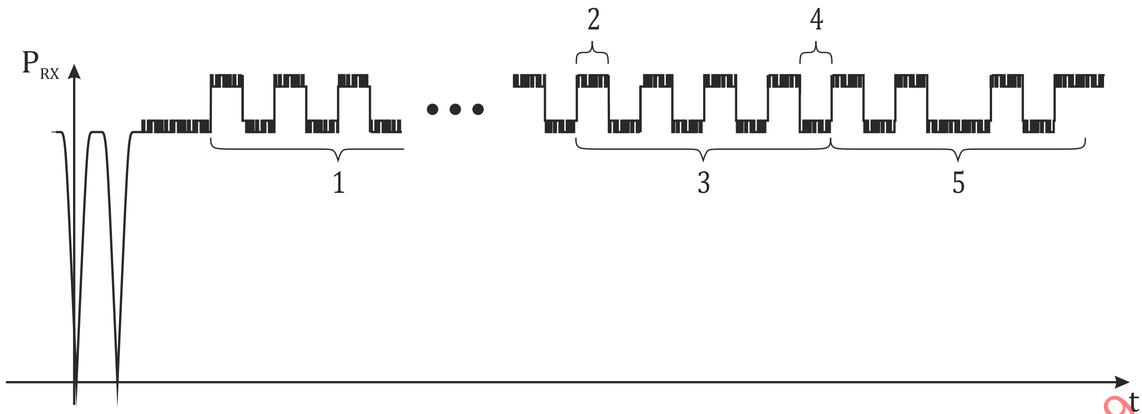
1 ranging signal

2 Query sequence

3 response from tag expected

Figure 1 — Superimposed ranging signal

The superimposed periodic signal S_{RRSEQ} (τ) shall have a periodicity not longer than the time of a single modulation-bit of the tag's backscatter signal. Due to data encoding, a modulation-bit can have a shorter length than an information-bit, depending on the chosen T=>R modulation. Additionally, the timing tolerance of the modulation-bit has to be taken into account. Figure 2 shows an example of the backscattered information bit-sequence “01” with Miller 4-encoding applied. Here, each information-bit consists of 8 modulation-bits. For ISO/IEC 18000-63 tags, the maximum length of one period of the ranging signal S_{RRSEQ} (τ), denoted by the time t_{RSEQ}, can be expressed by $t_{\text{RSEQ}} \leq \frac{1-f_{\text{T}}}{2\,f_{\text{BL}}}$, with f_{BL} as the backscatter-link frequency (BLF) and f_{T} as the tag's allowed frequency tolerance (FT) defined by ISO/IEC 18000-63.



Key

1 Miller Preamble

2 modulation-bit “1”

3 information-bit “0”

4 modulation-bit “0”

5 information-bit “1”

Figure 2 — Definition of modulation- and information-bit lengths

During T=>R backscatter-communication, the interrogator’s CW signal is reflected by the tag. The reflected signal depends on the tag’s current modulation-state. Beside the CW signal, the smaller ranging signal is reflected as well by the tag. For the ranging principle, the interrogator segments the received waveform according to the recovered modulation bit-rate into the time segments T_0, T_1, T_2..., each of them consisting of at least one period of the ranging signal. Figure 3 shows an example for a spread-spectrum like ranging signal.

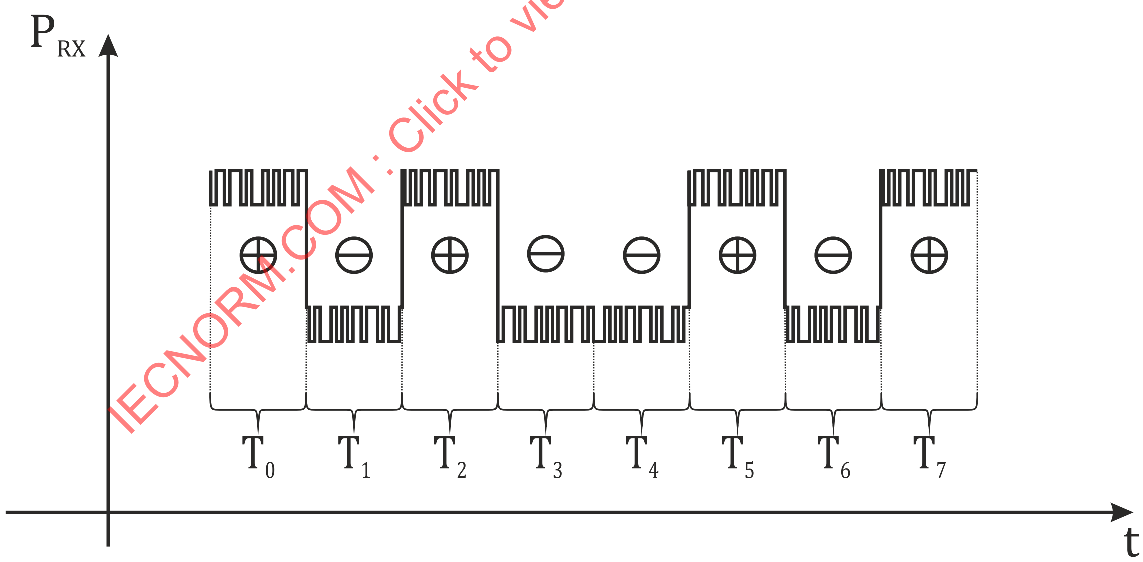
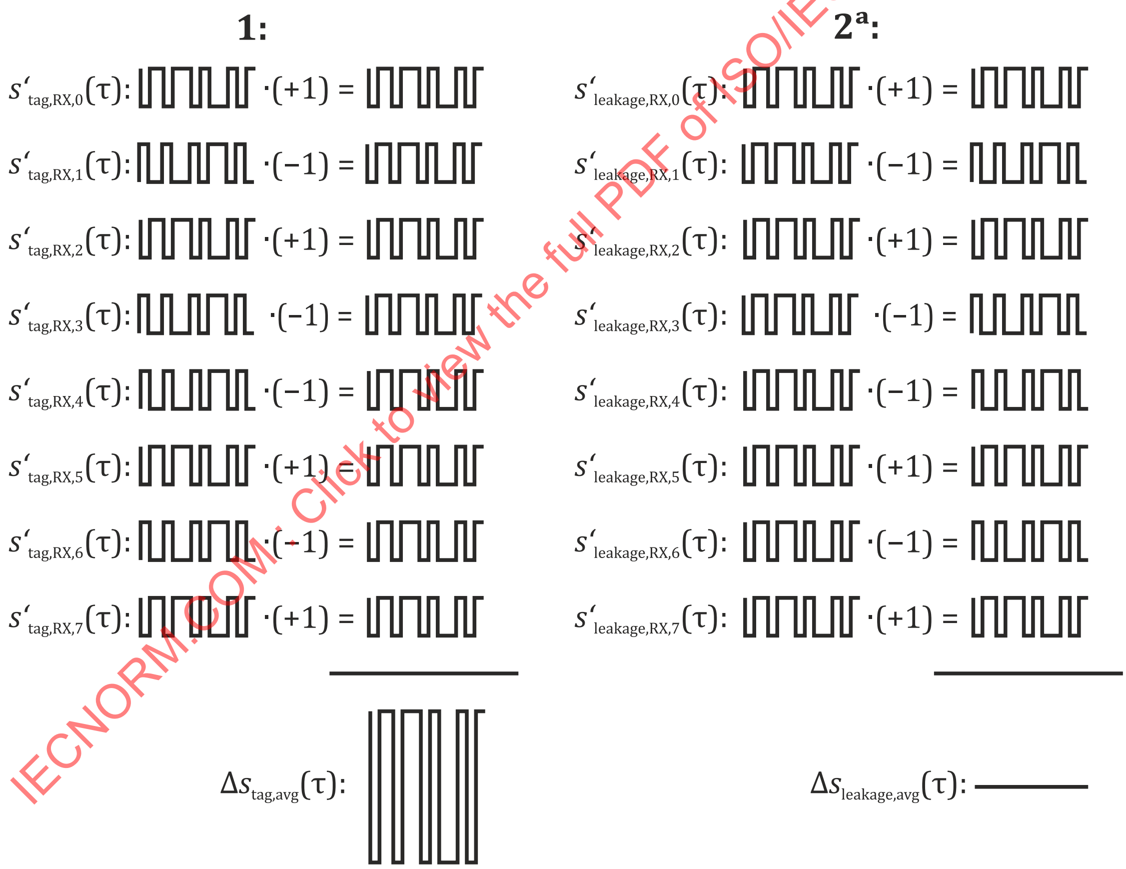


Figure 3 — Required segmentation of the RX-signal by the interrogator

As the periodicity of the ranging signal is less than or equal to the modulation-bits’ durations, the interrogator picks a signal of length t_{RSEQ}, called $s_{\mathrm{RX},k}(\tau)$ from each segmentation time-slot T_k with k indicating the number of the time-slot and τ indicating the time within the signal $0 \le \tau < t_{\mathrm{RSEQ}}$. The interrogator can take the signal $s_{\mathrm{RX},k}(\tau)$ from the centre of the timeslot, but other ways are also possible. The signal $s_{\mathrm{RX},k}(\tau)$ is a superposition of the signal reflected by the tag $s_{\mathrm{tag,RX},k}(\tau)$ and the leakage and static reflections of the environment $s_{\mathrm{leakage,RX},k}(\tau)$. It contains one period of the transmitted ranging signal S_{RRSEQ}. Due to the repetitive transmission of the ranging signal by the interrogator, its periodic boundary is found at a different random position in each signal $s_{RX,k}$ (τ). The interrogator performs cyclic rotation of the signal $s_{RX,k}$ (τ) such that the periodic boundary is aligned with the beginning of each signal $s_{RX,k}$ (τ). As the ToF measurement is not known yet, a zero ToF-time may be assumed for the cyclic rotation.

The corrected signals $s'_{RX,k}$ (τ) are afterwards grouped, depending on the received modulation-bit at the corresponding timeslot T_k. The interrogator calculates an averaged signal waveform of all signals $s'_{RX,k}$ (τ) grouped by their modulation-bit. In Figure 3, this corresponds to averaging the signals from timeslots 0, 2, 5, 7 to calculate the averaged signal waveform $s_{avg,1}$ (τ) and from timeslots 1, 3, 4, 6 to calculate the averaged signal waveform $s_{avg,0}$ (τ). Taking the difference Δs_{avg} $(\tau) = s_{avg,1}$ $(\tau) - s_{avg,0}$ (τ), it is shown in Reference [7] that Δs_{avg} (τ) only consists of echoes of the tag the T=>R communication was received from, while other echoes from the environment, other tags, and even TX-RX coupling are eliminated (Figure 4). Although it is preferable to average over as many information-bits as possible, the interrogator can limit the number of bits and can limit the averaging process to averages over the same amount of “0” and “1” modulation-bits. Instead of calculating a single averaged waveform over an entire T=>R communication, the interrogator can split one T=>R communication into several “sub”-averages. Furthermore, the interrogator can also combine multiple T=>R communications to a single averaged waveform.



Key

1 selected RFID tag

2 static reflections and coupling

a DC offset due to carrier leakage is not shown.

Figure 4 — Eliminating interferers and unwanted echoes by set-averaging

The delay between the transmitted ranging signal and the averaged waveform shall be calculated by the interrogator to provide the required ToF-measurement.

6.3 Ranging requirements for ISO/IEC 18000-63 based systems

6.3.1 Tag requirements

6.3.1.1 General

A tag shall be compliant to ISO/IEC 18000-63.

To enable ranging, the tag-to-interrogator (backscatter) communication shall fulfil the requirements of this document. The implementation of a ranging compliant tag shall not, in any event, change its conformance to ISO/IEC 18000-63.

6.3.1.2 Backscatter modulation

6.3.1.2.1 Test objective

While for the T=>R communication of ISO/IEC 18000-63 tags, the delta radar cross section (Δ_{RCS}) is of main importance, the ranging principle relies on processing complex valued quadrature baseband I and Q voltage waveforms. The ISO/IEC 18047-6 test setups for tag backscatter measurements shall be used but are extended by a $\overline{\Delta IQ}$ value.

Measurements are carried out in an anechoic chamber in a bistatic antennas configuration as shown in ISO/IEC 18047-6 with the tag positioned in the far field of the transmit antenna. For this test, the tag shall be placed and oriented for optimum field strength reception in the direction of the major power radiation of the interrogator.

6.3.1.2.2 Test procedure

Measurements shall be done at tag power levels $P_{\mathrm{I,min}}$+3 dB and $P_{\mathrm{I,min}}$+23 dB, where $P_{\mathrm{I,min}}$ is the minimum power allowing the DUT tag activation.

A vector signal analyzer as specified in ISO/IEC 18047-6 shall be used to record the quadrature baseband voltages I and Q versus time.

Test setup shall be calibrated to take antennas gain, mismatch and cables loss into account for all power measurements.

Delta IQ and delta radar cross section measurement procedure is as follows:

1) The signal generator shall be set to the required test frequency.

2) The signal generator amplitude shall be set to a value that allows the DUT tag activation.

3) Using the power meter, determine the power at the entrance of the transmit antenna, P_e, which is defined as the average power measured over at least 100 µs period during the continuous waves signal following the signal generator command.

4) The signal analyzer shall be set to measure the quadrature baseband I and Q power versus time, with a sampling bandwidth of at least 25 MHz.

5) With the tag placed in the anechoic chamber, the analyzer shall be set to capture the complex IQ baseband voltage waveforms for a complete ACK response (including preamble and dummy 1 bit) with at least 128 modulation bits. Averaging over multiple ACK response waveforms is acceptable (for increasing SNR) as long as it can be guaranteed that the measured parameters are not influenced by the averaging procedure.

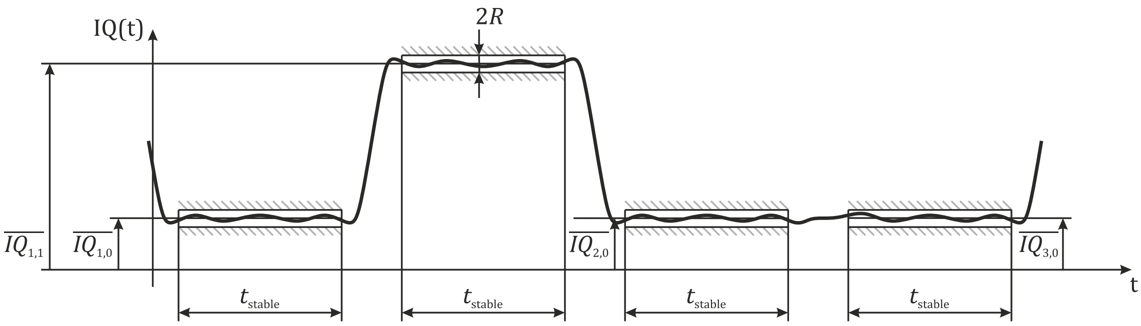


Figure 5 — Tag-to-interrogator (delta) IQ waveform (symbolic representation of the actual complex valued IQ voltage waveforms)

6) Calculate the average IQ voltages $\overline{IQ_{k,m}}$ for all modulation bits during t_{stable}. The index m indicates the modulation state (0 or 1) and k indicates the modulation bit index (see Figure 5).

7) Calculate the average delta IQ voltage:

$$\overline{\Delta \text{IQ}} = \frac{1}{N_1} \sum_{k=1}^{N_1} \overline{IQ_{k,1}} - \frac{1}{N_0} \sum_{k=1}^{N_0} \overline{IQ_{k,0}}$$

where

N_0 is the number of all recorded modulation 0 bits; and

N_1 is the number of all recorded modulation 1 bits.

8) Calculate the difference of power from the DUT tag backscattering according to the following formula:

$$\Delta P_{\text{tag}}(\text{RMS}) = \frac{1}{2Z_0} \left| \overline{\Delta IQ} \right|^2$$

where Z_0 is the wave resistance of the measurement equipment and is usually 50 Ω.

9) Calculate the Δ_{RCS} of the DUT tag using the radar formula given below:

$$\Delta\text{RCS} = \frac{\Delta P_{\text{tag}}}{P_e} \frac{4\pi d^4}{G_{0t} G_{0r}} \left(\frac{4\pi}{\lambda} \right)^2$$

6.3.1.2.3 Delta IQ variation

A transition between a tag's two backscatter modulation states (each with a different IQ value) shall comply with Figure 5 and Table 1 for the power levels given in 6.3.1.2.2. Figure 5 is a symbolic representation of the actual complex valued IQ voltage waveforms.

Table 1 — IQ and Delta-IQ modulation parameters

	Parameter	Symbol	Min	Nominal	Max	Units
	IQ stable time (time during which the IQ waveform shall be stable)	t_{stable}		$0{,}95 \cdot \frac{1 - f_T}{2 f_{BL}}$		µs

Table 1 *(continued)*

	Parameter	Symbol	Min	Nominal	Max	Units
	IQ ripple	$20\log_{10}\left\|\frac{R}{\overline{\Delta\mathrm{IQ}}}\right\|$			−30	dB

6.3.1.2.4 Tag ranging classes

The ranging principle requires a stable $\overline{\Delta\mathrm{IQ}}$ as well as a high Δ_{RCS} over the tag's frequency range. Tags are grouped in classes based on their frequency dependent $\overline{\Delta\mathrm{IQ}}(f)$ and $w_{\overline{\Delta IQ}}(f)$.

A tag's $\overline{\Delta\mathrm{IQ}}$-bandwidth $w_{\overline{\Delta\mathrm{IQ}}}$ shall be defined by the maximum bandwidth for which the following inequality holds true, with f_c denoting the frequency of operation. The measurement shall be conducted at tag power level $P_{I,min}$+3 dB.

$$-3 < 20\log_{10}\left|\frac{\overline{\Delta\mathrm{IQ}(f_c+\Delta f)}}{\overline{\Delta\mathrm{IQ}(f_c)}}\right| < +3 \quad \left(\text{for any} \left|\Delta f\right| < \frac{w_{\overline{\Delta\mathrm{IQ}}}}{2}\right)$$

A tag shall be categorized to fulfil a certain ranging class if the requirements of Table 2 are fulfilled for all operation frequencies f_c the tag is specified for.

Table 2 — Ranging classification

	$w_{\overline{\Delta\mathrm{IQ}}} \geq 40\,\mathrm{MHz}$	$w_{\overline{\Delta\mathrm{IQ}}} \geq 80\,\mathrm{MHz}$
Δ_{RCS} >= −20 dBsqm @ $P_{I,min}$+3 dB and Δ_{RCS} >= −30 dBsqm @ $P_{I,min}$+23 dB	Class 1A	Class 1B
Δ_{RCS} >= −15 dBsqm @ $P_{I,min}$+3 dB and Δ_{RCS} >= −25 dBsqm @ $P_{I,min}$+23 dB	Class 2A	Class 2B
Δ_{RCS} >= −10 dBsqm @ $P_{I,min}$+3 dB and Δ_{RCS} >= −20 dBsqm @ $P_{I,min}$+23 dB	Class 3A	Class 3B

6.3.1.3 User commands for ranging support

A tag may support a temporarily higher Δ_{RCS} and, therefore, a higher ranging classification by user-specific commands.

A tag may support persistent settings to permanently configure a higher Δ_{RCS}.

6.3.1.4 Multi frequency tags

A tag may support ranging in the ISM 2,45 GHz band. For being classified as multi-frequency ranging tag, the following shall be fulfilled:

1. The tag shall be fully compliant to ISO 18000-63 communication in the 860 MHz to 960 MHz band.
2. The tag shall have a dual-band- or second antenna for the ISM 2,45 GHz band.
3. The tag shall backscatter a sequence of “010101…” modulation-bits in the ISM 2,45 GHz band for the entire time the UHF backscatter link is active (i.e. preamble, tag-to-interrogator data, dummy-1) according to Figure 6. The transitions of each 2,45 GHz modulation-bit shall be synchronous with the UHF information-bit boundaries within a maximum tolerance of +/−100 ns.
4. The tag shall fulfil the criteria given in 6.3.1.2 (Table 1) also for ISM 2,45 GHz frequencies at field strengths in the range 0,01…1,0 V/m at the tag.

5. There is no ranging class specification within the ISM 2,45 GHz band. Instead, a multi frequency tag's $w_{\overline{\Delta \mathrm{IQ}}}$ in the ISM 2,45 GHz band shall be larger than 80 MHz for the UHF power levels given in 6.3.1.2.2, for field strengths at the tag in the range 0,01...1,0 V/m, measured at a centre frequency of 2 441,75 MHz (centre of the 2 400...2 483,5 MHz band).

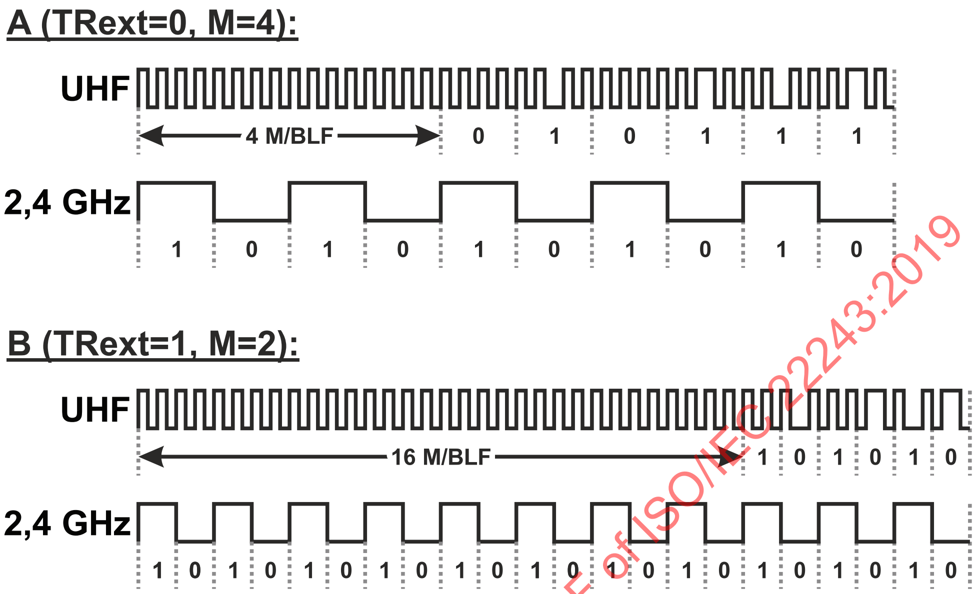


Figure 6 — UHF and 2,4 GHz backscatter alignment (Example A and Example B)

6.3.2 Interrogator requirements

6.3.2.1 General

An interrogator shall be compliant to ISO/IEC 18000-63.

6.3.2.2 Ranging signal

6.3.2.2.1 Ranging signal waveform

The interrogator's ranging signal can be chosen application specific. The signal can be binary modulated, use spread spectrum sequences or resemble a noise-like analog signal. Interrogators can change the ranging signal waveform and length depending on the BLF, the coding, or other parameters. The signal shall be superimposed to the interrogator's CW signal during the T=>R communication. Although it is favourable (regarding the signal to noise ratio) to superimpose the ranging signal for the entire T=>R communication, the interrogator can limit the transmission time.

6.3.2.2.2 Ranging signal centre frequency

The ranging signal may be centred at the frequency of the current radio channel or may be centred at other frequencies as well.

6.3.2.2.3 Ranging signal power, spectral mask and duty cycle

Requirements for the combined TX-signal of a ranging-enabled interrogator are given in the relevant national regulations. Examples are e.g. in FCC Part 15.247, FCC Part 15.205, FCC Part 15.209 or CEPT REC 70 03/ETSI EN 302 208.