

**Draft Recommendation for
Space Data System Practices**

**SPACECRAFT ONBOARD
INTERFACE SERVICES—
RFID-BASED INVENTORY
MANAGEMENT SYSTEMS**

PROPOSED DRAFT RECOMMENDED PRACTICE

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FOREWORD

This document is a CCSDS Recommended Practice, which is the consensus result as of the date of publication of the Best Practices for inventory management systems utilizing wireless communications in support of space missions.

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PREFACE

This document is a draft CCSDS Recommended Practice. Its 'Red Book' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

DOCUMENT CONTROL

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1 INTRODUCTION

1.1 PURPOSE

This document provides recommended practices for the utilization of Radio Frequency Identification (RFID) protocol and communication standards in support of inventory management activities associated with space missions. Relevant technical background information can be found in *Wireless Network Communications Overview for Space Mission Operations* (reference [B4]).

The recommended practices contained in this report enable member agencies to select the best option(s) available for interoperable RFID-based communications in the support of inventory management applications. The specification of a Recommended Practice facilitates interoperable communications and forms the foundation for cross-support of communication systems between separate member space agencies.

1.2 SCOPE

This Recommended Practice is targeted towards passive (unpowered) RFID tags transmitting in the 860 MHz – 960 MHz Industrial, Scientific, and Medical radio frequency band. The recommended practices are applicable to both terrestrial (ground-based) and space-based automated inventory management systems utilizing only passive RFID tags.

Active RFID systems and utilization of RFID tags for precision asset localization are not covered in this Recommended Practice.

1.3 APPLICABILITY

This Recommended Practice specifies protocols that enable interoperable wireless inventory management systems that utilize RFID technologies.

NOTE – Inclusion of any specific wireless technology does not constitute any endorsement, expressed or implied, by the authors of this Recommended Practice or the agencies that supported the composition of this Recommended Practice.

1.4 RATIONALE

From an engineering standpoint, mission managers, along with engineers and developers, are faced with a plethora of wireless communication choices, both standards-based and proprietary. A CCSDS RFID-based inventory management system Recommended Practice provides guidance in the selection of systems necessary to achieve interoperable communications in support of automated inventory management.

1.5 DOCUMENT STRUCTURE

NOTE – This document is composed from a top-down (technology) perspective, first defining the technology as a recommended practice, then providing normative recommendations for specific application profiles. For more information on space mission use cases addressed by RFID technology, see annex E in reference [B4].

Section 2 provides an informational overview of the rationale and benefits of spacecraft onboard wireless inventory management technologies for use in space operations. Included are an overview and comparison of the International Organization for Standardization, ISO, and the Electronic Product Code, known as EPCglobal, standards for RFID inventory management systems. EPCglobal is a joint venture between GS1 (formerly known as EAN International) and GS1 US (formerly the Uniform Code Council, Inc.). It is an organization set up to achieve worldwide adoption and standardization of Electronic Product Code (EPC) technology

Section 3 provides a normative description for recommended practices and applicable standards relating to RFID portal-based readers and RFID hand-held readers.

Annex A provides an overview of security concerns pertaining to RFID-based inventory management systems.

Annex B is a list of informative references.

Annex C is a glossary of abbreviations and terms used in this document.

Annex D provides a table of frequency ranges for ITU Industrial, Scientific, and Medical RF Bands.

Annex E identifies radio band designations.

Annex F identifies UHF spectrum utilization for major regions.

1.6 CONVENTIONS

1.6.1 NOMENCLATURE

The following conventions apply for the normative specifications in this Recommended Practice:

- a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
- b) the word ‘should’ implies an optional, but desirable, specification;
- c) the word ‘may’ implies an optional specification;
- d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.6.2 INFORMATIVE TEXT

In the normative section of this document (section 3), informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

- Overview;
- Background;
- Rationale;
- Discussion.

1.7 ACRONYMS

A glossary of terms including common acronyms is provided in Annex C.

1.8 REFERENCES

The following documents contain provisions that, through reference in this text, constitute provisions of this Recommended Practice. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Practice are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS documents.

- [1] *EPC™ Radio-Frequency Identity Protocols—Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz - 960 MHz*. Version 1.2.0. Specification for RFID Air Interface. Brussels: GS1, October 2008.¹
- [2] *Information Technology—Radio Frequency Identification for Item Management—Part 6: Parameters for Air Interface Communications at 860 MHz to 960 MHz*. International Standard, ISO/IEC 18000-6:2010. 2nd ed. Geneva: ISO, 2010.

¹ For this issue of this Recommended Practice, only the cited edition applies.

2 OVERVIEW

2.1 GENERAL

This section provides an overview of important practical issues associated with the utilization of RFID technologies in support of inventory management systems for space missions. The following subsections present an overview of:

- rationale and benefits of RFID for space-mission inventory management;
- basic RFID nomenclature and operation;
- important applicable protocol and transmission standards;
- RF spectrum planning notes; and
- the scope of interoperability to be achieved by adherence to recommended practices specified.

The goal of specifying an RFID standard is to enable engineering projects to utilize interoperable communication protocols, potentially in agency cross-support scenarios, that are standards-based.

2.2 RATIONALE AND BENEFITS

Inventory management is a critical function in many aspects of space operations, in both flight and ground segments. On the ground, thousands of controlled components and assemblies are stored in bond rooms across multiple centers and space agencies. These inventories are tightly controlled, typically using manual processes such as paper tags on individual items or small collections of identical items, such as small bags with screws.

Other ground operations also require complex inventories, including tracking all laboratory and office equipment with significant value.

Inventory management for flight applications entails an even greater degree of control, as improperly substituted items and early depletion of certain items can be catastrophic. Most short duration missions do not involve restocking, so resupply logistics are non-existent, but initial stocking and tracking of inventories is nonetheless quite important. For most long duration missions, resupply efforts are inherently complex, expensive, and infrequent.

The utilization of RFID tagging improves inventory visibility, leading to increased situational (inventory level) awareness, a decrease in resupply mission cost, and improvement in resupply mission efficiency.

2.3 RFID NOMENCLATURE AND DEFINITIONS

An RFID system consists of readers (also termed interrogators) and tags.

An RFID reader transmits information to an RFID tag by modulating an RF signal in a defined portion of the radio spectrum. Passive RFID tags receive both energy and information from the reader-transmitted RF signal, while active RFID tags provide their own power for radio transmission. Passive RFID tags respond to the reader-originated signal by modulating the reflection coefficient of their antenna in a technique termed ‘backscatter’ to provide an encoded informational response to the reader. See table 2-1 for standard RFID tag classifications. Each RFID tag is designed to a specific protocol. The protocol defines how the tag will communicate to the outside world. Built within the protocol are features such as security (data encryption, lock abilities, etc.) and anti-collision algorithms.

Table 2-1: RFID Tag Classifications

Class	Class Name	Tag Functionality
1	Strictly Passive Surface Acoustic Wave (SAW) RFID Tags	Purely passive, containing neither a battery nor an IC chip
2	Passive IC-Based RFID Tags	Passive; incident RF energy rectified to power an IC
3	Semi-Passive Tags	Onboard battery powers some functions, but RF signal is typically backscattered from incident field
4	Active Tags	Battery-powered, longer range

The performance characteristics of tag and reader devices may vary drastically because of application factors as well as the particulars of the RF air interface (frequency, modulation, multiple access scheme, etc.). Of key concern is the matching of the various performance characteristics to the user application (reference [B5]).

2.4 RF TRANSMISSION CHARACTERISTICS

There are several different versions of RFID that operate at different radio frequencies. The choice of frequency is dependent on the requirements of the application. Four primary frequency bands that have been allocated for RFID use include (see table 2-2 for associated transmission characteristics):

- a) **Low Frequency** (125/134 KHz) – LF: Most commonly used for access control and asset tracking;

- b) **High Frequency** (13.56 MHz) – HF: Used where medium data rate and read ranges are required;
- c) **Ultra High Frequency** (860 MHz to 960 MHz) – UHF;
- d) **Microwave Frequency** (> 1 GHz).

Table 2-2: RFID Performance Characteristics in LF/HF/UHF Frequency Bands

Characteristics / Frequency	125 - 150 kHz (LF)	13.56 MHz (HF)	860 - 960 MHz (UHF)	2.45 GHz (microwave)
Antenna technology	Air coil or ferrite coil	Typically printed	Multiple	Multiple
Typical read range	< 0.5 m	1.5 m	> 5 m	> 5 m
Typical data transfer rate	< 1 kbps	25 kbps	>128 kbps	>128 kbps
Characteristics	Short-range, low data transfer rate, some penetration of water and thin metal	Higher read range, low-to-moderate data rates, attenuated by water and metals	Long range, high data transfer rate, strongly attenuated by water and metals	Long range, high data transfer rate, strongly attenuated by water and metals
Metal influence (Approximate skin depth in mm for Aluminum)	0.2 mm	20 μm	3 μm	2 μm

The choice of operational frequency has important design impacts for practical RFID use. Engineering properties of higher frequency (e.g., UHF) tags include:

- a) smaller tag antennas, typically the largest physical tag component;
- b) less diffraction / increased shadowing;
- c) shallower penetration of lossy and conductive media;
- d) higher implementation cost;
- e) potential for spatial diversity.

While lower frequency (e.g., LF) RFID system properties include:

- a) larger antennas;
- b) greater diffraction / decreased shadowing;
- c) lower implementation cost;
- d) spatial diversity limited by long wavelengths.

Since UHF can cover dock or door portals up to 3 meters wide, it has gained widespread industry support as the choice bandwidth for inventory tracking applications including pallets and cases. For item-level applications, the read range requirements are often just as long. For some item-level tagging applications, however, it can become difficult to place tags in positions to avoid liquids and metals.

2.5 RFID STANDARDS

ISO and EPCglobal represent two of the more recognized RFID standardization efforts.

From a pragmatic perspective both ISO and EPCglobal strive to produce an RFID communication and data exchange standard to enable interoperability of multi-vendor systems. Historically, communication protocol standards have almost exclusively been the domain of IEEE and ISO. The Electronic Product Code (EPC) is not an international standard approved by ISO. However, EPC has significant traction because of the familiar UPC bar codes and member clout of the EPCglobal consortium. An important observation is that the EPC deals with more than just how tags and readers communicate: EPCglobal has established and maintains network standards to govern how EPC data is shared among companies and other organizations.

Table 2-3: Summary of RFID Standards for Item Management with Frequency Bands

Frequency Band	LF 125/134.2 kHz	HF 13.36 MHz	HF 433 MHz	UHF 860-960 MHz	UHF 2.45 GHz
ISO	ISO 18000-2A ISO 18000-2B	ISO 18000-3	ISO 18000-7	ISO 18000-6A ISO 18000-6B ISO 18000-6C	ISO 18000-4
EPCglobal				Class 0 Class 1 Class 1 Gen 2	

RFID standards have been established for the HF (13.65 MHz), UHF (860-960 MHz), and Industrial, Scientific, and Medical (ISM—2.45 GHz) bands by the International Organization for Standardization under the ISO 18000 series as shown in table 2-3. For the UHF frequency band that includes the popular 860-960 MHz ISM spectrum; ISO standard 18000-6 is the governing standard. The 18000-6 standard details the parameters for how interrogators send and receive data from UHF tags. It also specifies the frequencies and channels to be used, as well as bandwidth, channel utilization, frequency-hopping specifications, and other technical details. The two earlier amendments (A and B) to the 18000-6 protocols describe specific data-encoding schemes.

The UHF standard ISO 18000-6 has been widely adopted by industry and has evolved in practice to a working system that has been made into an augmented standard by EPCglobal,

termed ‘Class 1, Generation-2’, or ‘Class 1 Gen-2’; this augmentation has been fed back into the ISO standard to become ISO 18000-6 mode C. The Class 1 Gen-2 air interface standard establishes a single UHF (860-960 MHz) specification that addresses UHF spectrum regulations in differing terrestrial regions. Thus the EPCglobal Class 1 Gen-2 document has become the de facto standard for inventory management in UHF using RFID. This process is also underway for the HF band, currently governed by ISO 18000-3.

The EPCglobal Class 1 Gen-2 is one of the most rapidly growing standards with substantial industrial deployments worldwide (see reference [1]). Interrogators operate somewhere within the 860-960 MHz band, whereas tags are required to operate over that full range. European readers typically operate in the lower part of that band, whereas U.S. readers operate in the upper part. EPC Class 1 Gen-2 utilizes passive, IC-based RFID tags. Range has been reported historically as less than 3.3 meters, although at the time of this publication, ranges in the vicinity of 6.6 meters or more are not uncommon with moderate gain (e.g., 8 dBi) interrogator antennas and approximately 1W transmit power. The EPC Class 1 Gen-2 specification forecasts future classes with advanced features such as sensor capabilities, tag-to-tag communications, and ad hoc networking.

Table 2-4 summarizes the regional (terrestrial) regulatory status for using RFID in the UHF spectrum (reference [B1]). A status of ‘OK’ implies regulations are in place or will be in place shortly; a status of ‘I/P’ implies appropriate regulations are in progress—as of August 2010—and should be completed as of August 2011. See annex F for regional UHF channel allocations covering primary international RF spectrum allocation policies.

Table 2-4: Regional Regulatory Status for Using RFID in the UHF Spectrum²

Region	Status	Frequency	Power	Protocol Technique
China	OK	840.5-844.5	2W erp	FHSS
		920.5-924.5 MHz	2W erp	FHSS
Europe	OK	865.6-867.6 MHz	2W erp	No longer use LBT* ETSI EN 302 208
Japan	OK	952-954 MHz	4W eirp	LBT (note)
North America	OK	902-928 MHz	4W eirp	FHSS
Russia	I/P	865.6-867.6 MHz	2W erp	LBT* ETSI EN 302 208
NOTE – LBT: Listen Before Talk (see reference [B2] for more information regarding LBT protocol).				

² Source: reference [B1].

2.6 EVOLUTION OF THE BOOK

This Recommended Practice addresses only RFID tag and reader interoperability in the UHF (860-960 MHz) frequency band. As space-related applications arise that cannot be fulfilled based on the recommendations of this Recommended Practice, evolution of this book will be considered. Methods to extend or adapt previous recommendations will be considered with preference over adoption of new standards, providing the resulting performance and cost are advantageous relative to those associated with adoption of one or more new standards.

3 RFID-BASED INVENTORY MANAGEMENT RECOMMENDED PRACTICE

3.1 OVERVIEW

This section presents the recommended practice of utilizing the ISO 18000-6C/EPCglobal Class 1 Gen-2 RFID communication standard for PHY/MAC interoperability. Chapter 4 provides additional information, discussion, and application profiles associated with the recommended practice.

The recommended practice pertains to RFID systems that provide stored data only, as opposed to sensor telemetry. Applications are considered where no direct active tag power is required, which necessitates short-range communication and interrogator-talk-first (ITF) protocols. (See reference [B4] for supporting technical background.)

3.2 RECOMMENDED PRACTICE

3.2.1 EPCGLOBAL CLASS 1 GENERATION-2 UHF RFID PROTOCOL

For onboard spacecraft or internal-vehicle inventory management via wireless RFID, the air interface standard shall be the EPCglobal Class 1 Generation-2 UHF RFID Protocol for communications at 860 MHz – 960 MHz (references [1] and [2]).

NOTES

- 1 In 2006, ISO approved the EPC Class 1 Gen-2 standard as an amendment to its 18000-6 standard, as ISO 18000-6C.
- 2 Level of interoperability: Specific applications may necessitate greater interoperability at the Application layer than is provided by the recommended practice. For maximum application-layer interoperability the utilization of the Low Level Reader Protocol, LLRP, described in section 5.1.1.1 is recommended.

3.2.2 RESTRICTIONS/HAZARDS

3.2.2.1 Explosive Environments

Caution should be exercised with respect to compliance with governing regulations for RF transmissions, particularly in potentially explosive environments.

3.2.2.2 RF Exposure

Also, due consideration should be given to avoid RF exposure that exceeds limits established by the local governing regulations.

3.2.2.3 RF Scattering

Consideration should be given to scattering environments characterized by small confines with highly conductive perimeters within which resonances can result in increased field levels.

NOTE – Commercially available readers based on EPCglobal C1 Gen-2 typically transmit up to one Watt RF power.

4 CONFORMANCE AND INTEROPERABILITY

The ISO 18000-6C / EPCglobal Class-1 Gen-2 protocol specification is a CCSDS adopted (recommended practice) open standard. A substantial benefit of the EPCglobal specification is the significant interoperability afforded by multi-vendor commercial uptake. The EPCglobal hardware and software certification programs enable this RFID-based interoperability. EPCglobal Class 1 Gen-2 Certification Test documents and requirements are available at [B13]. The interoperability and conformance documents are organized into three categories:

- a) Hardware Conformance Requirements;
- b) Hardware Interoperability Requirements;
- c) Software Conformance Requirements.

4.1 SCOPE OF INTEROPERABILITY AND COEXISTENCE

The goal of this Recommended Practice is to provide a specification that enables cross-agency interoperability between RFID readers (e.g., portals, hand-held scanners) and RFID tags. Adherence to the Recommended Practice does not guarantee coexistence (i.e., non-interference) of multiple RFID readers that interact with overlapping or nearby tag populations. This Recommended Practice provides guidance with respect to achieving coexistence between multiple RFID readers and tag populations.

NOTE – The level of interoperability provided by the ISO 18000-6C (EPCglobal Class 1 Gen-2) is the ability to communicate with compliant devices at the Physical (PHY—RF data transmission) and Medium Access Control (MAC—transmission framing) layers. This is commonly referred to as PHY/MAC interoperability. Importantly, while ISO 18000-6C provides PHY/MAC layer interoperability, this does **not** imply automatic Application layer interoperability.

It should be noted that the ISO 18000-6C (EPCglobal Class 1 Gen-2) has optional features that facilitate ‘multi-interrogator’ or ‘dense interrogator’ usage; that is, scenarios involving multiple interrogators with potential overlapping fields-of-view. These features are achieved by spectrally displacing the tag response from the interrogating signal; thereby reducing the likelihood that one interrogator will interfere with tag responses to a second interrogator. Such features which are optional within the ISO 18000-6C / EPCglobal Class 1 Gen-2 protocol are also considered optional with respect to the recommended practice herein.

4.2 INTEROPERABILITY

Interoperability in the RFID context is defined as the ability of two or more systems or devices to exchange information utilizing a common protocol. The GS1 EPCglobal Interoperability Certification builds on the GS1 EPCglobal hardware and software

conformance testing: devices participating in the Interoperability testing must use components that are certified for compliance. The GS1 EPCglobal Interoperability Testing [B11] demonstrates the ability of different compliance certified products to work with other compliance certified products.

4.3 CONFORMANCE

The GS1 EPCglobal Conformance Testing [B11] verifies that EPC hardware and software comply with the GS1 EPCglobal standards. Conformance is an enabler of interoperability, but being strictly conformant does not guarantee interoperability. It is important to note that are typically multiple levels of conformance associated with a standard's specification. Pragmatically, there are many business cases where it makes sense to implement only a portion (a subset) of a standard. Hence, in such a case conformance is with regard to the subset of the standard implemented and testing is pared accordingly.

NOTES

- 1 CAUTION: As with all radio frequency communication, test results are influenced by the surrounding RF environment.
- 2 CAUTION: EPCglobal Conformance only requires *one* mode of many available modes to work on a Reader or Tag. In other words, when an interoperability test is run, only tags of a *specific* mode are tested against readers that also support the *specific* mode, not arbitrary tags versus arbitrary readers. To have a Conformance certification, readers and tags don't need to support more than one mode. Therefore an arbitrary EPCGlobal UHF Class 1 Gen 2 Conforming reader may not operate with an arbitrary Conforming tag. At an application level, separate entities (e.g., space agencies) that are operating together would have to at least agree on modes to interoperate.
- 3 CAUTION: EPCglobal Conformance is regional based. Both North American conformance and European Conformance are addressed in the EPCglobal conformance documents. A reader and/or tag only needs to support a single (one) region to be considered Conforming and/or, after tests, Interoperable. Users must agree on regional choices to be "interoperable".
- 4 CAUTION: Conformance testing is at "suitable" range – that is never specified – the test range is adjusted until there's a 0 dBm signal received at the tag. There is nothing in the Conformance testing, Interoperability Testing, or Standard, to ensure a given minimum range performance.
- 5 CAUTION: Specific applications may necessitate greater interoperability at the Application layer than is provided by the recommended practice. For maximum application-layer interoperability the utilization of the Low Level Reader Protocol, LLRP, described in section 5.1.1.1 is recommended.

5 RFID INVENTORY MANAGEMENT INFORMATIONAL DISCUSSION

5.1 OVERVIEW

This INFORMATIONAL section presents typical use cases for the recommended practice of utilizing the ISO 18000-6C/EPCglobal Class 1 Gen-2 RFID communication standard for PHY/MAC interoperability. Application profiles are included for the specific cases of:

- a) handheld RFID reader for inventory audits;
- b) handheld RFID reader for localizing objects;
- c) RFID enclosures for inventory audits;
- d) portal-based RFID reader.

5.1.1 DISCUSSION – APPLICATION LAYER SUPPORT

5.1.1.1 Background - Low-level Reader Protocol

Low-Level Reader Protocol (LLRP) is an Application layer protocol standard ratified by EPCglobal in April 2007 (see references [B3] and [B12]). It is a specification for the communication interface between the reader and its controlling hardware or software. While adoption of the EPCglobal Class 1 Gen-2 UHF air interface protocol does not require adoption of the LLRP for the Application layer protocol, it does provide a convenient and complete Application layer control of the air interface protocol. It also enables third-party extensions to be added, such that third-party add-ons to the EPCglobal Class 1 Gen-2 protocol are accessible through an extended LLRP-based Application layer. The complete protocol description, necessary to generate LLRP messages, has been implemented in a number of open-source toolkits available in a variety of programming languages (C, C++, Java, Perl, C# and .NET) making implementation of the protocol on Linux, Windows, and other standard hardware platforms straightforward. Since this is the Application layer protocol adopted by EPCglobal for use with its Class 1 Gen-2 protocol, it represents the best entry-point for high-level control of the Class 1 Gen-2 protocol across a wide range of possible RFID devices based on the Class 1 Gen-2 standard.

Some LLRP parameters are referenced in this document, particularly in describing typical settings with respect to application profiles. Typically, the functionalities associated with these parameters are evident by their names, and they are useful in conveying reader configurations even when LLRP is not being utilized as the Application layer protocol.

5.1.1.2 Discussion - Typical Use-Cases

Table 5-1 summarizes several common areas of application, or use case scenarios that can leverage RFID technology to enable or facilitate automated inventory management systems for space missions. General detail regarding these use cases can be found in reference [B4]. Specific applications relating to some of these use cases can be found in 5.1.3.

Table 5-1: ‘Quick-look’ Table for Space-Related RFID Use Cases

Ground supply chain logistics (flight equipment and components)	Provide inventory management tracking for ground and flight articles utilized to support an agency activity or mission
Space vehicle supply transfers	High-accuracy tracking of supplies transferred from one vehicle to another
Equipment/consumables inventory audits	Provide automated inventory management and consumable/equipment supply levels
Localize equipment and consumables	Provide consumable/equipment localization to minimize crew-associated tasks
Pharmaceuticals supply maintenance	Provide automated inventory, localization and expiration date management for pharmaceuticals
Parts identification and association	Provide immediate recognition of multitude of parts and association to pertinent database(s)
Science sample inventory	Provide “bag and tag” capabilities to accurately identify science sample inventory and acquisition location
Disposables tracking	Provide automated inventory item decrementation

5.1.2 DISCUSSION - GENERAL CONSIDERATIONS TO PROMOTE COEXISTENCE AND INTEROPERABILITY

5.1.2.1 Overview

Use of the EPCglobal Class 1 Gen-2 standard provides a communication protocol that enables compliant RFID interrogators and tags to function. A number of interrogator and tag characteristics, particularly relating to spectrum usage and channelization, are deferred by EPCglobal Class 1 Gen-2 to regional regulations. In addition, the standard provides a number of features that are considered optional. Some of these optional provisions determine how well the RFID system will work in an environment in which multiple EPCglobal Class 1 Gen-2 readers are operating, i.e., a multi-interrogator or dense-interrogator environment. Various spectrum constraints and possible requirements for a multi-interrogator environment will vary according to the specific application, so options provided by EPCglobal Class 1 Gen-2 are also considered optional with respect to the recommendations provided herein. Some discussion on these options is contained herein.

5.1.2.2 Discussion - Frequency Hopping Spread Spectrum

Frequency Hopping Spread Spectrum (FHSS) should be utilized in accordance with one of the established plans (see reference [1]).

NOTE – Frequency Hopping Spread Spectrum (FHSS) minimizes interference by transmitting within a number of channels in a pseudo-random fashion. For EPCglobal Class 1 Gen-2 systems, FHSS is commonly utilized where regulations have allocated a large amount of bandwidth (reference [B5]). This has typically, but not exclusively, been the band from 902 to 928 MHz.

5.1.2.3 Discussion - Sessions

5.1.2.3.1 To enhance interoperability, readers that might be interrogating a common tag population should use different sessions.

NOTE – A “session” is defined as a single instance of state information maintained on a tag to carry out the inventory process in communication with a Reader. Gen 2 tags provide for up to four sessions, which allows the tag to participate in inventory with more than one reader at a time, in a time-interleaved fashion.

NOTE – Use of sessions permits multiple readers to interrogate a common tag population. For each of four sessions (S0-S3), tags have an *inventoried* flag that can be toggled between *A* or *B*. The flags are used by the interrogator to determine whether a specific tag has already been inventoried within a given session.

5.1.2.3.2 The sessions (S0-S3) should also be selected according to application since the *inventoried* flags for specific sessions are characterized by different persistence intervals and reset policies.

NOTE – For example, the inventoried flag persistence is specified for conditions in which the tag is powered and unpowered (see reference [1]). The long persistence times associated with S2 and S3 render these sessions useful for reading tag populations that are relatively stationary. Session S0 has no persistence when the tag is not energized.

5.1.2.4 Discussion - *TagPopulation* and *TagTransitTime*

TagPopulation and *TagTransitTime* are LLRP input parameters (see references [B3] and [B12]) to the reader’s singulation algorithm for establishing Q , a variable, which determines how long a tag waits before responding to an interrogator query. Specifically, Q is defined as the slot count parameter. Tags select a pseudo-random number between 0 and $2^Q - 1$, decrement the number when instructed by the interrogator, and reply to the interrogator upon reaching 0. *TagPopulation* should represent the maximum expected number of tags in the reader’s range at one time. *TagTransitTime* specifies the time in milliseconds that a tag would remain

within the reader's field-of-view. It should be noted that the EPCglobal Class 1 Gen-2 standard does not specify the variables *TagPopulation* and *TagTransitTime*; i.e., these parameters are LLRP specific, and hence a reader that is not LLRP-based might not accept these variables.

Implementations that allow some provisions for the setting of Q are preferred, as unsuitable levels of Q can result in slow read rates or excessive collisions.

5.1.2.5 Background – Listen Before Talk

Listen Before Talk (LBT) protocols require the transmitter to sense whether the transmission channel is occupied prior to transmitting. It has typically been applied where spectrum allocation is insufficient for FHSS. LBT tends to be less efficient than FHSS because of the time required for the interrogator to determine channel usage. Both FHSS and LBT can fail when the allocated band becomes sufficiently saturated (reference [B5]), although FHSS tends to degrade more gracefully.

5.1.2.6 Background – ETSI ‘4-Channel’ Plan

The European Telecommunications Institute (ETSI) ‘4-channel’ plan is based on the ETSI standard EN 302 208 (references [B6] and [B7]) and provides for an unlimited number of readers operating in four transmit channels. The tags respond within other channels in the allocated band.

5.1.2.7 Background – Interrogator Mode Selection

Interrogators can be certified for operation in single-, multiple-, and dense-interrogator modes, henceforth referred to by SI, MI, and DI modes, respectively. The modes are characterized by the prescribed channelized signaling and associated transmit masks. Comparison of functionality for different inventory management applications using different modes has not been extensively tested at the time of this release.

5.1.3 INFORMATIVE - APPLICATION PROFILES

5.1.3.1 Overview

An application profile is an explicit listing of typical reader configuration settings that might be suitable for a class of use cases or applications. Table 5-2 below lists four such application profiles and is followed by detailed descriptions of each. Settings suggested under application profiles have been tested in specific scenarios that match the stated application.

Some capabilities offered by the EPCglobal Class 1 Gen-2 standard are governed by low-level parameters. Interrogators offered by third-party providers do not always provide access

to those parameters, but instead provide indirect access through higher-level parameters. An example is the EPCglobal Class 1 Gen-2 variable Q as defined above.

Table 5-2: Generic Applications Representative of EPCglobal Class 1 Gen-2 Infrastructure

Handheld (mobile) reader for inventory audits
Handheld (mobile) reader physical item searches
RFID enclosure
Portal-based reader

NOTE – It is strongly recommended that the system configuration and EPCglobal Class 1 Gen-2 settings be tested thoroughly for any specific implementation in a relevant scattering environment.

5.1.4 APPLICATION PROFILE - HANDHELD (MOBILE) READER FOR INVENTORY AUDITS

5.1.4.1 Background

Because of the mobility of the handheld reader, potential RF interference or hazards associated with RF transmission should be considered when using this device.

NOTE – ‘Hazard’ or ‘RFI’ location tags can be used as landmarks that result in a warning issued to the user.

Use of sessions S2 or S3 is recommended provided that the inventory is largely stationary.

NOTE – Consideration should be given to potential conflicting sessions because of the mobility of the handheld reader. The longer persistence associated with the inventoried flags in these sessions prevents tags from repeatedly responding and possibly obscuring other tags.

5.1.4.2 Discussion

In the inventory audit application, the handheld, or mobile, RFID reader is used to inventory collections of tagged items in containers or on shelves. The user points the handheld antenna in the general direction of the tagged items. In order to enhance the mobility of these devices, the handheld antennas are small and are thus typically characterized with very low directivity, so precision pointing is not required. Although the reader does not require visible line of sight to the tags, tags shielded by a metallic enclosure are not likely to be read by the handheld reader unless there is sufficient electromagnetic leakage into the enclosure.

Higher read accuracies are obtained by scanning the reader antenna around the container or collection of tagged items. For this reason, it is preferable that the user has access to all sides of the container. This practice is facilitated when the tagged items are in a mobile carrier such as the Cargo Transfer Bag (CTB) used on the International Space Station. For zero-g environments, the container can be allowed to slowly rotate on an axis while the user holds the interrogator antenna in a fixed position.

In order to create an unambiguous association between read tags and a particular container, it is necessary that the items in the container and any external tags be sufficiently isolated. This can be problematic, particularly in environments supporting high degrees of scattering. RFID enclosures can be used to circumvent this problem.

Tagged items can be partitioned, or filtered, through use of the *Select* command based on tag session inventory flags, EPC, Tag ID, or user memory banks. This can accelerate inventory audits, and enhance multi-reader interoperability, by requesting only specific subsets of tags to respond. Selection can be made according to identification fields or memory contents.

Reader transmit power and antenna: The RF transmit power required for this concept of operation is typically 0.5 to 1.0 Watts. Lower transmit power can be used, but read accuracy is typically reduced. Both linear and circular polarization antennas are used with handheld readers. Handheld reader antennas with circular polarization eliminate the need for the user to scan the item with multiple orientations of the reader antenna. However, assuming use of linearly polarized tag antennas, which is typical, there is an associated performance reduction on the order of 6 dB in the signal-to-noise ratio at the receiver. Use of a linearly polarized antenna can avoid this performance loss, provided that the user scans the tagged items with a sufficient number of orientations to avoid comparable, or worse, polarization loss. For example, if the user scans at two orthogonal angles, the worst polarization loss would be roughly equivalent to the polarization loss associated with use of the circularly polarized antenna in conjunction with linearly polarized tag antennas.

Table 5-3 summarizes typical configuration parameters for the Class 1 Gen-2 RFID reader and tag protocol.

5.1.4.3 Informative - Application Profile Specification

**Table 5-3: Typical Operating Parameters for Handheld Reader Audit Use
(Class 1 Gen-2)**

Parameter	Typical Value
Mode Index (LLRP)	Dense Interrogator Settings (LLRP Mode Index 4) (note)
Antenna Gain	Typically low gain (< 2 dBi)
Transmit power	Typically 15 dBm to 30 dBm
Antenna Polarization	Linear or circular
Channel	FHSS according to plan (see reference [1])
Session	S2 or S3 for audits
Tag Population (LLRP)	60 (typical for ISS CTBs)
Tag Transit Time (ms) (LLRP)	2000 (note)
NOTE – Additional testing recommended.	

5.1.5 APPLICATION PROFILE - HANDHELD (MOBILE) READER FOR OBJECT LOCALIZATION

5.1.5.1 Background

5.1.5.1.1.1 Because of the mobility of the handheld reader, potential RF interference or hazards associated with RF transmission should be considered when using this device.

NOTE – ‘Hazard’ or ‘RFI’ location tags can be used as landmarks that result in a warning issued to the user.

5.1.5.1.1.2 Circular antenna polarization is recommended because of the time required for the user to cover search areas with two or more orientations.

NOTE – Switched or synthesized linear is potentially a suitable alternative, although at the first release of this publication, such a feature does not exist ‘off-the-shelf’.

5.1.5.1.1.3 At the time of this publication, session S1 is recommended for this application because of the short persistence times.

NOTE – Additional testing is required to confirm this. Other approaches to assure rapid, continual tag responses are possible, including

- a) selection of a unique tag followed by an interrogator *NAK* (no acknowledge) command;
- b) *Select* command to reset the inventoried flag(s); and

c) successive query commands in which the target is toggled between *A* and *B*.

5.1.5.1.1.4 Tag population should be reduced, via the *Select* command, to the minimal set required in order to minimize the response time and hence accelerate the localization.

NOTE – This set might be a single item, or it could represent a class of items.

5.1.5.2 Discussion

In this search application, the handheld, or mobile, RFID reader is used to locate missing items. It is presumed in this application that the user will employ tag partitioning, possibly to a unique tag ID, or perhaps to a class of items; e.g., on ISS a user might be interested in restricting the search to drink pouches.

Localization is enabled by a small degree of reader antenna directionality (typically a little less than hemispherical) and limited operational range. In addition, the range can be decreased to facilitate localization by reducing the transmit power. Tests indicate that restricting transmit power is typically required when searching in confined spaces that are highly reflective, since, in these scenarios, multipath can cause the apparent direction of arrival associated with tag responses to be misleading. Another approach to searching based on a mobile interrogator is to monitor the signal strength received from the sought tag.

5.1.5.3 Informative - Application Profile Specification

Table 5-4: Typical Operating Parameters for Handheld Reader Used to Locate Tagged Items (Class 1 Gen-2)

Parameter	Typical Value
Mode Index (LLRP)	Dense Interrogator Settings (LLRP Mode Index 4) (note)
Antenna Gain	Typically low gain (< 3 dBi)
Transmit power	Variable 15 dBm to 30 dBm
Antenna Polarization	Circular or possibly switched linear
Channel	FHSS according to plan (see reference [1])
Session	S1
Tag Population (LLRP)	1-60
Tag Transit Time (ms) (LLRP)	500 (note)
NOTE – Additional testing recommended.	

5.1.6 APPLICATION PROFILE - RFID ENCLOSURES

5.1.6.1 Background

In RFID enclosure application, mobile or fixed readers interrogate tags inside of a conductive enclosure (Figure 5-1).

NOTE – The enclosure should have sufficient shielding effectiveness in the EPCglobal band that only internal tags are read.

5.1.6.2 Discussion

This characteristic results in some significant advantages for this class of applications. First, because the fields are confined, higher read accuracies can be obtained with the RFID enclosures compared to scanning with a handheld reader or portal reader. Second, the location of interrogated tags is known with a high degree of certainty if the shielding effectiveness is sufficient. Third, potential RFI threats posed by the RFID reader are eliminated or greatly reduced. Fourth, coexistence of multiple users is enhanced because of containment of RF energy. Typically, the RFID enclosure will be triggered upon closure of all openings or lids.

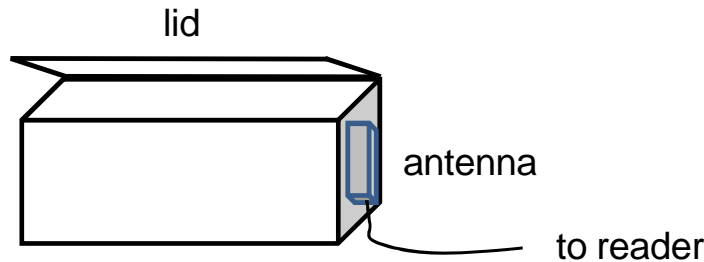


Figure 5-1: RFID Enclosure

5.1.6.3 Informative - Application Profile Specification

Table 5-5: Typical Operating Parameters for RFID Enclosures (Class 1 Gen-2)

Parameter	Typical Value
Mode Index (LLRP)	Further testing required
Antenna Gain	Low
Transmit power	15 dBm to 33 dBm
Antenna Polarization	Linear or circular
Channel	Further testing required
Session	S2 or S3
Tag Population (LLRP)	80 or more (further testing required)
Tag Transit Time (ms) (LLRP)	2,000

5.1.7 APPLICATION PROFILE - PORTAL-BASED READER

5.1.7.1 Background

Portal configurations should be tested in situ, as local scattering environments can greatly affect performance.

NOTE – Some commercial systems have recommended locations for portal antennas, and new portal technologies are entering the market frequently, including switched and synthesized polarizations.

Linear polarization is not recommended unless sufficient polarization diversity is provided because of the often-random orientations of tags with-respect-to the fixed portal antennas.

5.1.7.2 Discussion

RFID portals are used to track tagged items moving through established areas of coverage that are also referred to as the reader's field-of-view. Such coverage areas are often established in the vicinity of doorways in order to capture migration of items. Compared to interrogation with handheld readers or RFID enclosures, the range requirement between the interrogator antennas and tagged items is often greater. Furthermore, unintended scatterers, such as people, are often within the coverage area. These characteristics often render portal item-level interrogation less accurate than handheld- or enclosure-based interrogation, particularly for item-level interrogation with dense packing. Portal interrogation above item level (e.g., box, palette, or 'ziplock' levels) can be effective with read accuracies exceeding 90 percent (references [B8] and [B9]).

5.1.7.3 Informative - Application Profile Specification

Table 5-6: Typical Operating Parameters for Portal-Based Readers (Class 1 Gen-2)

Parameter	Typical Value
Mode Index (LLRP)	Dense Interrogator Settings (LLRP Mode Index 4) (note)
Antenna Gain	Medium to High
Transmit power	30 dBm
Antenna Polarization	Circular or multi-linear
Channel	FHSS according to plan (see reference [1])
Session	S1
Tag Population (LLRP)	60 or more
Tag Transit Time (ms) (LLRP)	250
NOTE – Additional testing recommended.	

ANNEX A

SECURITY CONCERNS FOR RFID SYSTEMS

(INFORMATIVE)

A1 INTRODUCTION

RFID technology is evolving rapidly, and along with the potential benefits, there are also associated certain risks. An RFID system typically comprises an RF subsystem in addition to more traditional data networks and databases, possibly in the form of an enterprise or inter-enterprise architecture. The risks and controls discussed herein focus on those that are unique to RFID technology as opposed to general information technology. Risks and controls associated with conventional network security are considered beyond the scope of this document. Much of the security terminology and description of risks and controls in this section is adopted from reference **Error! Reference source not found.** The reader is referred to reference **Error! Reference source not found.** for more in-depth treatment. The intent of this section is to summarize and discuss the primary security concerns as applied to the management and tracking of space-based inventories.

A2 RFID RISKS

A2.1 GENERAL

Identification of risks and applicable controls presented herein are taken in large part from reference **Error! Reference source not found.**, in which RFID risks are categorized as business process risks, business intelligence risks, privacy risks, and externality risks. These risks are summarized below, with some discussion on the relevance to the applications served by this book. Following summarization of the risks, controls intended to mitigate risks are discussed.

A2.2 BUSINESS RISK

Business process risk pertains to the threat to the business operations, for which RFID technology was intended to serve, when the technology is compromised. The severity of the risk depends, in part, on the criticality of the underlying business mission and its dependence upon RFID technology, and the presence and robustness of a backup system (continuity planning) should the RFID technology fail. The physical environment of the RFID technology and the existence of adversaries are also factors that characterize the business process risk.

Typically, missions involving human spaceflight are highly dependent upon adherence to timelines. Estimates of the monetary values of crew time are usually quite high. Thus minimizing time associated with conducting inventories is likely more critical for space

operations than for most terrestrial business operations. Furthermore, once the crew and ground operations personnel become accustomed to the timesavings afforded by RFID technology, less crew time will be allocated for conducting inventories. In this case, an unanticipated failure of the RFID system is likely to have significant impact on the crew schedules.

Science missions are also likely to build dependencies on RFID technology. If the crew is unable to locate items required for an experiment, thus delaying its execution, ground controllers often have to spend considerable resources rescheduling crew activities. The loss of science sample identities could also have costly impacts. Samples with lost or damaged tags could result in extreme losses if an experiment has to be repeated or is abandoned. Thus a substantial collapse of a space-based RFID inventory system could have considerable consequences on a mission. An inability to quickly locate critical on-board equipment could entail even more severe ramifications. For all of the reasons stated, a backup plan in the event of RFID failures should be established.

For space applications of RFID, the physical environment is typically a risk requiring mitigation. Exposure to extreme environments can include temperatures, vacuum, and ionizing radiation.

A2.3 BUSINESS INTELLIGENCE RISK

Business intelligence risk is typically associated with the loss of sensitive information to adversaries of the organization deploying RFID. The attributes of RFID technology that render it a valuable tool, that is, the independence from line-of-sight for automated identification capture and the ability to interrogate tags remotely, provide opportunities for espionage. Such information can be exploited in near-term exploits such as *targeting*, in which an adversary remotely identifies items worth stealing (reference **Error! Reference source not found.**). Or, monitored tag interrogations can permit data accumulation over an extended time by adversaries in order to discern business practices or proprietary methods, such as dependence on a specific type of item or combination of ingredients.

Factors affecting business intelligence risks include (reference **Error! Reference source not found.**): the existence of adversaries, the relevance of information available to the adversary, and the location of RFID components. Of paramount importance is the type of data stored on the tag; that is, whether the tag stores identifiers or indices into a database or actual information such as personal records or sensor data.

Although business intelligence risks do not seem as relevant to space-based inventory management as business process risks, there are some examples of such risks. For example, some space-based experiments produce data that is considered sensitive or proprietary to a sponsoring commercial or academic institution. Similarly, ingredients or equipment used to enact such an experiment might be considered sensitive or proprietary. Furthermore, as joint agency-commercial space endeavors continue to increase, these types of risks will also require greater consideration. Thus when these types of items are tracked with RFID systems, associated risks should be gauged and mitigated by proper controls when necessary.

Adversarial threats, whether to business process or business intelligence, are more likely to occur on the ground than on the vehicle. Possibilities of damage, both intentional and accidental, to tagged items during transport should be considered. Adversaries seeking publicity or action against a government or agency might try to kill or reprogram tags. Tag commands issued by airport or shipping crews could likewise impact item tags without intent. Adversarial threats could also occur with the downlink of tag data in spacecraft telemetry if the link is not properly secured, or if unencrypted data is disseminated beyond the authorized receivers.

A2.4 PRIVACY RISK

Privacy risks pertain to information gleaned from tags that are in some way associated with an individual. For example, information might be read from a tagged prescription bottle that reveals a medical condition associated with the carrier. Consequences can be legal action for violation of privacy laws or a consumer or constituent backlash when it is perceived that a trust is breached, even when no laws were broken. Typically, personal information is segregated as ‘personally identifiable’ or ‘non-personally identifiable’ according to whether the subject information is sufficient to designate or contact a specific individual. Laws in many countries regulate how personally identifiable information is managed. The type of data stored on the tags is again a major factor in the level of risk.

For applications served by this document, it is likely that the privacy risks are largely or wholly oriented to the crew. Care must be exercised to ensure that RFID data associated with specific crewmembers is available only to individuals authorized to receive that data. For example, tagged medical samples are likely to be subject to laws protecting privacy. As with business process and business intelligence, privacy must be safeguarded when certain RFID data is downlinked or disseminated, or when returned science sample tags carry data subject to privacy laws.

A2.5 EXTERNALITY RISK

Externality risks describe the inadvertent undesirable effects of an RFID system on other systems. The main externality risk for the RF subsystem is hazards resulting from electromagnetic radiation, which could range from adverse health effects to ignition of a combustible material (reference [B10]). The reader is referred to 3.2.2 ‘Restrictions/Hazards’. Commercial RFID tags often are manufactured from low-cost materials and rely on low-cost adhesives in order for viability of the technology. Out-gassing of these materials constitutes an externality risk relevant to confines with closed-loop ventilation, such as spacecraft.

A3 RFID SECURITY CONTROLS

This subsection describes security controls to mitigate risks described above. As in the preceding subsection, treatment pertains to the RFID sub-system, and security controls

associated with general IT are considered out-of-scope. As in reference [B10], controls are categorized as belonging to management, operational, and technical. These are summarized briefly below, along with considerations pertaining especially to space-based RFID systems.

Management controls involve the oversight of the security of the RFID system, including the enactment and enforcement of policies involving RFID security. Management controls include RFID usage policy, IT security policies, agreements with external organizations, and minimization of sensitive data stored on tags (reference [B10]).

Operational controls regulate the daily use of RFID systems, and include personnel limitation on physical access to RFID systems, placement to reduce electromagnetic interference and radio frequency interference, regulation of the RF component thermal environment, destruction of tags that have served their function, and proper training of personnel. A redundant inventory tracking method is considered an important operational control for most space-based inventory applications.

Separation of duties is an operational control in which no single individual has sole oversight over an entire RFID system, or a significant subsection thereof. This mitigates risks associated with disgruntled employees as well as risks stemming from human error.

Other operational controls include proper training of personnel, proper use of labels and notices, proper disposal of tags, and non-revealing identifier formats.

Technical RFID security controls include those that (reference [B10]):

- a) provide authentication and integrity services to RFID components and transactions;
- b) protect RF communication between reader and tag; and
- c) protect the integrity of the tag data.

Authentication and integrity services are typically more limited for RFID subsystems than general IT because of tight restrictions on the tag with respect to power consumption and memory capacity, especially for passive tag RFID subsystems. The most common techniques for the RFID subsystems are passwords, keyed Hash Message Authentication Codes (HMAC), and digital signatures. Primary objectives of the authentication technology can include:

- a) prevention of unauthorized reading from or writing to a tag;
- b) detection of tag cloning; and
- c) tag data integrity protection.

A summary of these methods, including strengths and weaknesses, is included in reference [B10]. At the time of this publication release, only password authentication is practical for the recommended practice of section 3. The ISO 18000-6C/EPCglobal Class 1 Gen-2 RFID communication standard provides for separate 32-bit *kill* and *access* passwords. The *kill* password irrevocably terminates all functionality of the tag. It can only be invoked

if a non-zero password is set and presented prior to issuance of the command. If an access password is set, it must be presented to the tag in order to lock or alter any of the tag's memory banks, including identification, password, and user memory banks. It is also required for the *permalock* command, which permanently locks the memory banks.

Use of password authentication is highly recommended, as intentional or unintentional impairment or destruction of tags might otherwise result. However, assigning arbitrarily unique passwords to each tag is typically impractical.

A number of technical controls can provide security for the RF communication to the tag, including cover-coding, data encryption, shielding, frequency designation, and selective (e.g., periodic or event-driven) use of RF subsystems. Summarizations of these controls are provided in (reference [B10]). For most space-based RFID systems, the RF reader-tag communication link enjoys a high degree of isolation and shielding from adversarial threats once launched. Technologies such as RFID enclosures provide additional degrees of shielding.

Tag data protection controls include tag memory access control, encrypting tag data, the *kill* feature, and tamper protection. Tags that are *frangible*, typically implemented by antennas that are destroyed when a tag is removed from an item, provide tamper protection.

Radio Frequency Identification Systems (RFIS) systems engineers should thoroughly assess all risks and provide mitigation required to reduce the risks to acceptable levels. Table 5-1 in reference [B10] provides a convenient table listing controls and the risks that they mitigate.

ANNEX B

INFORMATIVE REFERENCES

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- [B10] Tom Karygiannis, et al. *Guidelines for Securing Radio Frequency Identification (RFID) Systems*. National Institute of Standards and Technology Special Publication 800-98. Gaithersburg, Maryland: NIST, April 2007.
- [B11] GS1 EPCglobal Certification Program <http://www.gs1.org/epcglobal/implementation>
- [B12] LLRP Toolkit; <http://www.llrp.org>
- [B13] GS1 Certification Test Requirements;
http://www.gs1.org/epcglobal/certification/cert_con

ANNEX C

GLOSSARY & ACRONYMS

(INFORMATIVE)

C1 ABBREVIATIONS

CCSDS	Consultative Committee for Space Data Systems
CTB	Cargo Transfer Bag
DI	dense-interrogator
EPC	Electronic Product Code
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific, and Medical
ISO	International Organization for Standardization
LBT	Listen Before Talk
LLRP	Low Level Reader Protocol
MAC	Media Access Control
MI	multiple-interrogator
PHY	Physical (layer)
RF	Radio Frequency
RFID	Radio Frequency Identification
RFIS	Radio Frequency Identification Systems
SAW	Surface Acoustic Wave
SI	single-interrogator

C2 TERMS

active tag: a type of RFID tag that contains an internal power source, and in some cases also a radio transceiver. These additional component(s) are used to enhance the effective read / write range, and rate of data transfer characteristics of the RFID tag. This type of integrated tag circuit is usually of a complex design with many components. Active tags can be read over greater distances than passive tags.

ad hoc: a network typically created in a spontaneous manner. An ad hoc network requires no formal infrastructure and is limited in temporal and spatial extent

antenna: a device for sending or receiving electromagnetic waves.

anti-collision: a feature of RFID systems that enables a batch of tags to be read in one reader field by preventing the radio waves from interfering with one another.

backscatter: a method of returning a tag's identification that involves selective reflection of the incident electromagnetic wave.

bandwidth: the difference in Hertz between the upper and lower limiting frequencies of a spectrum.

Class 1 Gen-2: the second-generation global protocol operating in the UHF (ultra high frequency) range.

coexistence: the capability of a wireless network to operate properly in an environment in which noise and interference are present, e.g., a state in which two or more RF systems function within an acceptable level of mutual interference.

collision: interference caused when more than one RFID tag sends back signals to the reader at the same time.

collision: radio signals interfering with one another. Signals from tags and readers can collide.

Electronic Product Code (EPC): a standard format for a 96-bit code that was developed by the Auto-ID Center. It is designed to enable identification of products down to the unique item level. EPCs have memory allocated for the product manufacturer, product category and the individual item. The benefit of EPCs over traditional bar codes is their ability to be read without line of sight and their ability to track down to the individual item versus at the SKU level.

EPCglobal: the association of companies that are working together to set standards for RFID in the retail supply chain. EPCglobal is a joint venture between EAN International and the Uniform Code Council, Inc.

frequency: the radio wave transmission rate of oscillation, measured in cycles per second (Hz). Frequencies allocated for RFID use exist in the low, high, ultra-high, and microwave frequency bands.

interference: unintended RF energy present in the operating frequency band of a system resulting in performance degradation to the intended communications link.

interrogator: a device that is used to read and or write data to RFID tags.

line-of-sight: a tag or bar code characteristic that requires an item to be ‘seen’ to be automatically read or identified by a machine.

network: a connected, potentially routable and multi-hop, communication infrastructure for data transmission between multiple communication nodes.

passive RFID tag: an RFID tag that does not use a battery.

portal: a defined physical area of RF signal coverage; an RF field of view.

read range: the distance from which a reader can communicate with a tag.

reader: an interrogator. The RFID reader communicates via radio waves with the RFID tag and passes information in digital form to the computer system.

read-only tags: tags that contain data that cannot be changed. Read-only chips are less expensive than read-write chips.

read-write tags: RFID chips that can be read and written multiple times.

RF: the radio frequency segment of the electromagnetic spectrum, from 3 Hz to 300 GHz.

RFID transponder: a microchip that is attached to an antenna and communicates with a reader via radio waves; an RFID tag. RFID tags contain serial numbers that are encoded, allowing them to be uniquely identified. RFID tags vary widely in design. They may operate at one of several frequency bands, may be active or passive, and may be read-only or read-write.

singulation: a method by which an RFID reader identifies a tag with a specific serial number from a number of tags in its field.

spread spectrum: a technique in which the information in a signal is spread over a wider bandwidth using a spreading code.

tag: an RFID transponder.

transponder: (see RFID transponder).

ANNEX D

ITU INDUSTRIAL, SCIENTIFIC, AND MEDICAL BANDS

(INFORMATIVE)

Table D-1: ITU Industrial, Scientific, and Medical RF Bands

Frequency Range*	Center Frequency
6.765 - 6.795 MHz	6.780 MHz
13.553 - 13.567 MHz	13.560 MHz
26.957 - 27.283 MHz	27.120 MHz
40.66 - 40.70 MHz	40.68 MHz
433.05 - 434.79 MHz	433.92 MHz
902 - 928 MHz	915 MHz
2.400 - 2.480 GHz	2.450 GHz
5.725 - 5.875 GHz	5.800 GHz
24 - 24.25 GHz	24.125 GHz
61 - 61.5 GHz	61.25 GHz
122 - 123 GHz	122.5 GHz
244 - 246 GHz	245 GHz

* Wireless networking communications equipment use of ISM bands is on a non-interference basis (NIB).

ANNEX E

RADIO BAND DESIGNATIONS

(INFORMATIVE)

Table E-1: NATO or Electronic Warfare (EW) RF Band Designations

Radar Designation	ITU Designation	IEEE Designation	Wireless Bands
HF 3-30MHz	HF 3-30MHz	A 0-250MHz	
Not designated	VHF 30-300MHz	B 250-500MHz	
P 216-450MHz	UHF 300-3000MHz	C 500 – 1000MHz	802.15.4
Not designated		D 1-2GHz	
L 1-2GHz		E 3-3GHz	802.11b, 802.11g, 802.11n 802.15.1, Bluetooth, 802.15.4
S 3-4GHz	SHF 3-30GHz	F 3-4GHz	
C 3-8GHz		G 3-6GHz	802.11a, 802.11k
X 8-12.4GHz		H 6-8GHz	
J / Ku 12.4 –18GHz		I 8-10GHz	
K 18-26.5GHz		J 10-20GHz	
Q / Ka 26.5 - 40GHz		K 20-40GHz	
	EHF 30-300GHz		

Table E-2: IEEE Std. (521-2002) Letter Designations for Radar Frequency Bands

International table				
Band designation	Nominal frequency range	Specific frequency range for radar based on ITU assignments (see Notes 1, 2)		
		Region 1	Region 2	Region 3
HF	3-30 MHz	(Note 3)		
VHF	30-300 MHz	None	138-144 MHz 216-225 MHz (See Note 4)	223-230 MHz
UHF	300-1000 MHz (Note 5)	420-450 MHz (Note 4) 890-942 MHz (Note 6)		
L	1-2 GHz	1215-1400 MHz		
S	2-4 GHz	2300-2500 MHz		
		2700-3600 MHz	2700-3700 MHz	
C	4-8 GHz	4200-4400 MHz (Note 7)		
		5250-5850 MHz	5250-5925 MHz	
X	8-12 GHz	8.5-10.68 GHz		
Ku	12-18 GHz	13.4-14 GHz		
		15.7-17.7 GHz		
K	18-27 GHz	24.05-24.25 GHz	24.05-24.25 GHz 24.65-24.75 GHz (Note 8)	24.05-24.25 GHz
Ka	27-40 GHz	33.4-36 GHz		
V	40-75 GHz	59-64 GHz		
W	75-110 GHz	76-81 GHz		
		92-100 GHz		
mm (Note 9)	110-300 GHz	126-142 GHz		
		144-149 GHz		
		231-235 GHz 238-248 GHz (Note 10)		

NOTES

- 1 These international ITU frequency allocations are from the table contained in Article S5 of the *ITU Radio Regulations*, 1998 Edition. The ITU defines no specific service for radar, and the frequency assignments listed are derived from those radio services that use radiolocation. The frequency allocations listed include those for both *primary* and *secondary* service. The listing of frequency assignments are included for reference only and are subject to change.
- 2 The specific frequency ranges for radiolocation are listed in the NTIA Manual of Regulations & Procedures for Federal Radio Frequency Management, section 4. The NTIA manual (known as the Redbook) can be downloaded from the website: <http://www.ntia.doc.gov/osmhome/redbook/redbook.html>.

- 3 There are no official ITU radiolocation bands at HF. So-called HF radars might operate anywhere from just above the broadcast band (1.605 MHz) to 40 MHz or higher.
- 4 Frequencies from 216 – 450 MHz were sometimes called *P-band*.
- 5 The official ITU designation for the ultra high frequency band extends to 3000 MHz. In radar practice, however, the upper limit is usually taken as 1000 MHz. L- and S-bands being used to describe the higher UHF region.
- 6 Sometimes included in L-band.
- 7 Designated for aeronautical navigation, this band is reserved (with few exceptions) exclusively for airborne radar altimeters.
- 8 The frequency range of 24.65 – 24.76 GHz includes satellite radiolocation (earth to space only).
- 9 The designation mm is derived from *millimeter* wave radar, and is also used to refer to V- and W-bands, and part of Ka-band, when general information relating to the region above 30 GHz is to be conveyed.
- 10 No ITU allocations are listed for frequencies above 275 GHz.

Table E-3: Comparison of Radar-Frequency Letter Band Nomenclature

Radar letter designation	Frequency range	Frequency range	Band No.	Adjectival band designation	Corresponding metric designation
HF	3-30 MHz	3-30MHz	7	High frequency (HF)	Dekametric waves
VHF	30-300 MHz	30-300 MHz	8	Very high frequency (VHF)	Metric waves
UHF	300-1000 MHz	0.3-3 GHz	9	Ultra high frequency (UHF)	Decimetric waves
L	1-2 GHz				
S	2-4 GHz				
C	4-8 GHz	3-30 GHz	10	Super high frequency (SHF)	Centimetric waves
X	8-12 GHz				
Ku	12-18 GHz				
K	18-27 GHz				
Ka	27-40 GHz	30-300 GHz	11	Extremely high frequency (EHF)	Millimetric waves
V	40-75 GHz				
W	75-110 GHz				
mm	110-300 GHz				

ANNEX F

UHF REGIONAL SPECTRUM UTILIZATION

(INFORMATIVE)

F1 OPERATION IN NORTH AMERICA

The FCC specifies frequency hopping across the North American spectrum allocated to UHF RFID (902-928 MHz with frequency hopping occurring between 902.75-927.25 MHz in 500 kHz increments). (See table F-1.)

Table F-1: UHF Frequency Plan for North America

Transmit Channel Number	Center Frequency (MHz)
1	902.75
2	903.25
3	903.75
4	904.25
...	...
49	926.75
50	927.25

F2 OPERATION IN NORTH EUROPE

Operation is as per ETSI EN 302-208 specification v.1.2.1. This specification states that no listen-before-talk (LBT) is performed. (See table F-2.)

Table F-2: UHF Frequency Plan for Europe

Transmit Channel Number	Center Frequency (MHz)
4	865.7
7	866.3
10	866.9
13	867.5

F3 OPERATION IN CHINA

Chinese regulations provide sixteen high power channels in the 920.625–924.375 MHz frequency band, numbered 3 to 18. The default operation is 1 MHz channel spacing, with the four channels specified in table F-3. Or as an alternative, the user may provide a list up to 16 in length from the available channels specified in table **Error! Reference source not found.**

Table F-3: UHF Frequency Plan for China

Transmit Channel Number	Center Frequency (MHz)
3	920.625
4	920.875
5	921.125
6	921.375
...	...
15	923.675
16	923.875
17	924.125
18	924.375

Table F-4: UHF Default Frequency Plan for China

Transmit Channel Number	Center Frequency (MHz)
3	920.625
7	921.625
11	922.625
15	923.625

F4 OPERATION IN JAPAN

RFID UHF is within a 6 MHz (950-956 MHz) band as segmented in table F-5.

Table F-5: UHF Frequency Plan for Japan

Transmit Channel Number	Center Frequency (MHz)
1	952.2
2	952.4
...	...
8	953.6
9	953.8