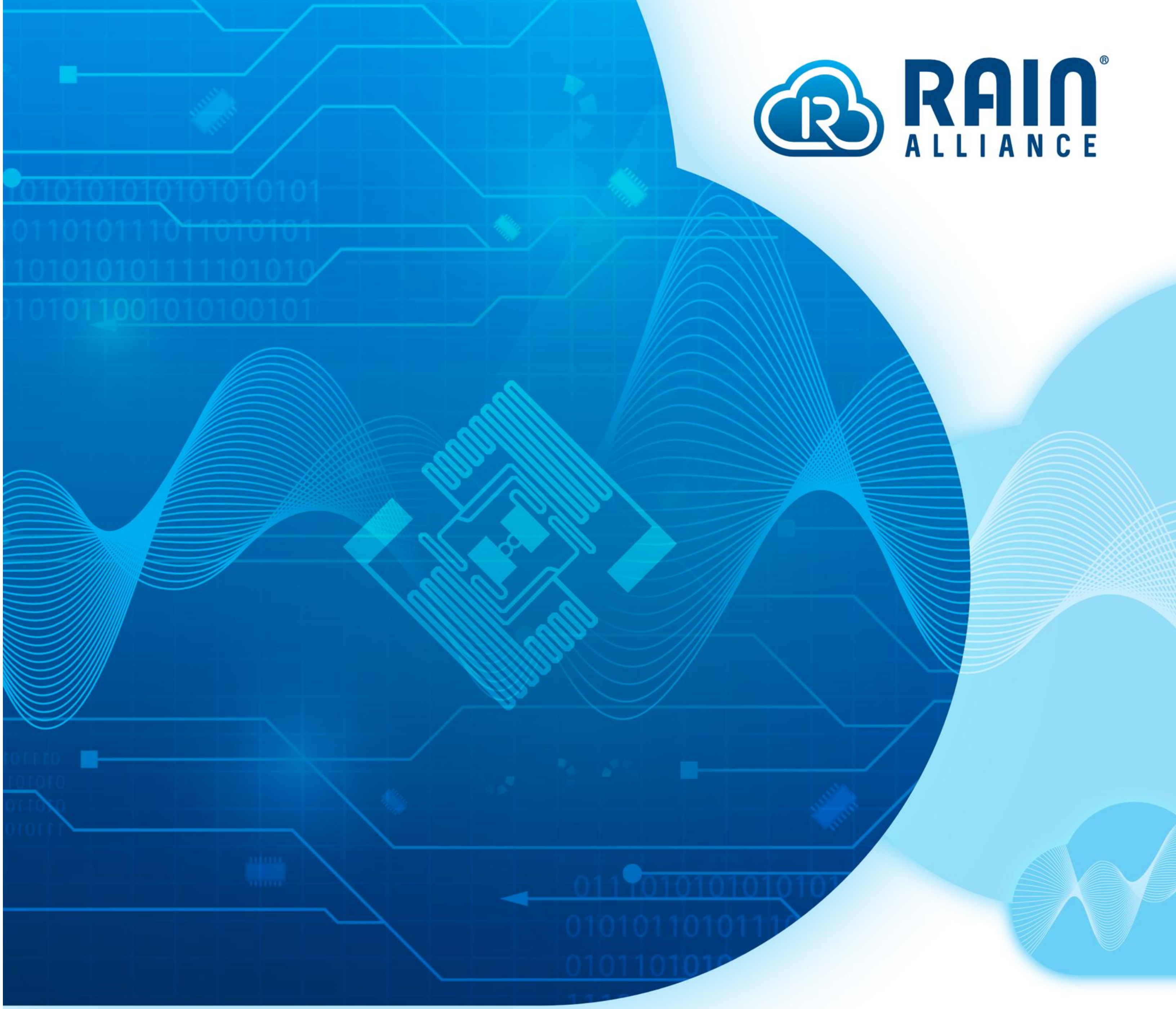


# RAIN RFID System Design Guidelines

## Air Interface and Protocol Considerations

# Table of Contents

# 1. Introduction

A RAIN RFID system (see Figure 1) comprises tagged items, tags, readers, software, and supporting network infrastructure. Effective deployments require coordinated design across these components.

The technology, standards, and ecosystem are sufficiently mature to support large-scale, global deployments.

A RAIN system is a standards-based, wireless system where the tags and readers both implement the RAIN air-interface protocol (ISO/IEC 18000-63 also known as GS1 UHF Gen2) and the tags are encoded utilizing controlled numbering practices either following applicable ISO standards or the GS1 EPC TDS. This document addresses both passive and battery-assisted passive (BAP) tags, both of which are valid RAIN implementations.

This guideline focuses on key air interface considerations that require attention during system design and deployment.


**Figure 1: RAIN RFID System Overview**

This document references two versions of the RAIN air interface protocol: Gen2v2 and Gen2v3.

Gen2v2 was published by GS1 in July 2018 and is incorporated in ISO/IEC 18000-63:2021. Gen2v3 was published by GS1 in January 2024 and is incorporated in ISO/IEC 18000-63:2026.

Gen2v3 is fully backward compatible with Gen2v2. All mandatory Gen2v2 commands remain valid and supported in Gen2v3.

Gen2v3 introduces additional commands, including *QueryX*, *QueryY*, and *ReadVar*, which improve:

- selective inventory of tag populations of interest; and
- efficient access to data stored in RAIN tags.

It also adds features that support:

- enhanced cryptographic tag functionality; and
- improved handling of low-power (“fringe”) tags that may not reliably complete a standard inventory round.

The RAIN air interface protocol is described in section 3.

# 2. Regulatory settings

## 2.1 Introduction

Radio frequency (RF) characteristics are fundamental to the correct operation and regulatory compliance of RAIN RFID systems. Regulatory requirements, including frequency bands, transmission power limits, modulation techniques, and associated operational parameters, vary by jurisdiction and shall be considered in system design and configuration.

## 2.2 Overview

Clause 2.3 introduces the country list.

Clause 2.4 defines the essential radio frequency setting.

Clause 2.5 describes in detail radio frequency settings.

Clause 2.6 discusses the European frequency bands.

Clause 2.7 provides RF recommendations.

Clause 2.8 provides the RAIN RF settings country list.

## 2.3 Country introduction

Table 7 lists the specific codes that must be applied for the various countries. The country abbreviation consists of a 2-letter country ISO 3166-1 alpha-2 code.

The code for the essential radio frequency regulations settings consists of the 2-letter country code, a digit representing the frequency range and a letter to distinguish the available options.

For countries that are not listed there is no RAIN RFID recommendation available yet. Country codes may be added in a future edition of this document.

Requests for extensions shall be addressed to RAIN RFID at https://rainrfid.org/contact-us/.

Additional information is also provided by GS1 under https://www.gs1.org/sites/default/files/docs/epc/uhf_regulations.pdf.

## 2.4 Essential radio frequency regulations settings

Table **1** defines RAIN RFID settings for UHF RFID regulations in various regions and countries. The

Table **1** headers are described in detail in Table 2. The intention of the RAIN Alliance is to limit the number of different header codes. For example, and where possible, European countries are assigned the code 'EU', American countries are assigned the code 'US'. Country code abbreviations are based on ISO 3166-1 alpha-2 codes[1].

**IMPORTANT NOTE: These tables are guidelines. Current local Regulations must be checked before enabling the RAIN Reader. Please inform the RAIN Alliance of inaccuracies and/or oversights.**

**Table 1: CODE overview for radio frequency regulations settings**

| CODE | TX-BW / kHz | TX-SP / kHz | BLF / kHz | DRM | CH-USE | REMARK |
|---|---|---|---|---|---|---|
| EU8A | 200 | 600 | 320 | Yes, M=4 | AFA | Max. 2 Werp |
| EU9B | 400 | 1200 | 640 | Yes, M=4 | AFA | Max. 4 Werp |
| US9A | 250 (500 channel width) | 500 | 256 | Yes, M=4 | FHSS | Max. 4 Weirp |
| CN9A | 250 | 500 (250 would be possible) | 256 | Yes, M=4 | FHSS | Max. 4 Weirp |
| JP9A | 200 | 1200 | 320 | Yes, M=4 | NCS | Max. 1W conducted + 6 dBi antenna, Licensed |
| JP9B | 200 (Note: 200 to 600 are allowed, but not supported by this code)[2] | 1200 / 200 | 320 | Yes, M=4 | CS | Max. 1W conducted + 6 dBi antenna, Registered |
| JP9C | 200 (Note: 200 to 1000 are allowed, but not supported by this code)[3] | 200 | 320 | Yes, M=4 | CS | Max. 250mW conducted + 3 dBi antenna, free of license |

[1] See https://en.wikipedia.org/wiki/ISO_3166-1_alpha-2#QM

[2] For other TX BW values new codes may be developed, if there is a market need

[3] For other TX BW values new codes may be developed, if there is a market need

| CODE | TX-BW / kHz | TX-SP / kHz | BLF / kHz | DRM | CH-USE | REMARK |
|---|---|---|---|---|---|---|
| | | | | | | and registration[4] |
| KR9A | 200 | 600 | 320 | Yes, M=4 | FHSS | Max. 4 Weirp |
| KR9B | 200 | 600 | 320 | Yes, M=4 | CS | Max. 4 Weirp |
| IN8A | 200 | 600 | 320 | Yes, M=4 | AFA | Max. 2 Werp |

**Table 2: Parameter description**

| PARAMETER | DESCRIPTION |
|---|---|
| CODE | Country code according ISO 3166-1 alpha-2 codes, followed by frequency band (8 for 800 MHz and 9 for 900 MHz), followed by frequency plan numbering ( A, B, C, ….) |
| TX-BW / kHz | Maximum transmit (TX) bandwidth (BW) to be used. Bandwidth definitions may be different depending on the country or region. Refer to regulations and documents. |
| TX-SP / kHz | Channel spacing between two transmit (TX) channels. Use the value defined through regulations, or if not defined by regulations, use the values in Table 1 for this parameter. |
| BLF / kHz | BLF (Backscatter Link Frequency) is defined in GS1 EPC Gen2v2 and ISO/IEC 18000-63:2021<br>A digital BLF (DBLF) is defined in GS1 EPC Gen2v3 and ISO/IEC 18000-63:2026 |
| DRM | Defines whether DRM (Dense Reader Mode) shall be applied and what M according Gen2/ISO shall be used |
| CH-USE | Channel use principle with the following abbreviations:<br>AFA Adaptive Frequency Agile<br>FHSS Frequency Hoping Spread Spectrum<br>CS Carrier Sense (or LbT – Listen before Talk)<br>NCS Non-Carrier Sense |

## 2.5 Regulatory setting details

### 2.5.1 EU8A

This setting is based on CEPT REC 70-03 and EN 302 208 for 865-868 MHz.

[4] However, when EIRP (Equivalent Isotropically Radiated Power) is less than the value of 3dBi plus 250mW of antenna power, you may fill in the gap with the antenna gain.

### 2.5.2 EU9A

This setting is based on CEPT REC 70-03 and EN 302 208 for 915-921 MHz with 3 transmit channels at 916.3 MHz, 917.5 MHz, and 918.7 MHz.

### 2.5.3 EU9B

This setting is based on CEPT REC 70-03 and EN 302 208 for 915-921 MHz with 4 transmit channels at 916.3 MHz, 917.5 MHz, 918.7 MHz, and 919.9 MHz.

### 2.5.4 US9A

This setting is based on FCC 15.247 (FCC 47CFR15.247).

Canadian Regulations are managed by Industry Canada (ISED: Innovation, Science and Economic Development). The related standard is RSS-210.

The codes for USA and Canada are the same, as the settings are equal and only the legal documents defining it are different but have the same applicable content.

### 2.5.5 CN9A

This setting is based on the current regulations for the 920-925 MHz band.

### 2.5.6 JP9A

ARIB STD-T106/107 applies. This band is 1 W licensed.

If the conducted power is less than 1 W, then the antenna gain may be more than 6 dBi to compensate for this.

### 2.5.7 JP9B

ARIB STD-T106/107 applies. This band is 1 W registered.

If the conducted power is less than 1 W, then the antenna gain may be more than 6 dBi to compensate for this.

1200 kHz channel spacing applies for the lower channels, while 200 kHz spacing applies for channels 23 and above.

### 2.5.8 JP9C

ARIB STD-T106/107 applies. This band is 250 mW.

If the conducted power is less than 250 mW, then the antenna gain may be more than 3 dBi to compensate for this.

### 2.5.9 IN8A

This setting is based on the current regulations for the 865 – 868 MHz band.

## 2.6 Lower and Upper European frequency band

In Europe, RAIN RFID (aka UHF RFID) initially operated in the 865–868 MHz frequency band. With the growth of global trade, alignment with the widely used 902–928 MHz band became increasingly advantageous, as operation in the 900 MHz range enables greater cross-jurisdictional product harmonisation.

Such harmonisation reduces the need for region-specific tag and reader variants, leading to increased economies of scale and lower manufacturing and deployment costs.

In addition, the availability of wider bandwidth and higher permitted transmission power in this range can enable improved system performance, including higher data throughput, increased robustness, and more efficient inventory operations, subject to jurisdictional regulations.

To support this, portions of the so-called "GSM gap" were made available in Europe for RAIN RFID operation, providing additional spectrum and greater flexibility for system design.

Table 3 summarizes the benefits of the upper European frequency band.

**Table 3: Comparison of lower and upper European frequency band**

| PARAMETER | LOWER BAND | UPPER BAND | BENEFITS UPPER BAND |
|---|---|---|---|
| Frequency | 865–868 MHz | 915–921 MHz | Global frequency range<br>Easier global product design |
| Reader transmit power | 2 W erp | 4 W erp | 40% more read range |
| Transmit channel width | 200 kHz | 400 kHz | Double communication speed reader → tag |
| Reader channel spacing | 600 kHz | 1200 kHz | Double communication speed tag → reader<br>Less interference |
| Number of reader transmit channels | 4<br>(2 pairs) | 3<br>(3 distant) | Less interference |
| Tag backscatter power allowance | 10 µW | 100 µW | Less challenge on reader receiver sensitivity |

# 2.7 Recommendations for radio spectrum definitions

## 2.7.1 General

The radio spectrum for RAIN RFID is defined in various countries and regions already. For those **countries looking for new spectrum** for RAIN RFID (UHF RFID) radio spectrum this section provides input and guidance.

## 2.7.2 Frequency range

**Figure 2: Global RAIN RFID radio bands overview**

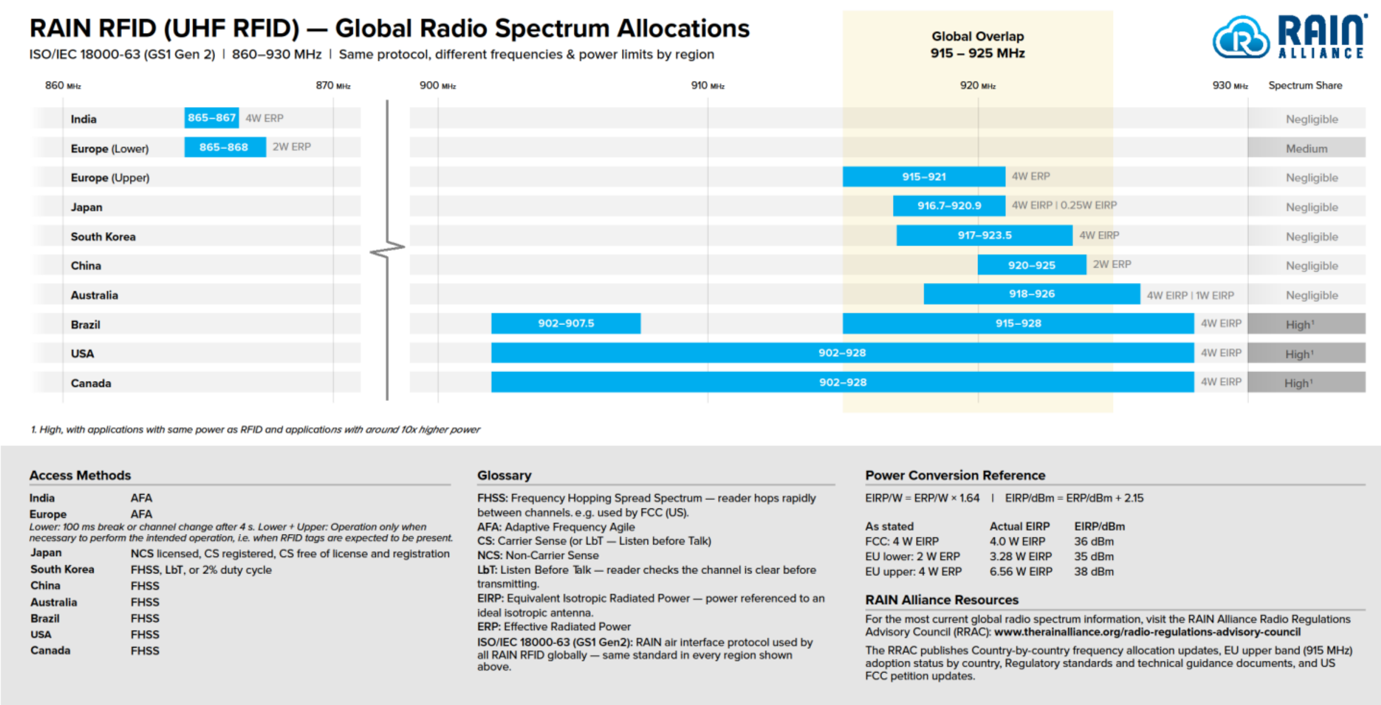



**Figure 2** shows the available radio spectrum for several countries and regions. All bands are in the 902 – 928 MHz range, with the exception of the 865 - 868 MHz band used in Europe and a few select countries in Asia.

The channel width varies accordingly to accommodate reader (forward link) and tag backscatter (return link) data rates. The RAIN Air Interface has a minimum forward link bit length of 6.25 μs, with 1/6.25 μs = 160 kHz and a maximum frequency for backscatter BLF = 640 kHz. RAIN tag thus has inputs filters that attenuate intermodulation with cut-off frequencies of at least 640 kHz. It is beneficial, if two neighbouring reader transmit channels have carrier frequencies that are set at a distance of at least 1000 kHz apart. The upper European band has a 1200 kHz distance between reader transmit frequencies. Maximum transmitter separation in the lower European band is achieved by operating readers on channels 4 and 10, and channels 7 and 13 when readers operate in a dense, close environment.

### 2.7.3 Channel use

Channel availability and use are defined by regulatory bodies where the number of channels, dwell time and channel bandwidth are specified. Channel dwell time for the US (FCC) is limited to ≤400 ms, as within 20 seconds all 50 channels need to be utilized to the same extent. For Europe (ETSI) the dwell time is limited to ≤4000 ms. Shorter channel use times shall always be allowed.

### 2.7.4 Power

The unlicensed transmit power is limited by regulatory bodies for each of the Jurisdiction. For best performance, systems are typically set to operate at the maximum allowable power limits, but some applications may require operating under lower power settings. The maximum power level is 4 Weirp (US/FCC, 36 dBm eirp), or 2 Werp (EU lower band, 33 dBm erp, which is 35.15 dBm eirp). Higher values reach up to 4 Werp (EU upper band, 36 dBm, which is 38.15 dBm eirp) for unlicensed operation. For licensed operating the power even exceeds this value significantly. For licensed use often 10 dB more are allowed.

### 2.7.5 Licensing

Licensing shall be avoided whenever possible.

### 2.7.6 Backscatter power

The tag backscatter power is very low. This is not typically limited by regulatory bodies with the exception of Europe where backscatter power is limited to -10 dBm erp to support spectrum sharing with SRD (Short Range Devices).

### 2.7.7 Mobile devices

RAIN RFID readers are used both as fixed and mobile devices. Mobile readers may be easily used across borders and therefore there is a desire to achieve radio regulation harmonization with regional trading partners.

For countries seeking advice the following recommendations as shown in Table 4 and Table 5 are given by the RAIN Alliance considering the experience with existing radio regulations for RAIN RFID.

**Table 4: Recommendations for frequencies**

| PARAMETER | RECOMMENDATION | COMMENT |
|---|---|---|
| Band | The preferred band is 900 – 930 MHz | If available, then the GSM gap from 915–921 MHz shall be used |

| PARAMETER | RECOMMENDATION | COMMENT |
|---|---|---|
| Transmit channel width Channel spacing | For ≤ 2 MHz band available:<br>200 kHz channels with 600 kHz spacing and AFA<br>For ≤ 8 MHz band available:<br>400 kHz channels with 1200 kHz spacing and AFA<br>For > 8 MHz band available:<br>500 kHz channels with FHSS | The spectrum between transmit channels shall be available for tag backscatter.<br>Recommended channel mitigation methods are AFA and FHSS, whereas channel selection shall be unrestricted.<br>CS (LbT) shall not be proposed, as the usability failed already multiple times. |

**Table 5: Recommendations for power**

| PARAMETER | RECOMMENDATION | COMMENT |
|---|---|---|
| Transmit power (radiated) | ≤4 Weirp (or ≤ 2 Werp, if definition in erp is required) | If it is required to specify conducted power and antenna gain, then the conducted power shall be at least 1 W |
| Tag backscatter | As the tag backscatter is inherent to the system no limit shall be defined | If it is imperative to define a limit, then it should be ≤ -10 dBm |

In the unavoidable case that antenna gain shall be included in the radio regulations, then only a maximum gain shall be defined, without limitation to particular antennas.

### 2.7.8 References

The regulatory documents in Table 6 shall be considered for further studies.

**Table 6: Regulatory documents**

| DOCUMENT | DESCRITPION | LINK |
|---|---|---|
| FCC Part 15 | Radio regulations USA | https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15 |
| CEPT REC 70 03 | Radio regulations Europe | https://docdb.cept.org/document/845 |
| ETSI EN 302 208 V3.3.1 | Test standard Europe | https://www.etsi.org/deliver/etsi_en/302200_302299/302208/03.03.01_60/en_302208v030301p.pdf |

### 2.7.9 Support

For support, please contact RAIN Alliance under https://rainrfid.org/contact-us/.

## 2.8 Country list

The information included in this Clause and Table 7 is believed to be correct as of publication of this document. Regulations can change at any time. Users of this information are advised to contact the country in question before making any decisions. RAIN is not liable for the accuracy of this information.

Country codes in Table 7 are a best effort, however, unofficial overview with no liability of RAIN allocations for RAIN RFID within the 860 to 960 MHz band worldwide.

All worldwide countries and shows the applicable code. "nyi" means that RAIN RFID has "not yet investigated".

NOTE: Adoption of EU9A is an ongoing effort and several updates are expected in coming years.

**Table 7: Country list**

| COUNTRY | COUNTRY | APPLICABLE CODES |
|---|---|---|
| Albania | AL | EU8A<br>EU9A |
| Algeria | DZ | --- nyi |
| Argentina | AR | --- nyi |
| Armenia | AM | --- nyi |
| Andorra | | EU8A |
| Australia | AU | --- nyi |
| Austria | AT | EU8A<br>EU9A |
| Azerbaijan | AZ | EU8A |
| Bahrain | BH | --- nyi |
| Bangladesh | BD | --- nyi |
| Belarus | BY | EU8A |
| Belgium | BE | EU8A<br>EU9A |
| Bolivia | BO | --- nyi |
| Bosnia and Herzegovina | BA | EU8A<br>EU9A |
| Botswana | BW | --- nyi |
| Brazil | BR | US9A, but smaller frequency range |
| Brunei Darussalam | BN | --- nyi |

| COUNTRY | COUNTRY | APPLICABLE CODES |
| --- | --- | --- |
| Bulgaria | BG | EU8A<br>EU9A |
| Cambodia | KH | --- nyi |
| Cameroon | CM | --- nyi |
| Canada | CA | US9A |
| Chile | CL | --- nyi |
| China | CN | CN9A |
| Colombia | CO | --- nyi |
| Congo, Rep. | CD | --- nyi |
| Costa Rica | CR | --- nyi |
| Côte d'Ivoire | CI | --- nyi |
| Croatia | HR | EU8A<br>EU9A |
| Cuba | CU | --- nyi |
| Cyprus | CY | EU8A<br>EU9A |
| Czech Republic | CZ | EU8A<br>EU9A |
| Denmark | DK | EU8A<br>EU9A |
| Dominican Republic | DO | --- nyi |
| Ecuador | EC | --- nyi |
| Egypt, Arab Rep. | EG | --- nyi |
| El Salvador | SV | --- nyi |
| Estonia | EE | EU8A<br>EU9A |
| Finland | FI | EU8A<br>EU9A |
| France | FR | EU8A<br>EU9A |
| Georgia | GE | EU9A |
| Germany | DE | EU8A |
| Ghana | GH | --- nyi |
| Greece | GR | EU8A<br>EU9A |
| Guatemala | GT | --- nyi |

| COUNTRY | COUNTRY | APPLICABLE CODES |
|---|---|---|
| Honduras | HN | --- nyi |
| Hong Kong, China | HK | --- nyi |
| Hungary | HU | EU8A<br>EU9A |
| Iceland | IS | EU8A<br>EU9A |
| India | IN | IN8A |
| Indonesia | ID | --- nyi |
| Iran, Islamic Rep. | IR | --- nyi |
| Ireland | IE | EU8A<br>EU9A |
| Israel | IL | --- nyi |
| Italy | IT | EU8A<br>EU9A |
| Jamaica | JM | --- nyi |
| Japan | JP | JP9A<br>JP9B<br>JP9C |
| Jordan | JO | --- nyi |
| Kazakhstan | KZ | --- nyi |
| Kenya | KE | --- nyi |
| Korea (DPR) | KP | --- nyi |
| Korea, Rep. | KR | --- nyi |
| Kuwait | KW | --- nyi |
| Kyrgyz Republic | KG | --- nyi |
| Latvia | LV | EU8A<br>EU9A |
| Lebanon | LB | --- nyi |
| Libya | LY | --- nyi |
| Liechtenstein | LI | EU8A<br>EU9A |
| Lithuania | LT | EU8A<br>EU9A |
| Luxembourg | LU | EU8A<br>EU9A |
| Macao, China | MO | --- nyi |

| COUNTRY | COUNTRY | APPLICABLE CODES |
|---|---|---|
| Macedonia, FYR | MK | EU8A<br>EU9A |
| Malaysia | MY | --- nyi |
| Malta | MT | EU8A<br>EU9A |
| Mauritius | MU | --- nyi |
| Mexico | MX | --- nyi |
| Moldova | MD | EU8A<br>EU9A |
| Mongolia | MN | --- nyi |
| Montenegro | ME | --- nyi |
| Monaco | | EU8A |
| Morocco | MA | EU8A |
| Netherlands | NL | EU8A |
| New Zealand | NZ | --- nyi |
| Nicaragua | NI | --- nyi |
| Nigeria | NG | --- nyi |
| Norway | NO | EU8A<br>EU9A |
| Oman | OM | --- nyi |
| Pakistan | PK | --- nyi |
| Panama | PA | --- nyi |
| Paraguay | PY | --- nyi |
| Peru | PE | --- nyi |
| Philippines | PH | --- nyi |
| Poland | PL | EU8A<br>EU9A |
| Portugal | PT | EU8A<br>EU9A |
| Romania | RO | EU8A<br>EU9A |
| Russian Federation | RU | --- nyi |
| San Marino | | EU8A |
| Saudi Arabia | SA | --- nyi |
| Senegal | SN | --- nyi |
| Serbia | RS | EU8A |

| COUNTRY | COUNTRY | APPLICABLE CODES |
|---|---|---|
| | | EU9A |
| Singapore | SG | --- nyi |
| Slovak Republic | SK | EU8A<br>EU9A |
| Slovenia | SI | EU8A<br>EU9A |
| South Africa | ZA | --- nyi |
| Spain | ES | EU8A<br>EU9A |
| Sri Lanka | LK | --- nyi |
| Sudan | SD | --- nyi |
| Sweden | SE | EU8A<br>EU9A |
| Switzerland | CH | EU8A<br>EU9A |
| Syrian Arab Rep. | SY | --- nyi |
| Taiwan | TW | --- nyi |
| Tajikistan | TJ | --- nyi |
| Tanzania | TZ | --- nyi |
| Thailand | TH | --- nyi |
| Trinidad and Tobago | TT | --- nyi |
| Tunisia | TN | --- nyi |
| Turkey | TR | EU8A<br>EU9A |
| Turkmenistan | TM | --- nyi |
| Uganda | UG | --- nyi |
| Ukraine | UA | --- nyi |
| United Arab Emirates | AE | --- nyi |
| United Kingdom | GB | EU8A<br>EU9A |
| United States | US | US9A |
| Uruguay | UY | --- nyi |
| Uzbekistan | UZ | --- nyi |
| Venezuela, RB | VE | --- nyi |
| Vietnam | VN | --- nyi |
| Yemen, Rep. | YE | --- nyi |

| COUNTRY | COUNTRY | APPLICABLE CODES |
| --- | --- | --- |
| Zimbabwe | ZW | --- nyi |

# 3. Protocol considerations

The air interface protocol defines communication between tags and readers. It is standardized by GS1 as EPC UHF Gen2 Air Interface and by ISO as ISO/IEC 18000-63.

Such a protocol defines the physical and logical requirements for a passive-backscatter, Interrogator-talks-first (ITF), radio-frequency identification (RFID) system operating in the 860 MHz – 930 MHz frequency range.

An interrogator (reader) transmits information to a tag by modulating an RF signal in the 860 MHz – 930 MHz frequency range. An interrogator receives information from a tag by transmitting a continuous-wave (CW) RF signal to the tag; the tag responds by modulating the reflection coefficient of its antenna, thereby backscattering an information signal to the interrogator. The system is ITF, meaning that a tag modulates its antenna reflection coefficient with an information signal only after being directed to do so by an interrogator.

Passive tags receive all their operating energy from the interrogator's RF signal and battery-assisted passive (BAP) tags draw their power from an external source attached to the tag.

Interrogators and tags are not required to talk simultaneously; rather, communications are half-duplex, meaning that interrogators talk and tags listen, or vice versa.

The logical interface between an Interrogator and a Tag may be viewed as the lowest level in the data link layer of a layered network communication system. The logical interface defines tag memory, flags, states, selection, inventory, and access.

An interrogator manages tag populations using three basic operations:

a) **Select**. Choosing a Tag population. An Interrogator may use a *Select* command to select one or more tags based on a value or values in tag memory, and may use a *Challenge* command to challenge one or more tags based on tag support for the desired cryptographic suite and authentication type. An interrogator may subsequently inventory and access the chosen tag(s). With Gen2v3 air interface protocol, an interrogator may also use *QueryX* command followed by zero or more *QueryY* commands to select a population of tags based on a value or values in tag memory.

b) **Inventory**. Identifying individual tags. An interrogator begins an inventory round by transmitting a *Query* command or a *QueryX* command followed by zero or more *QueryY* commands using one of four sessions to initialize an inventory round. One or more tags may reply. The interrogator detects a single tag reply and requests the tag's EPC/UII or, with

Gen2v3 the tag's TID. Inventory comprises multiple commands. An inventory round operates in one and only one session at a time.

c) **Access**. Communicating with an identified tag. The interrogator may perform a core operation such as reading, writing, locking, or killing the tag; a security-related operation such as authenticating the tag; or a file-related operation such as opening a particular file in the tag's User memory. Access comprises multiple commands. An interrogator may only access a uniquely identified tag.

Section 3.3.11 describes basic mechanisms to inventory a population of tags. It also describes way to focus only on relevant tags.

Section 3.2 describes the different Session flags that can be used for tag inventory.

Section 3.3 provides information about BAP and high sensitivity passive tags.

Section 3.4 gives some session implementation examples.

Section 3.5 provides information about the *Req_RN* command.

Section 3.6 explains the benefits of using standardized tag encodings.

Section 3.7 explains how the air interface protocol can manage a population of tags with identical EPC/UII encodings (SAMEs).

## 3.1 Tag selection and inventory

### 3.1.1 Inventory

Tag inventory operation is a process by which RFID reader can singulate tags that are surrounding its antenna and are energized. Tag inventory operation consists of multiple reader commands and tag responses allowing tags to transition from the **ready** state to **open** or **secured** state. Once a tag has been inventoried, a reader can access it using multiple commands like *Read*, *Write*, *Lock*, etc.

Gen2v2 (ISO/IEC 18000-63:2021) tag inventory operation is based on the following commands: *Query*, *QueryAdjust*, *QueryRep*, *ACK* and *NAK*. A huge number of parameters allows to control the efficiency of the tag inventory operation (speed vs. reliability). Different session flags can be used depending on the environment. The *Query* command parameters are shown in Table 8.

In Gen2v3 (ISO/IEC 18000-63:2026), tag inventory operation can be initiated by the new *QueryX* command (and optional subsequent *QueryY* commands). The *QueryX* and *QueryY* commands allows tag selection and inventory at the same time. Like Gen2v2 commands, these new commands can benefit from both session and **SL** flags. It is worth noting that *QueryX* and *QueryY* commands cannot change the value of the **SL** flag but can use it for tag selection purposes. For more information about selecting a population of tags using *QueryX* and *QueryY*, see the Overview of Gen2v3 Air Interface document published in December 2024. The *QueryX* command parameters are shown in

Table **9**.

**Table 8: Query command**

| | Command | DR | M | TRext | Sel | Session | Target | Q | CRC |
|---|---|---|---|---|---|---|---|---|---|
| # of bits | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 4 | 5 |
| description | 1000 | 0: DR=8<br>1: DR=64/3 | 00: M=1<br>01: M=2<br>10: M=4<br>11: M=8 | 0: no pilot tone<br>1: use pilot tone | 00: All<br>01: All<br>10: ~**SL**<br>11: **SL** | 00: S0<br>01: S1<br>10: S2<br>11: S3 | 0: *A*<br>1: *B* | 0–15 | CRC-5 |

**Table 9: QueryX command**

<table>
<tr><th colspan="2"></th><th># of bits</th><th colspan="4">description</th></tr>
<tr><td colspan="2">Cmd</td><td>4</td><td colspan="4">1011</td></tr>
<tr><td colspan="2">Init</td><td>1</td><td colspan="4">0: continue initializing inventory round with QueryY<br>1: complete initializing inventory round</td></tr>
<tr><td colspan="2">Session</td><td>2</td><td>00: S0</td><td>01: S1</td><td>10: S2</td><td>11: S3</td></tr>
<tr><td colspan="2">Action[2]</td><td>3</td><td colspan="4">See Table 6-31</td></tr>
<tr><td colspan="2">SelType</td><td>3</td><td colspan="4" rowspan="2">See Table 6-36</td></tr>
<tr><td colspan="2">FastMask</td><td>0 or 9</td></tr>
<tr><td colspan="2">Flx</td><td>1</td><td colspan="4">0: no flexible filter<br>1:flexible filter included</td></tr>
<tr><td rowspan="2">Flexible filter (included if <u>Flx</u>=$1_2$,</td><td>Comp</td><td>0 or 2</td><td>00: ≥</td><td>01: ≤</td><td>10: ≠</td><td>11: =</td></tr>
<tr><td>MemBank</td><td>0 or 2</td><td colspan="4">00: terminate initializing inventory round<br>01: EPC<br>10: TID<br>11: File_0</td></tr>
</table>

<table>
<tr><th colspan="2"></th><th># of bits</th><th colspan="4">description</th></tr>
<tr><td rowspan="4">excluded if Flx=$0_2$)</td><td>Pointer</td><td>0 or EBV</td><td colspan="4">Start Mask address (bit address not word address)</td></tr>
<tr><td>Length</td><td>0 or 8</td><td colspan="4">Mask length (in bits)</td></tr>
<tr><td>Mask</td><td>varia ble</td><td colspan="4">Mask value</td></tr>
<tr><td>Truncate</td><td>0 or 1</td><td colspan="4">0: disable truncation<br>1: enable truncation</td></tr>
<tr><td colspan="2">ReplyCRC</td><td>1</td><td colspan="4">0: reply with RN16<br>1: reply with RN16||CRC-5</td></tr>
<tr><td colspan="2">AckData</td><td>2</td><td colspan="4">00: terminate initializing inventory round<br>01: EPC<br>10: TID<br>11: terminate initializing inventory round</td></tr>
<tr><td colspan="2">DBLF</td><td>3</td><td colspan="4">See Table 6-9</td></tr>
<tr><td colspan="2">DR</td><td>1</td><td colspan="4">0: DR=8<br>1: DR=64/3</td></tr>
<tr><td colspan="2">M</td><td>2</td><td>00: M=1</td><td>01: M=2</td><td>10: M=4</td><td>11: M=8</td></tr>
<tr><td colspan="2">TRext</td><td>1</td><td colspan="4">0: no pilot tone<br>1: use pilot tone</td></tr>
<tr><td colspan="2">Sel</td><td>2</td><td>00: All</td><td>01: All</td><td>10: ~SL</td><td>11: SL</td></tr>
<tr><td colspan="2">Target</td><td>1</td><td colspan="4">0: A<br>1: B</td></tr>
<tr><td colspan="2">Q</td><td>4</td><td colspan="4">0–15</td></tr>
<tr><td colspan="2">CRC</td><td>16</td><td colspan="4">CRC-16</td></tr>
</table>

### 3.1.2 Tag selection

The increased adoption of RAIN RFID has increased the probability of readers being exposed to tags that applications have no interest in. These unwanted tags take up valuable times slots. It becomes a problem when reading tags of interest is critical. It lowers the reading probability of those tags of interest when reader exposure time is limited like at dock doors and conveyers.

We now have RAIN tags here, there and everywhere, and these tags can be from many different applications. This means that reader systems can no longer assume that only relevant tags are in the read-zone, nor can reader systems assume that they can even process in some limited time (imagine a conveyor belt) all the tags appearing in the read-zone.

The starting point is to make sure that your tags are encoded properly using a standards-based encoding scheme (see section 3.6). This sets up your tags to be unique and filterable based on a structured encoding.

Tag filtering can be set up at three different levels:

1. In the host application; for example, in an Inventory Management application. In other words, read all the tags, the reader reports all the tag values to the application, and then logic in the application filters for tags of interest.
2. In an "edgeware" application in the reader itself. The reader still reads all the tags, but the filtering logic runs in the reader and sorts out the tag values before passing only the relevant tag data to the application.
3. "Over the air." This means that the reader is set up to send out one or multiple *Select* commands that select activate only tags that fulfil certain criteria. The next step is for the reader to instruct the selected or unselected tags to participate in the inventory round so that the reader can capture relevant information that is encoded in the tags, including but not always limited to the unique identifiers. The filtering criteria can be set up and sent out over the air using the *Select* commands[5], or now, even as part of the inventory round directly by using the *QueryX* and *QueryY* commands introduced with GS1 Gen2v3 specifications. Note that to use the new *QueryX* and *QueryY* commands, both the reader and tag chip must support Gen2v3.

From a technical perspective, the environment might dictate using one of the other options or even some mix of the options. Here are some environmental factors to consider when selecting the best approach for filtering:

- the number of tags that are energized by the reader (tag density)
- the reader throughput (how many tags the reader can read in a set amount of time)
- the number of unwanted tags (stray tags) among the entire population of tags
- the dynamics of tags relative to the reader (how long tags remain energized, and do they remain energized while in the read-zone?)

[5] The *Select* command in Gen2v2 provides criteria that a tag shall meet in order to assert or de-assert the **SL** flag (see 3.2.5). Complex selection criteria typically require multiple Select commands.

As *Select* is a broadcast command and does not elicit a tag response, the interrogator cannot confirm that all energised tags have received and correctly applied the selection criteria. This may affect subsequent inventory performance.

- are tags entering and/or exiting the read-zone during the read operations?
- the “quality” of the read-zone (there could, for example, be a lot of metal pieces or other liquids coming and going in the read-zone. Do the tags remain sufficiently energized while in the read-zone?)

An effective strategy is to apply coarse filtering over the air to limit the number of responding tags, while deferring precise filtering to higher system layers. A simple Select command can be used to partition the population, followed by inventory of the selected subset.

Subsequent filtering is performed within the reader or host application. This approach reduces air interface load while maintaining a high probability of capturing all tags of interest.

It should be noted that the best setup is not always clear from the start. Experimentation and fine-tuning are usually needed.

## 3.2 Session flags

### 3.2.1 Overview

The RAIN RFID protocol supports five session flags, which have three different characteristics and the selection of the session flags for an application depends on:

- session persistence values,
- number of tags in system, and
- reader’s throughput (tag reads per second),

Details on the session flag characteristics are shown in Table 10.

To some extent the maximum regulatory dwell time plays a role, but even without this dwell time limit, the reader must disable RF power to switch antennas or frequency channels. In a large, static tag population the reader will always need to switch antennas or channels to provide spatial or frequency diversity in order to energize/read all tags.

**Table 10: Session flags**

| FLAG | PERSISTENCE TIME (Tag not energized) | PASSIVE TAG BEHAVIOUR ENERGIZED AND BAP[6] TAG BEHAVIOUR ABOVE SENSITIVITY THRESHOLD | PASSIVE TAG BEHAVIOUR NOT ENERGIZED | BAP TAG BEHAVIOUR BELOW SENSITIVITY THRESHOLD |
|---|---|---|---|---|
| S0 | No persistence | Value remains forever | Cleared immediately with tag power loss | Cleared when RF remains below sensitivity threshold and exceeds the RF fade control time for the tag |
| S1 | Persistence time from 0.5 – 5 seconds | Value remains for 0.5 – 5 seconds after it was set | Same behaviour as when energized | Same behaviour as when energized |
| S2, S3, SL | Persistence time of > 2 seconds | Value remains forever | Cleared at the earliest 2 seconds after tag power loss[7] | Cleared earliest 2 seconds after RF remains below sensitivity threshold and exceeds the RF fade control time for the tag |

## 3.2.2 Session flag S0

If the number of tags is small, so that all energized tags can be read prior to the maximum regulatory dwell time, then session S0 would normally work fine.

EXAMPLE: Approximately 20 tags in read zone, 100 tags per second throughput, then “number of tags / throughput” = 200 ms (milliseconds), which is less than the FCC part 15 max dwell time of 400 ms. All tags can be read in one dwell period, which is important since as soon as the reader hops

[6] Battery Assisted Passive

[7] The minimum persistence time for a certain temperature range is defined in ISO/IEC 18000-63. The actual persistence time depends on various parameters as e.g. the available RF power and certainly the temperature, where the minimum type is typically met for the upper temperature range, while it is significantly higher for room temperature and can get very long for freezing temperatures. This variation is not defined in the standard, but tag type dependent.

frequency, any tags singulated from S0 = A to B will be reset back to A when the RF energy goes away for the hop. These tags will now participate in the next S0 = A singulation round since they reset to A.[8]

COUNTER EXAMPLE: If there are 50 tags under the same conditions as above, then the reader cannot singulate all of them prior to the frequency hop. All tags reset on the hop. Thus, it is not possible to get reliable performance using S0 under FCC part 15 in these conditions. A faster reader or a longer persistence session would be required. However, S0 can be used when supporting ETSI EN 302-208 as this standard allows the channel use for up to 4 seconds dwell time.

Session S0 is particularly useful with small populations of fast-moving tags. For example, in conveyor systems or vehicle tolling. The “guarantee” that S0 will reset to A when de-energized is used to advantage to be able to reliably read tags entering the system from a powered off state.[9]

### 3.2.3 Session S1

If the number of tags is larger, so that all illuminated tags cannot be read prior to the maximum antenna RF dwell time, then session S0 will not be reliable and the reader must use one of sessions S1 through S3. These session flags maintain their state across brief periods of no RF energy. Session S1 is unique in that this flag will always return to the A state even with RF power on, with the persistence time as stated above. This can be used to advantage when the reader is able to reliably singulate all tags in the read zone from A to B state in less than 500 ms, the minimum S1 persistence time. Thus, the reader can continually singulate from A to B in session S1, knowing that no tags will return to the A state within 0.5 seconds. Again, this depends on the tag volume and reader throughput. On the other hand, the reader could use A -> B -> A singulation to get faster read rates, when the reader is able to reliably singulate all tags in the read zone from A -> B -> A in less than 500 m. However, if the tag volume divided by reader throughput is greater than 0.5 seconds, then the reader must use session S2 or S3 for reliability.

### 3.2.4 Session S2 and S3

When there is a larger number of tags than cannot be read reliably within 0.5 seconds, then the “infinite persistence” sessions S2 or S3 must be used.

Which one to use? There may be some advantage in multi-reader deployments to use a “cellular” approach to the sessions, e.g., use session S2 on one reader, then session S3 on the adjacent reader, etc., alternating between the two sessions to provide as much separation as possible between any two readers using the same session. This is because, once a tag joins an inventory round by hearing a matching *Query*, that tag will ignore spuriously heard *QueryRep* and *QueryAdjust* commands.

[8] This example does typically not apply for BAP tags

[9] This counter-example does typically not apply for BAP tags

Once inventoried, getting this large set of tags back from B to A state in session S2 or S3 can be done by inventorying them B -> A, or through select commands. Waiting for the persistence to expire is not a good approach typically, since depending on the temperature and the tag silicon, it can take a very long time for the persistence of S2 and S3 to expire. While the minimum is 2 seconds, the actual value at room temperature can be above 1 minute and even much longer for low temperatures. In general, S2 and S3 might never be assumed to be reset, when arriving in an RFID application. Power harvested from cell towers, cell phones might have provided enough power to keep S2 and S3 alive.

### 3.2.5 Session SL

The timing behaviour of **SL** flag is the same as S2 and S3. It may be used to select or unselect tags before starting a inventory round. The use of the *Select* command is a requirement to isolate from other RFID tags. For example, for baggage sorting you should only focus on baggage tag and ignore the garment tags inside the suitcase. For that reason, a select on the AFI value 0xC1 might make sense. As tags that miss the *Select* commands due to e.g. RF disturbance would be lost, it is more appropriate to not select the tags that are not intended. So, tags missing the *Select* or late arrivals could then be considered for the inventory round instead of missing them. They would then be filtered on a higher level.

**Example:**

This example described how the use of the **SL** should be used as described above, only showing the relevant command parameters:

Select on AFI <> C1

```
Select (Target=100 [SL], Action=100, MemBank=01 [UII], EBV=00011000 [18h],
Mask=00110001 [C1h], Truncate=0)
```

Query on SL==0

```
Query (Sel=10)
```

As mentioned at the beginning of this section, tags can also be selected using the Gen2v3 *QueryX* and *QueryY* commands. These commands do not manipulate the **SL** flag but can use it to perform the tag selection.

## 3.3 BAP tags and high sensitivity passive tags

### 3.3.1 BAP Tags and RF Fade Control

RF fading often occurs from multipath conditions present at the tag as it, or another object, moves within the reader's RF field. If the fade condition drops the RF field strength by a sufficient amount, passive tags will lose power and then power-up again once the fade condition is no longer present. All state and session information in the passive tag is lost due to the fade condition. BAP tags will see the RF field drop below the field detection level and then see it rise again above the detection level when the fade condition is no longer present. Since BAP tags do not lose power during the fade condition, it is possible to retain all state and session information.

RF fade control is implemented by checking the elapsed time since the RF field has dropped below the field detection level. All state and session information is retained so long as the elapsed time does not exceed RF fade control time. Once the RF fade control time has been exceeded, the BAP tag loses its state and session information in the same manner as a passive tag when it loses power. BAP tags benefit the most when having an RF fade control time that is 10 ms to 100 ms.

It shall be noted that products on the market provide a fixed RF fade control time with nominal values. Typical values available in the market are 125 μs, 1 ms, 10 ms, and 100 ms with the default being 10 ms. RF fade control is illustrated in Figure 3.

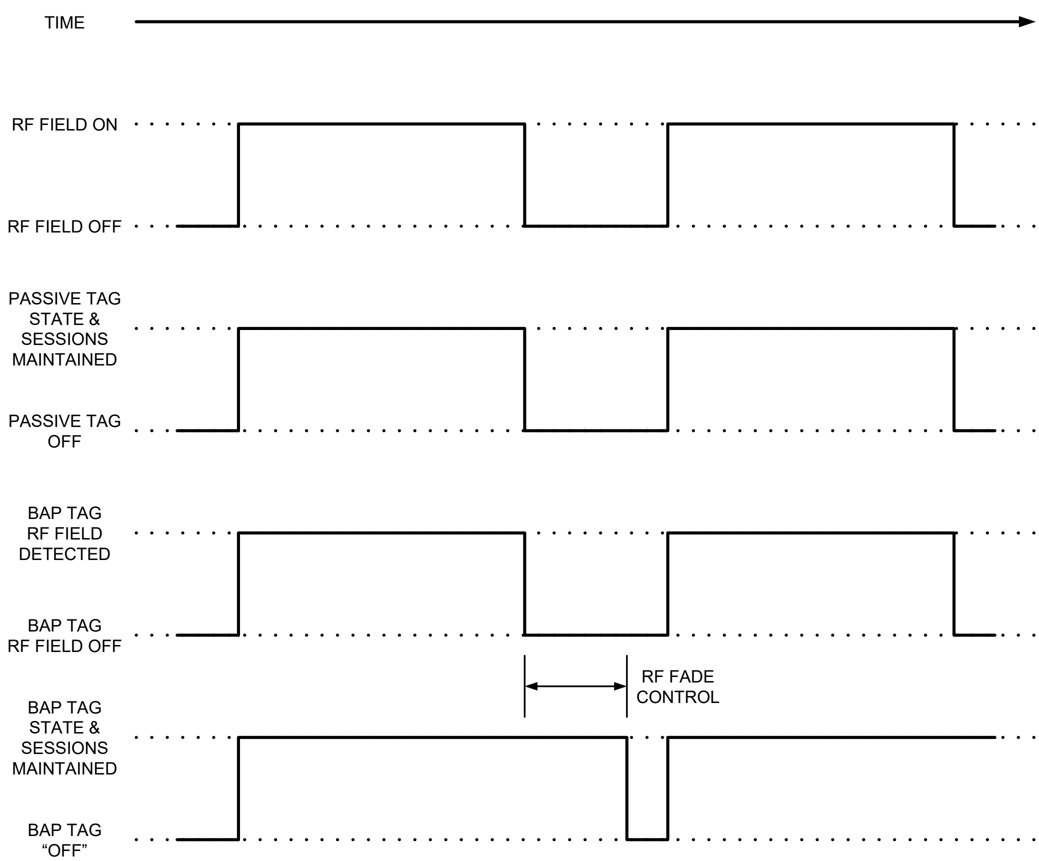



**Figure 3: RF Fade control**

### 3.3.2 Readers and BAP Tags

Readers should be aware of two aspects of BAP tags that differ from passive tags:

1. BAP tags implement RF fade control to provide some resistance to temporary nulls in the RF field. The tag maintains state and session information for some period of time after the RF field is no longer detected.
2. BAP tags typically have significantly better sensitivity than passive tags (e.g. -30 dBm for BAP versus -20 dBm for passive). Consequently, the ambient RF noise level in the environment may not be at a high enough level to power-up passive tags but possibly may affect BAP tags in that they detect the presence of an RF field. This situation results in the tag maintaining state and session information even when the reader has its RF field turned off. **(NOTE: Sensitivity for passive tags continues to improve and eventually ambient RF noise levels will affect them in the same manner as BAP tags.)**

Readers often have several operating mode configurations to support inventory of tags. These configurations obviously support passive tags because that is all that has existed until recently. The same configurations may, or may not, result in different behaviour from a BAP tag as compared to a passive tag. Ideally, readers will implement at least one operating mode configuration that supports BAP tags.

Consider the case below where a reader is performing inventory operations by continuously polling using Frequency Hopping Spread Spectrum (FHSS) operation. Only three frequency hops are shown but it could be many, many more hops.

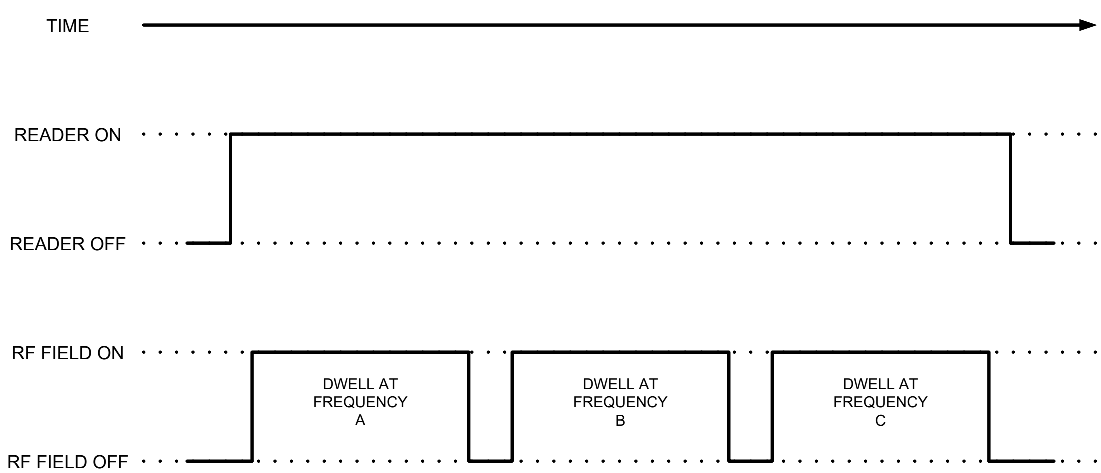



**Figure 4: Reader Continuously Polling with FHSS Operation**

The reader is turned on to begin polling and FHSS operation begins. The reader turns on the RF field and dwells at one frequency for some period of time, turns off the RF field to hop to another frequency, turns on the RF field and dwells at a different frequency for some period of time, turns off the RF field to hop to another frequency, and so on until the reader is turned off. The maximum time between frequency hops and the minimum RF off time during a hop must meet the local regulatory requirements. FCC 15.247 requires the maximum dwell time for a reader to be less than 400 ms and the RF off time between frequency hops to be at least 1 ms.

It can be seen above that the RF fade control mechanism in BAP tags must be considered. If the RF fade control time is less than the RF off time during frequency hops, then the BAP tag behaves the same as a passive tag. However, if the RF fade control time is more than the RF off time during frequency hops, then the BAP tag behaves differently from a passive tag in that it will maintain its state and session information.

Readers have two options to always ensure that BAP tags and passive tags behave in the same manner. The first option is to increase the RF off time to be longer than the RF fade control time. This may not be desirable for relatively long RF fade control times. The second option is to never assume session states due to turning the RF field off and on again. This is easily implemented in a reader by starting an inventory session using a Select command. It also has the added benefit of correctly processing tags in environments that have an ambient RF noise level above tag sensitivity levels. Two simple examples are provided to illustrate how this works.

## 3.4 Session implementation examples

### 3.4.1 Example #1

Typical inventory session in which the reader assumes all tags are powered off when RF field is off. (Bad example)

| |
|---|
| Reader is turned on. |
| RF field is turned on to start first inventory session.<br>Reader assumes all tags in field will power-up and by default set S0 inventoried flag→ A.<br>Reader issues *Query* command to inventory all tags with S0 inventoried flag = A.<br>Reader inventories tags in field using *QueryRep*/*QueryAdjust* and *ACK* commands.<br>RF field is turned off at end of inventory round. |
| RF field is turned on to start second inventory session.<br>Reader assumes all tags in field will power-up and by default set S0 inventoried flag → A.<br>Reader issues *Query* command to inventory all tags with S0 inventoried flag = A.<br>Reader inventories tags in field using *QueryRep*/*QueryAdjust* and *ACK* commands.<br>RF field is turned off at end of inventory round. |
| and so on … |
| Reader is turned off. |

### 3.4.2 Example #2

Typical inventory session in which the reader assumes nothing about the tags. (Good example)

| |
|---|
| Reader is turned on. |

| |
|---|
| RF field is turned on to start first inventory session.<br>Reader assumes nothing and issues *Select* command to have all tags in field set S0 inventoried flag → A.<br>Reader issues *Query* command to inventory all tags with S0 inventoried flag = A.<br>Reader inventories tags in field using *QueryRep*/*QueryAdjust* and *ACK* commands.<br>RF field is turned off at end of inventory round. |
| RF field is turned on to start second inventory session.<br>Reader assumes nothing and issues *Select* command to have all tags in field set S0 inventoried flag → A.<br>Reader issues *Query* command to inventory all tags with S0 inventoried flag = A.<br>Reader inventories tags in field using *QueryRep*/*QueryAdjust* and *ACK* commands.<br>RF field is turned off at end of inventory round. |
| and so on ... |
| Reader is turned off. |

The difference between the two examples is the addition of the *Select* command at the start of each inventory session in Example #2. Now, let's examine the effect this has on BAP tags and passive tags. Assume that the reader's RF off time is less than the tag's RF fade control time and that the ambient RF noise level is below the tag's sensitivity level.

**Example #1**: The first time the RF field is turned on to start the first inventory session will result in a BAP tag setting its S0 inventoried flag → A. During the first inventory session, the BAP tag will participate in the session, respond to the reader, and change its S0 inventoried flag → B. The BAP tag then maintains the session info when the RF field is turned off and then back on again. During the second inventory session, the BAP tag will not participate in the session. The BAP tag then maintains the session info when the RF field is turned off and then back on again. During all the subsequent inventory sessions, the BAP tag will not participate in the sessions. Eventually, the reader suspends all inventory sessions and the RF field is off long enough to exceed the RF fade control time and the BAP tag will no longer maintain the session info.

**Example #2**: The first time the RF field is turned on to start the first inventory session will result in a BAP tag setting its S0 inventoried flag → A. The inventory session starts with the reader using the Select command and the BAP tag will set its S0 inventoried flag → A. During the first inventory session, the BAP tag will participate in the session, respond to the reader, and change its S0 inventoried flag → B. The BAP tag then maintains the session info when the RF field is turned off and then back on again. The inventory session starts with the reader using the Select command and the BAP tag will set its S0 inventoried flag → A. During the second inventory session, the BAP tag will participate in the session, respond to the reader, and change its S0 inventoried flag → B. The BAP tag then maintains the session info when the RF field is turned off and then back on again. During all the subsequent inventory sessions, the session starts with the reader using the Select command and the BAP tag will set its S0 inventoried flag → A, the BAP tag will participate in the session, respond to the reader, and change its S0 inventoried flag → B. Eventually, the reader suspends all inventory sessions and the RF field is off long enough to exceed the RF fade control time and the BAP tag will no longer maintain the session info.

In Example #1, passive tags participate in every inventory session, but a BAP tag will only participate in the very first inventory session. In Example #2, both passive tags and BAP tags participate in every inventory session.

A variation of Example #2 is found in many readers whereby successive inventory sessions continuously alternate between the A and B states for a session flag. This is often represented by a reader as Target = AB or referred to as Dual Target.

## 3.5 Req_RN use - Advantage/Disadvantage

Earlier types of ISO/IEC 18000 used a collision arbitration where the tag replied its unique identifier (e.g., UII) and was assuming that the reader recorded the identifier. However, when there was a communication problem, the tag identifier was lost.

RAIN RFID (ISO/IEC 18000-63 / GS1 Gen2) handles this differently. During the collision arbitration, the tag backscatters a randomly chosen 16-bit word (RN16). If the reader detects RN16 (e.g., no collision with other tags), it sends an *ACK* command. The tag therefore backscatters EPC/UII[10] and transitions to the **acknowledged** state.

If a *Req_RN* command with the correct RN16 is received within a specific time ($T_{2(max)}$), then the tag transitions to the **open** or **secured** state depending on the access password value. In case the tag does not receive a *Req_RN* it transitions back to the **arbitrate** or **ready** state. In case the tag transitions to **ready** state and it joins the next collision arbitration loop and can be inventoried again.

The RAIN air interface does not require the use of the *Req_RN* command when capturing the EPC/UII. It is possible to skip the *Req_RN* command and to continue with e.g., *QueryRep* or *QueryAdjust*. The advantage is that it saves time and speeds up inventory. The first disadvantage is that tags do not transition to the **open** or **secured** state. It is therefore impossible to access a tag (e.g., reading the TID or User memory bank, locking/unlocking the tag, etc.). The second disadvantage, in case of the inventory of a huge population of tags, is that the tags participate to the next inventory round.

## 3.6 Tag encoding

RAIN technology is about Radio Frequency (RF) and Identification (ID). The RAIN air interface protocol deals with these two aspects of the technology. While it is important to understand the RF communication links between readers and tags, it is also crucial to understand how to properly encode RAIN tags and how RAIN readers report tag's responses.

[10] The tag also backscatters additional information like PC bits and optionally XPC_W1 and XPC_W2.

As described in Figure 5, RAIN tags encode much more than a globally unique identifier (EPC/UII).

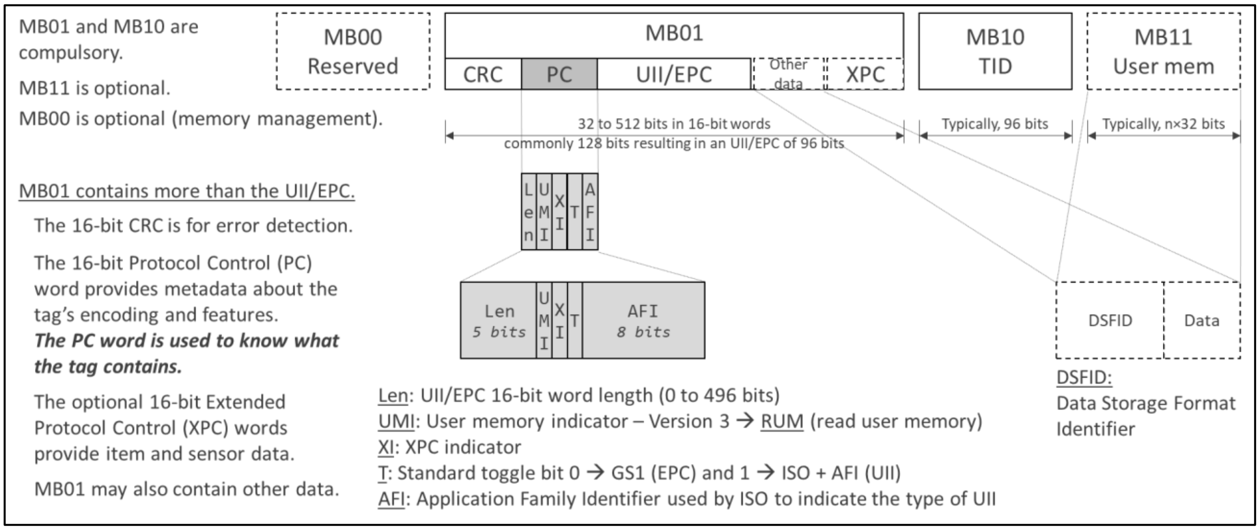



**Figure 5: RAIN tag memory map**

The four memory banks are described in the RAIN air interface protocol. The most "important" one is MB01 because its content is automatically backscattered by the tag during an inventory round and also because it encodes EPC/UII, the user-defined (globally) unique identifier. EPC/UII is either an UII (Unique Item Identifier) or an EPC (Electronic Product Code) based on the T-Bit value.

MB11, also known as "User Memory bank", is an optional memory bank (not all the tags on the market support this memory bank and its size varies from one RAIN chip to another). MB11, when present, can encode relevant data that the reader is worth capturing.

For RAIN tag encoding, the Toggle bit is key. It is encoded at memory location 0x17 of MB01. When T=$0_2$, MB01 and MB11 shall be encoded as per [GS1 EPC Tag Data Standard](#) (TDS). When T=$1_2$, MB01 and MB11 shall be encoded using AFI (Application Family Identifier) and DSFID (Data Storage Format Identifier). AFI and DSFID values and related encoding schemes are defined in ISO/IEC 15961-2 [Data Construct Register](#).

MB10 encodes the TID (Tag Identifier) as defined in [GS1 EPC Tag Data Standard](#). This identifier uniquely identifies the RAIN chip and is encoded and locked by the chip manufacturer. If MB10 can be read after the tag has been inventoried, it is worth noting that the new RAIN air interface Gen2v3 allows for the tag to backscatter MB10 instead of (but not in addition to) MB01 (see

Table **9**).

As you can see in Figure 5, MB01 encodes the PC (Protocol Control) word and optionally the extended PC words 1 and 2 (XPC_W1 and XPC_W2). As per the RAIN air interface protocol, when MB01 is backscattered during inventory, these words are included in the tag's response together with EPC/UII. This allows the reader to correctly parse the tag's response. It is worth noting that the different components of MB01 in the tag's response are not displayed in the same sequence as they are encoded in MB01. For example, when XPC_W1 is present, it is backscattered by the tag right after the PC word (before the EPC/UII) even if it is encoded after the EPC/UII (from a memory location point of view). This is described in Figure 6.

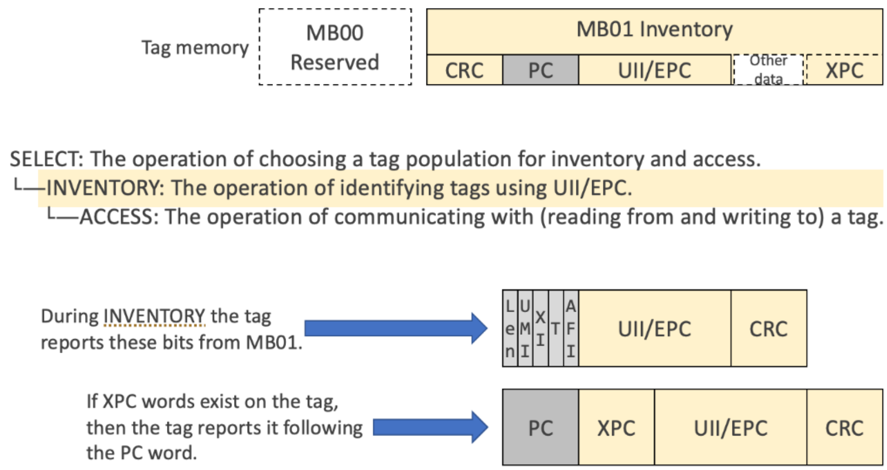



**Figure 6: Reading a tag during inventory**

Unfortunately, what the tag actually backscatters is not always properly reported by the reader as described in Figure 7.

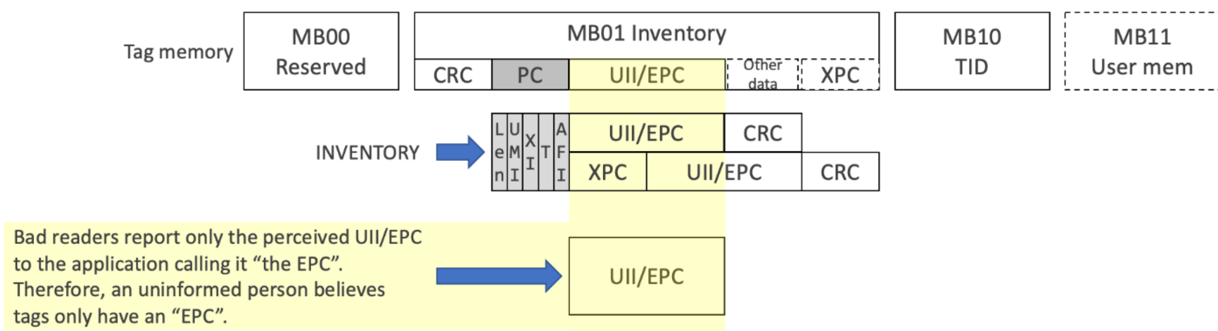



**Figure 7: Reader interface interference**

In that case, the RAIN application will improperly decode what is considered as an EPC or a UII. In order to verify that a reader correctly reports the tag's response to the application, the RAIN Alliance has created a guideline: RAIN RFID Test Procedure for RAIN Reader Tag Reporting Round Robin. This document provides multiple different tag encodings and expected reader's report.

Tag access should be done directly after a tag has been inventoried. An application should inform a reader which tags requires additional access as described in the RAIN Alliance Reader Communications Interface Guide (RCI). Gen2V3 now facilitates a tag to inform the reader that data valid data is stored in MB11. This data can be read with the Gen2V3 command *ReadVar* removing the requirement for the reader to know the length of the data. Figure 8 describes the process.

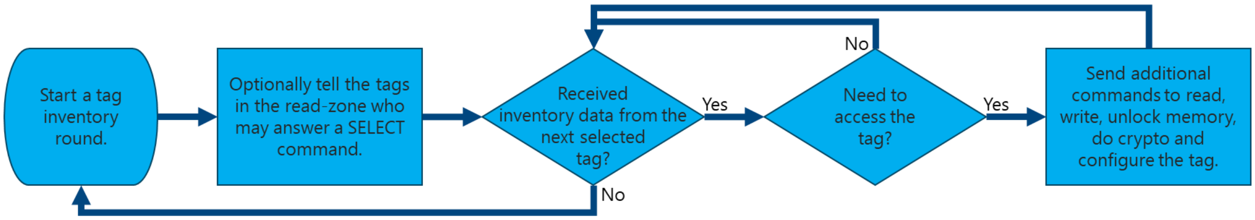



**Figure 8: Reader interface interference flowchart**

Additional information about proper tag encoding can be find at: [https://therainalliance.org/rain-alliance-tag-encoding-guide-and-specifications](https://therainalliance.org/rain-alliance-tag-encoding-guide-and-specifications).

## 3.7 Inventorying "SAMEs"

There is nothing that prevents RAIN tags to encode a same value of UII/EPC. This may be by design, to facilitate untraceability, by mistake or even maliciously. Such duplicate tags are named "SAMEs".

As explained in section 3.5 the RAIN air interface protocol is designed so that tags first backscatter RN16 and wait for the reader to send an *ACK* command (with the correct RN16) before backscattering EPC/UII.

For a given inventory round, initiated by a *Query* or a *QueryX* command, the reader can report the number of RN16 that have been captured as well as the list of EPC/UII that have been backscattered by the tags. Because tags can only backscatter EPC/UII once during an inventory round, readers can detect and report the presence of SAMEs during an inventory round.

Both RAIN Alliance RCI from version V6 and GS1 LLRP from version V2 propose mechanisms to detect SAMEs during an inventory round. Additional algorithms in the reader firmware may extend the SAMEs detection beyond a single inventory round.

When SAMEs are detected or, at least, when their presence is suspected, we need to rely on a mechanism to know how many different tags are present. One solution is to rely on the TID. TID is supposed to be globally unique because chip manufacturers ensure this uniqueness and lock the TID during the chip manufacturing process. Unfortunately, TID doesn't provide information about the object to which the RAIN tag is attached to. Therefore, we need to both capture the EPC/UII and the TID during inventory operation.

### 3.7.1 Gen2v2 approach

The Gen2v2 (ISO/IEC 18000-63:2021) air interface protocol only supports the tag to backscatter EPC/UII during inventory operation. Capturing the TID requires additional *Read* commands that can only be sent by the reader once the tag has transitioned to either **open** or **secured** state.

To do that, the reader must issue a *Req_RN* command right after the tag has entered the **acknowledged** state. It can then issue a Read command to capture the TID. Reader is able to associate the EPC/UII and the TID values. Based on the fact that TIDs are supposed to be globally unique, reader can count the exact number of SAMEs.

Once the TID has been captured, the reader can resume the inventory by issuing a *QueryRep* or *QueryAdjust* command.

### 3.7.2 Gen2v3 approach

The Gen2v3 (ISO/IEC 18000-63:2026) approach is similar to the Gen2v2 approach when initiating an inventory round with a *Query* command.

The difference is that rather than using the Read command to capture the TID, reader can use the new Gen2v3 *ReadVar* command. This command simplifies the capture of the TID because it can instruct the tag to backscatter the TID memory from address 0x00 up to the end of the last word of the TID serialization.

The Gen2v3 approach also differs from Gen2v2 because of the new Gen2v3 *QueryX* command. This command allows to instruct the tag to backscatter the TID instead of EPC/UII when replying to an *ACK* command. Once the TID has been captured, the reader can issue a *Req_RN* to transition the tag from **acknowledged** to **open** or **secured** state. The reader simply has to read the content of the EPC/UII memory bank and do the 1 to 1 association with the TID.

In case SAMEs encode some form of known values (e.g., new RAIN Alliance URI encoding that use AFI value 0xBD), it is also possible to use the *QueryX* (and potentially *QueryY*) command to only capture tags that encode a specific EPC/UII value. In that case, it is not worth capturing the EPC/UII (that is de facto known) and the reader only needs to capture the TID to resolve SAMEs.

# 4. System budget and tag backscatter

## 4.1 Introduction

There are differences in the power propagation for near and far field. The near field characteristics are complex to describe and are not covered in this document yet. The far field starts at a distance = $\frac{2L^2}{\lambda}$, where λ lambda is the wavelength and L is the maximum dimension of the test antenna. For a 30x30 cm RFID patch antenna, the far field starts approximately at 50 cm from the antenna. The far field power propagation is described through the Friis equations as follows:

*Equation 1:* $$\boldsymbol{P_{tag,read} = P_{reader,TX}\left(\frac{l}{4\pi R}\right)^2}$$

Where $P_{tag,read}$ is the radiated power at the tag position, $P_{reader,TX}$ is the power radiated by the reader antenna and $\left(\frac{\lambda}{4\pi R}\right)^2$ is the free space path loss.

*Equation 2:* $$\boldsymbol{P_{tag,read}\, G_{tag} = P_{chip,read}}$$

Where $P_{chip,read}$ is the power received by the RFID chip and $G_{tag}$ is the antenna gain of the RFID tag.

*Equation 3:* $$P_{reader,TX} = P_{reader,out}\, G_{reader}$$

Where $P_{reader,out}$ is the conducted power that feeds the reader antenna and $G_{reader}$ is the antenna gain of the RFID reader.

RAIN RFID tags were first introduced in 2006. Since then, there was major progress reducing the minimum power for tag operation. The examples in 4.2 also show that the backscatter power[11], $P_{tag,back}$, became lower and lower as well resulting in differences up to 10 dB from the early tags. Furthermore, following the Friis Formula the available power at the receiver of the reader became even lower. The link budget calculations are outlined in 4.3.

## 4.2 Examples

### Vendor A

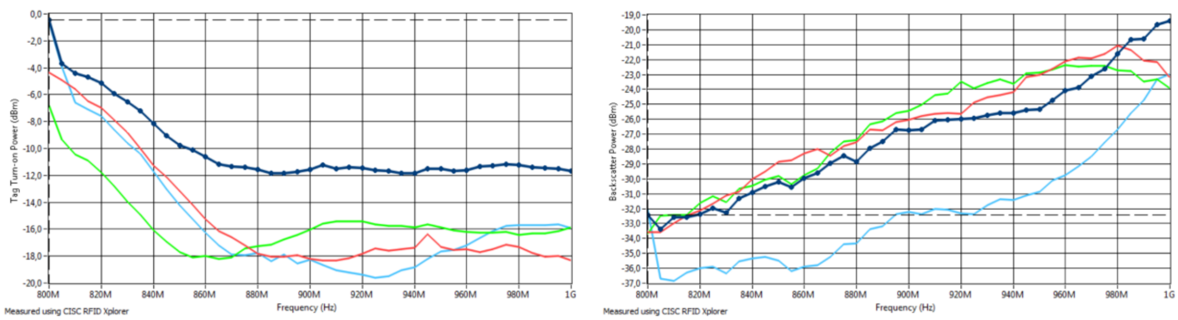
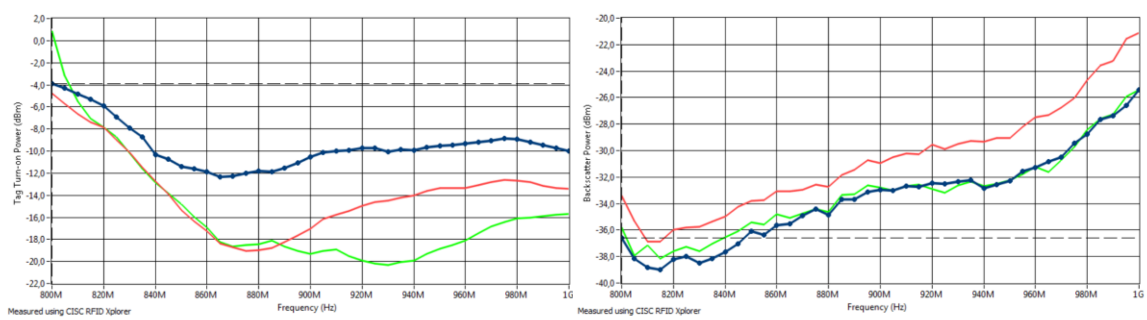



**Figure 9: $P_{tag,read}$ and $P_{tag,back}$ example A**

### Vendor B




[11] Following ISO/IEC 18046-3 the backscatter power ($P_{tag,back}$) is measured slightly above the minimum operating power ($P_{min}$) at $P_{min} + 2dB$.

**Figure 10: $P_{tag,read}$ and $P_{tag,back}$ example A**

## 4.3 Link budget calculations

The link budget calculations are done according to Figure 11, Equation 4 and Equation 5, which are derived from Equation 1, Equation 2 and Equation 3.

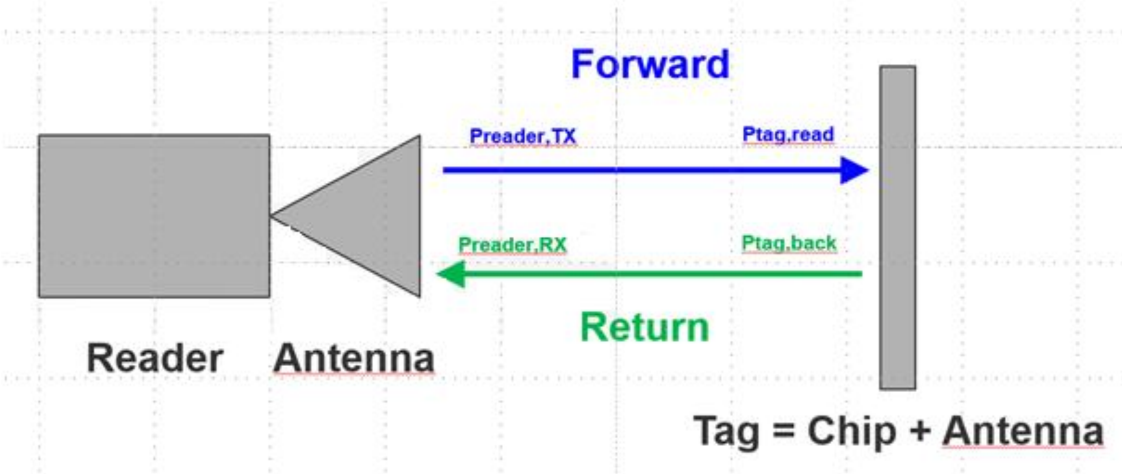



**Figure 11: RAIN RFID System budget overview**

*Equation 4:* $$R_{forward} = \frac{l}{4p}\sqrt{\frac{P_{reader,TX}}{P_{tag,read}}}$$

*Equation 5:* $$R_{return} = \frac{l}{4p}\sqrt{\frac{P_{tag,back}}{P_{reader,RX}}}$$

The impact of the reader receiver sensitivity, which gets worse with lower backscatter, can be seen in the figure below, with the following terms used:

- Reader gap is the range loss caused by the reader sensitivity limits
- Tag gap is the range loss caused by the tag minimum operating power limit

Minimum is the minimum range on forward and return link, caused by the limits of the following performance parameters:

- reader transmit power (maximum is limited by radio regulations)
- reader sensitivity (measured according to ISO/IEC 18046-2)
- tag operating power (measured according to ISO/IEC 18046-3)
- tag backscatter power (measured according to ISO/IEC 18046-3)

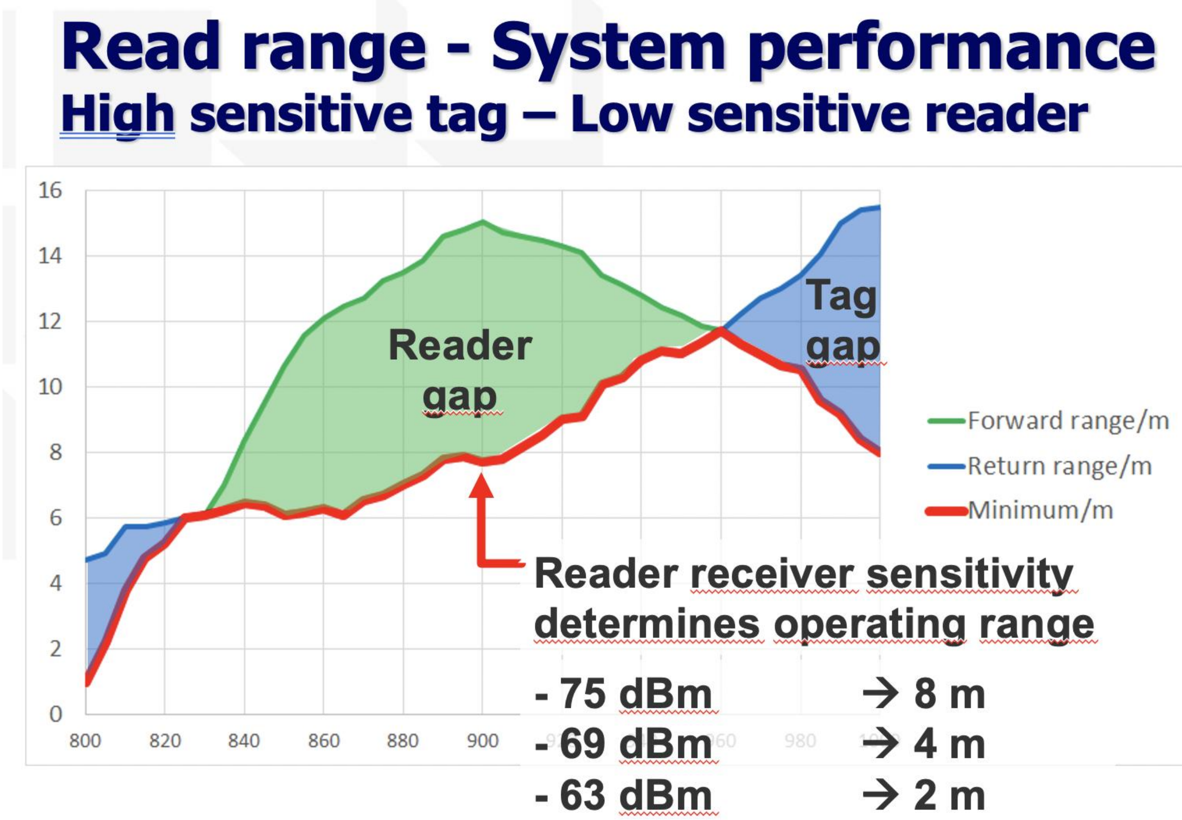



**Figure 12: RAIN RFID System limitations**

NOTE: In multi-reader environment, tags may be influenced by received commands from multiple readers as the tag is not frequency selective, which might have significant impact on the ability of the tag to respond. ISO/IEC 18046-3 clause 9.5 "Interference rejection" describes a test method for this.

# 5. Background and Contributors

This document was developed within the RAIN RFID Technical Workgroup. While frequently updated drafts were available for comment to the entire Workgroup, the following contributors played a major role in shaping the final document:

| | |
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| Don Ferguson | (Lyngsoe) |
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# 6. About the RAIN Alliance

The RAIN Alliance enables organizations to improve traceability, effectiveness, and sustainability by simplifying, standardising and accelerating the adoption of RAIN technology through global collaboration and innovation. Its global membership consists of companies and organizations which develop and deploy RAIN technology solutions across many vertical markets.

RAIN is a standards-based wireless technology that enables businesses and consumers to identify, locate and authenticate billions of items connected to the Internet of Things. RAIN technology uses the ISO/IEC 18000-63 protocol (also known as GS1 UHF Gen2).

Learn more at therainalliance.org

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**For more information, please visit therainalliance.org**