JUMP START YOUR PROJECT

RFID CRASH COURSE

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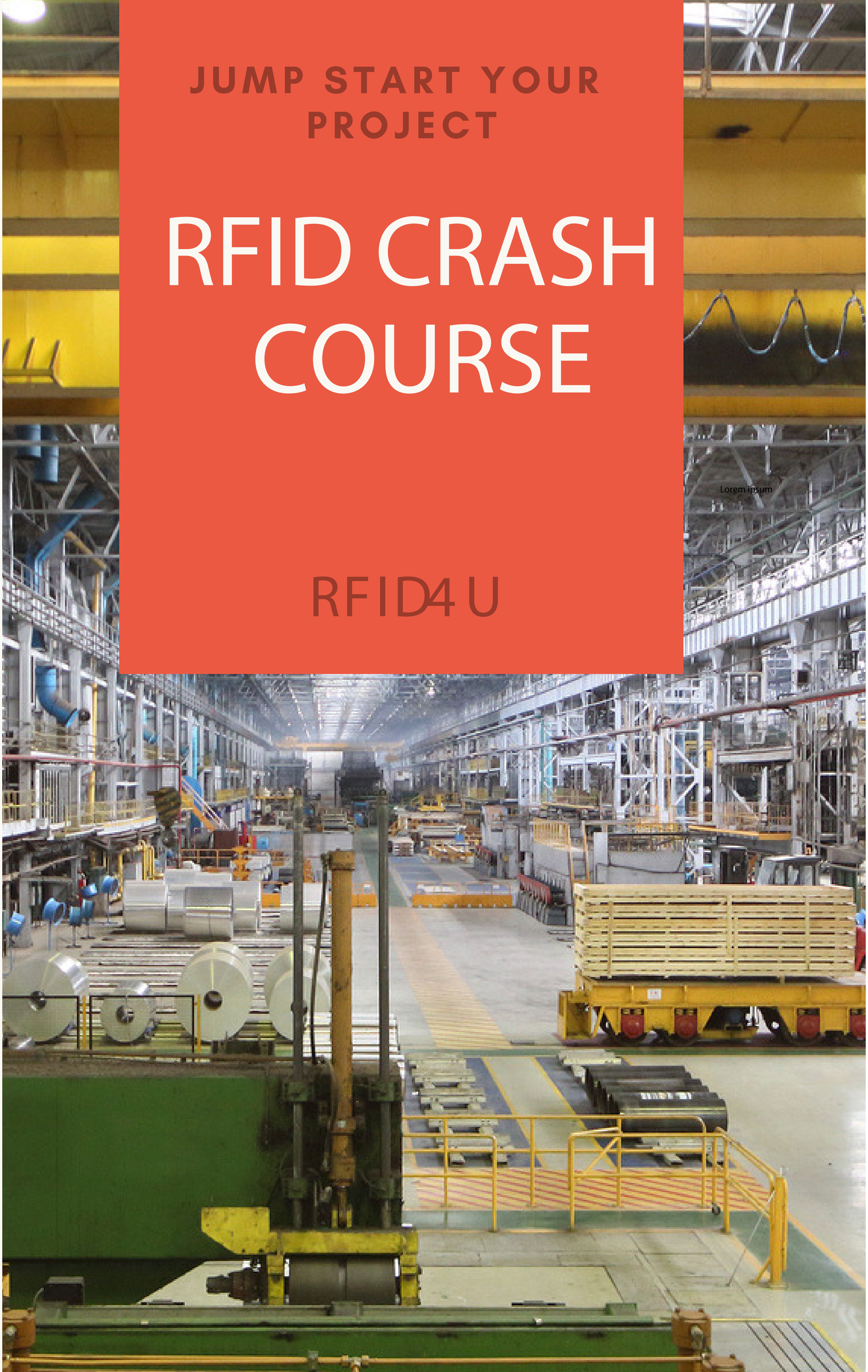


RFID Crash Course

Copyright Statement

Welcome to our e-book! This book is intended to provide an overview of RFID technology, its applications and best practices for anyone who would like to implement RFID in their business and would like to get information on what it does, how it works, its advantages and disadvantages as well as things to consider before an RFID solutions provider is approached. RFID technology is not plug-and-play and has many components and variables as it is highly dependent on the items tracked and the environment. We will try to make it the technology as transparent as possible!

Table of Contents

1. What is RFID Technology?

RFID (Radio Frequency Identification) technology is just one of several technologies known as auto-identification (Auto-ID) technology. It uses radio-frequency waves to transfer data between a reader and movable or stationary objects to identify, categorize, and track the objects as they move through a controlled environment. It consists of a combination of technologies, such as:

- Radio-frequency (RFID) tags,
- RFID readers and antennas,
- Sensors,
- Networking – Wired, Wireless,
- Software,
- Internet,
- and Business process management.

> ***Note***: *RFID also referred to as automatic identification and data capture technology (AIDC).*

The primary goals of an RFID system are to:

- Increase efficiency
- Reduce data entry error
- Decrease manual labor and free staff to perform more value-added functions

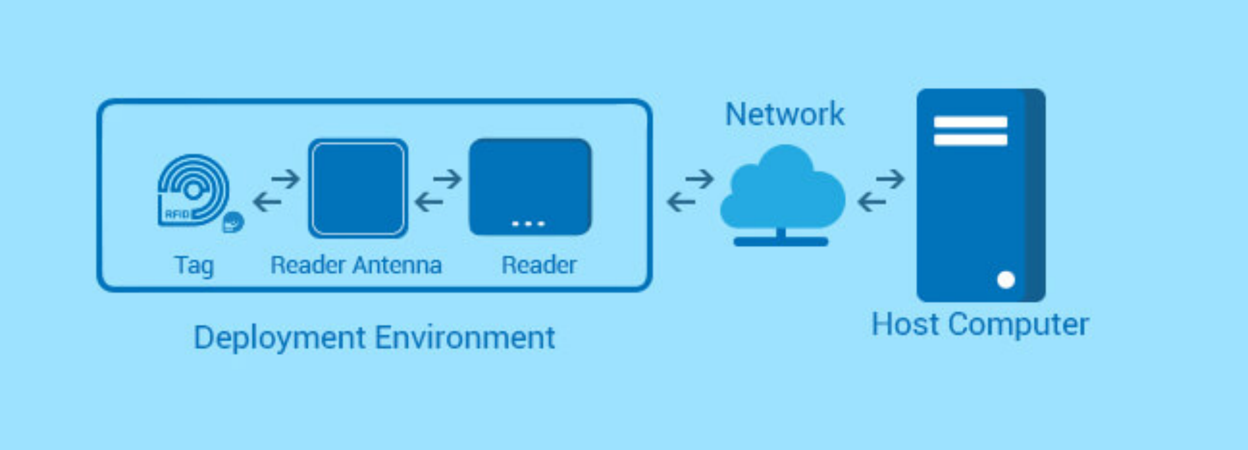


Fig. 1.1 Basic Overview of an RFID System

The process begins with the data transferring from the asset identifier (i.e. RFID tag attached to the tracked asset). RFID readers interrogate and collect data from the tags. The data is then converted into digital form, entered into the data network, and transferred to the host applications. From here, humans use the host applications to control the business process.

RFID System consists of three parts: RFID Hardware, RFID Software and Environment. All parts utilize the organization’s network and computers and integrates with their enterprise systems.

Hardware part of the system includes:

- One or more RFID tags
- One or more RFID interrogators (readers)
- One or more reader antennas attached to the interrogators
- Optionally: RFID Printers, Barcode Scanners and Sensors

Software part of the system includes:

- RFID Middleware
- Application software

Environment is a space where the RFID system will be deployed and used.

Don’t Miss! The environment significantly affects the system performance, especially if there are long distances, metal objects, liquids and harsh conditions involved.

2. RFID Tags

The RFID tag is a device that in its most basic form consists of an electronic circuit and an antenna integrated into one piece (this is called RFID inlay). Tags come in various form factors that will be discussed later. The electronic circuit generally has a memory to store data and some processing logic. Some of the memory may be read only and is used for unique serial numbers and/or tag-id written at the tag production stage. Other portions of the memory may be both written to and read repeatedly. Memory may also be field or factory programmed and can optionally be permanently locked.

2.1 RFID Tag Construction

As shown in the photo below, the most basic RFID tag (or RFID Inlay) consists of four components (antenna, chip, interconnect, and substrate).

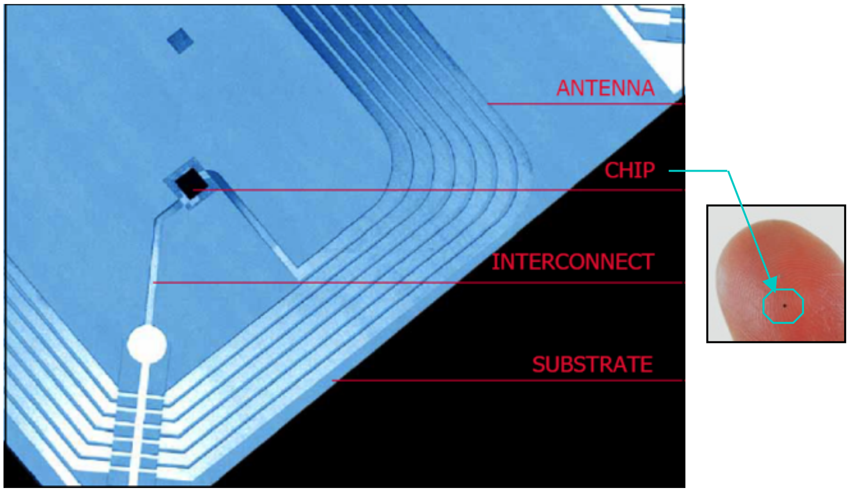


Fig. 2.1 HF RFID Tag Inlay Construction

An integrated circuit (IC or chip) consists of the following components:

- A microprocessor with 40k to 50k transistors for passive Gen 2 (Intel 8086 in first PCs: 29,000 transistors).
- Receives power from radio-frequency (RF) waves captured by antenna and modulates backscattered RF waves to communicate with the reader.
- Memory to store data:
    - Read only, or rewritable memory
    - 64 to 64K bits.
    - May be divided into several banks which can be individually manipulated.

The strap is made up of an IC and two conducting pads that can be connected to an antenna to enable high-speed conversion into inlays, labels, or packaging materials.

The antenna:

- Receives and reflects radio-frequency (RF) waves.
- As the largest part of the tag, it affects the size of the tag.
- Customized for application.
- Designed for a particular frequency band.

The substrate:

- Holds IC, strap, and antenna together on the tag and inlays.
- May have adhesive to attach tags to objects (if adhesive present, it is called a wet inlay, if adhesive not present, it is called a dry inlay).

2.2 RFID Tag Form Factors

RFID Tags come in different form factors, which are usually suitable for a particular application.

RFID Inlay

Most basic type of RFID tag. Can be a wet inlay or dry inlay, based on the presence of adhesive. Sometimes the RFID Inlays are printable and function as an RFID label. These are suitable for embedding into product or packaging or product tagging.

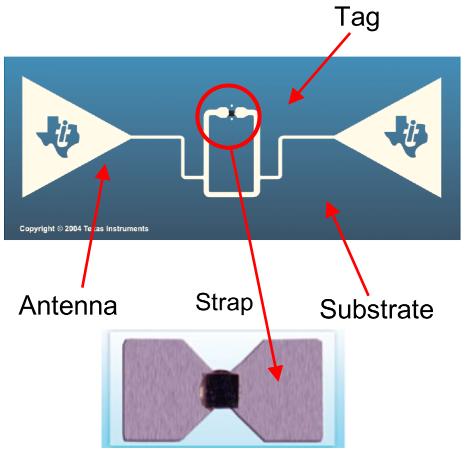


Fig. 2.2. UHF Tag Construction

RFID Smart Label

RFID label also called a Smart Label is basically a paper label that has an embedded RFID inlay. RFID labels are suitable for case and pallet tracking or anywhere with enough surface and light wear and tear.

Rigid (or Encapsulated) RFID Tag

Encapsulated tags embed the RFID Inlay within a hard (sometimes flexible) RF transparent material, such as PET, PC or ABS that protects them against being damaged by factors such as heat, steam, abrasion and also provides various means of attachment, where simple label would not work. Encapsulated tags are often used for tracking metal assets as the tag’s antenna can be insulated and offset from the metal surface to prevent detuning.

The encapsulated tags may be used to:

- Track a tote/carrier/pallet in closed-loop systems.
- Track carriers in production.
- Track returnable assets used through the supply chain.
- Provide isolation from the object so metal objects may be tracked.

Fig. 2.3 Confidex Ironside Rigid Encapsulated RFID Tag

Fig. 2.4. HID Slimflex Family of Encapsulated Flexible RFID Tags

2.3 RFID Tag Types

RFID Tags can be categorized based on Power Source, Frequency, Protocol and other characteristics. Let's review the three most basic categories.

Based on power source, RFID Tags can be divided into:
- Passive
- Semi-Passive (sometimes called Semi-Active or Battery Assisted Passive or BAP)
- Active

Based on frequency, RFID Tags can be categorized as:
- Low Frequency – 125/134 kHz
- High Frequency – 13.56 MHz
- Ultra-High Frequency – 433 MHz, 860-960 MHz
- Microwave Frequency – 2.45 and 5.8 GHz

There are many standards and protocols, however, the most used ones that the tags comply with are:
- EPC Class 1 Gen 2 or ISO 18000-6C (passive UHF)
- ISO 18000-7 (active UHF)
- ISO 15693 (passive HF, NFC)
- ISO 14443 (passive HF, NFC)
- NFC Forum Standards (NFC technology)

2.3.1 Tag Types Based on Power Source

The RFID tag is an electronic device requiring power to operate. Depending on the source of the power and how this power is used, tags are classified as:

- Passive
- Semi-passive (also called Semi-active or Battery Assisted Passive tags - BAP or Battery Assisted Tag - BAT)
- Active

All the above tags also come in different frequencies, use different protocols, and have different functionalities.

2.3.1.1 Passive Tags

Passive RFID tag does not have its own power source (no onboard battery) or a radio transmitter. It obtains power from the RF waves emitted by the reader. Therefore, it can communicate only when inside the read zone and when is energized by the RF waves. When a passive tag comes into the reader's read zone (that is, the area where you have radio frequency signals of a specific strength), power is harvested by the tag antenna and provided to the tag IC. Power from the radio waves operates the tag's integrated circuit, which then sends data back to the reader by a method called Passive Backscatter (UHF and Microwave tags) or Inductive Coupling (LF and HF tags).

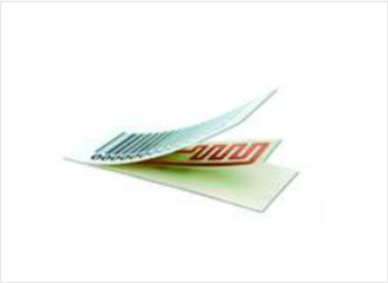


Fig. 2.5 Examples of Passive RFID Tags

How does it work?
All passive tags employ a unique communication system to avoid the need for a radio transmitter on the tags. Instead of transmitting its own signal, the tag reflects the signal received by it from the reader. The tag IC changes the reflective property of the tag antenna and thus modulates the reflected signal. The reader receives this modulated signal and extracts data from it. As an analogy, use a mirror that will tilt to reflect a flashlight.

Passive tags utilize either **passive backscatter** or **inductive coupling** (load modulation) depending on which part of the RF wave is used. Whether the electric part (passive backscatter) or the magnetic part (inductive coupling).

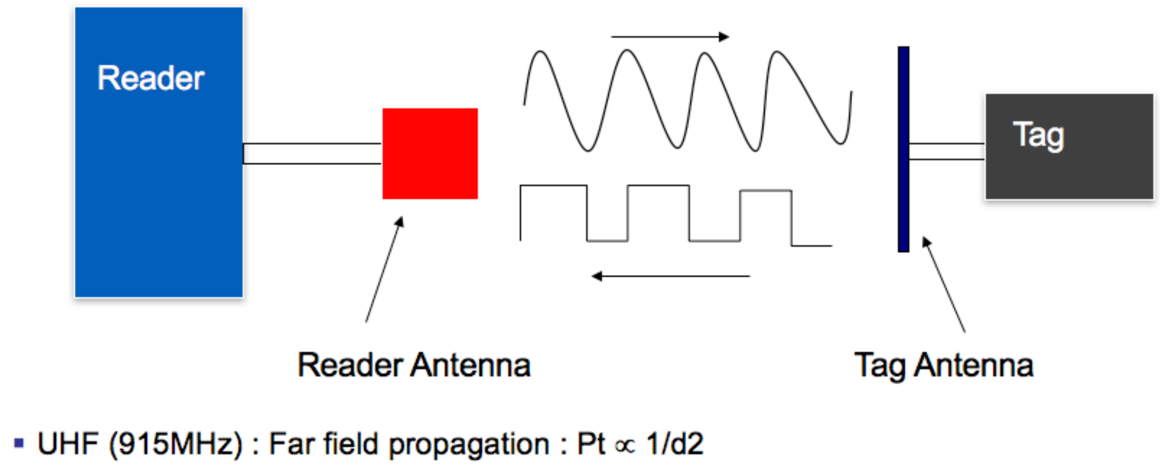


Fig. 2.6 Diagram of Passive Backscatter Principle

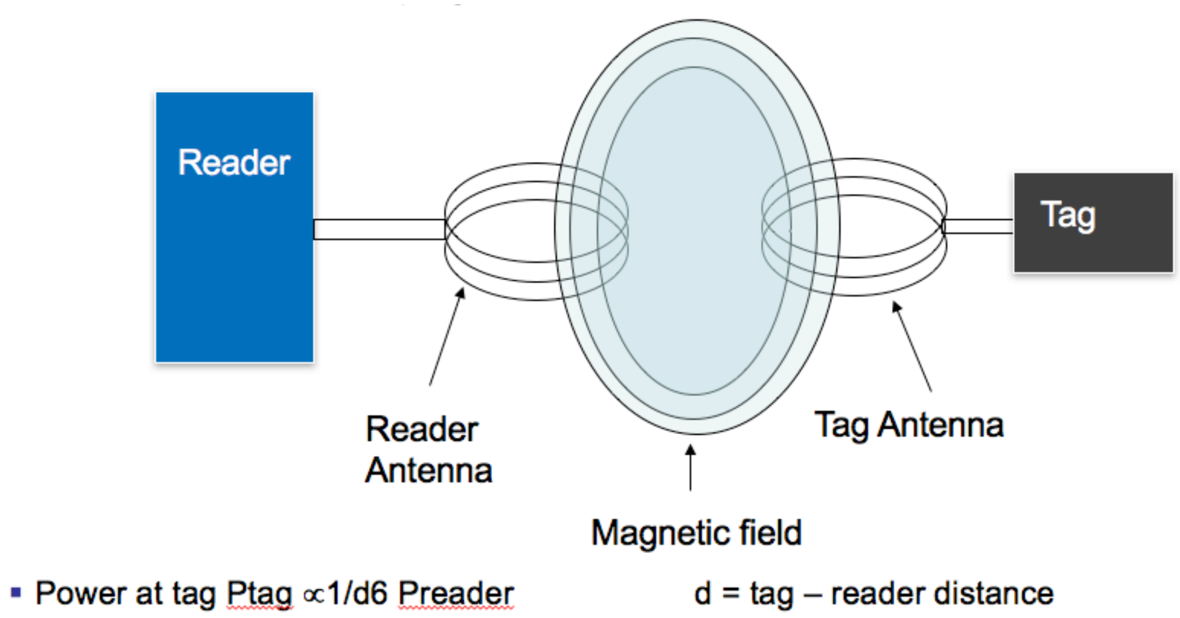


Fig. 2.7 Diagram of an Inductive Coupling Principle

More Info: For more information about Passive Backscatter and Inductive Coupling, please check our website at: http://rfid4u.com/rfid-basics-resources/inductive-and-backscatter-coupling/

Passive RFID tags usually have read range of anywhere from few inches to 20 feet (sometimes more) and cost approximately $0.15 when purchased in large quantities. They are primarily used in the applications requiring low cost, simple and lightweight tags.

***Note**: The passive tag's read range is limited by the frequency (and subsequently type of communication) and the amount of power that can be obtained from the RF waves from the reader. Beyond approximately 20 feet from the reader antenna, the tag cannot collect enough power to turn on its IC and thus cannot communicate with the reader.*

Advantages:
Some of the advantages of the passive tag are small size, lightweight, inexpensive and a long life (20+ years).

Disadvantages:
The disadvantages of passive tags are a lower read range and high power readers.

2.3.1.2 Semi-passive Tags

The semi-passive tag has a battery but no radio transmitter. The battery powers its integrated circuit (IC), which helps it to modulate the reflected signal and respond to the reader. Semi-passive tags use passive backscatter for communication with the reader just as the passive tags do. The battery only increases they read range or can run sensors.

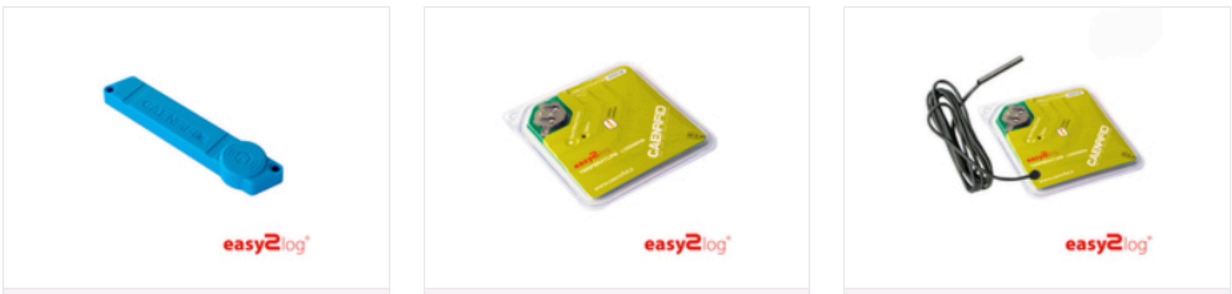


Fig. 2.8 Examples of Semi-passive RFID Tags

Advantages:
The advantage of this type of tag is that you need much less power from the reader to communicate. Therefore, you can use low-power readers, store more data on the tag as well as integrate sensors. This type of tags is used to get longer read range or to couple the tag with environmental sensors such as temperature, pressure, relative humidity, etc. Semi-passive tags can be read in distances up to 100 feet and often use the same communication protocols as passive RFID tags making them interoperable with standard passive readers.

Disadvantages:
The disadvantages of these tags are higher cost, larger and heavier tag and a limited life due to battery. There are not many vendors on the market that produce semi-passive tags.

2.3.1.3 Active Tags

Active tags have their own battery and radio transmitter. This tag communicates at a longer distance because it is not dependent on a reflected signal. Active tags can deploy two modes of communication, either beaconing or response. Beaconing tag send its signal in periodical intervals regardless the presence of the reader. Response tag waits for a wake up from the reader and then responds.

The active tag may also contain environmental sensors. Active tags are often used in Department of Defense (DoD) applications like container or vehicle tracking. They are also used in cold chain applications like refrigerated trucks that may be equipped with active RFID tags and temperature sensors.

Advantages:
Active tag has the longest communication distance ranges from 300 up to 750 feet. It can have more memory, up to 64 Kbytes and carry sensors.

Disadvantages:
The cost of active tags is relatively high, they are usually larger and heavier than passive tags and their life is limited by the battery life. In addition, they do not use the same protocols as semi-passive and passive RFID and need a specific reader.

Fig. 2.9 Example of an Active RFID Tag

More Info: For more information on Active, Passive and Semi-passive tags, please visit our website at: http://rfid4u.com/resources/how-to-select-a-correct-rfid-tag-passive-vs-active/

2.3.2 RFID Tag Types Based on Frequency

Tags are designed to operate at different frequencies because of:

- Government regulatory requirements
- Performance on and around certain materials (such as metal, water, etc.)
- Read range and speed required

Four frequency bands are used in tag design:

- Low Frequency – 125/134 kHz
- High Frequency – 13.56 MHz
- Ultra-High Frequency – 433 MHz (sometimes called Very High VHF), 860-960 MHz
- Microwave Frequency – 2.45 GHz

Different frequency tags have different characteristics. They behave differently when tagged to different types of material. The read range varies from a few centimeters to few meters or feet. Because of government regulations and customer mandates, certain frequency tag may be selected.

Low Frequency – 125/134 kHz
LF Tags have great penetration of water and aqueous liquids and is often used for animal tracking. LF does not penetrate or perform well around metal and provides low data transfer rates, suitable for small amounts of data sent over short read ranges. LF tags use inductive coupling for communication. LF tags are used for specialty applications.

High Frequency – 13.56 MHz
HF Tags have also a good penetration of water and aqueous liquids and are often used for tracking produce or pharmaceuticals. HF does not penetrate or work well around metals and has also short read ranges. HF uses inductive coupling. Same frequency but partially different protocols are also used by NFC (Near Field Communication) systems that are often used for payment. HF tags are most commonly used for access control (smart cards).

Ultra-High Frequency - 433 MHz (sometimes called Very High VHF)
433 MHz is used by active RFID technology. As discussed earlier Active tags have very long read ranges and use a transmitter to communicate. These are used for tracking high value assets such as containers and military assets. This frequency does not penetrate water or metal but due to active technology it performs well in environments with these materials present.

Ultra-High Frequency 860-960 MHz
The UHF frequency is mostly utilized by passive UHF Tags (but there are some manufacturers that use active RFID in this band). UHF tags do not penetrate or perform well around water or metal and techniques must be employed to avoid these materials negatively affect the system performance. These are most commonly used for supply chain management and asset tracking.

Microwave Frequency – 2.45 GHz
This frequency is utilized by both passive and active RFID, although active is more common. The advantages are very fast data transfer rates. In passive version, the microwave tags have relatively short read ranges but due to short size of an antenna they can be made very small. In active version, they provide long read ranges and very fast reading suitable for toll collection and other high speed high performance systems.

Frequency Bands	Antenna	Data & Speed	Read Range	Usage
Low Frequency (LF) 125 kHz – 134 kHz	Induction Coil on Ferrite Core	- Low Read Speeds - Small Amount of Data (16 bits)	Short to Medium 3-5 feet	- Access Control - Animal Tagging - Inventory Control - Car Immobilizer
High Frequency (HF) 13.56 MHz	Induction Coil flat 3-9 turns	Medium Read Speed Small to Medium amounts of data	Short 1-3 feet	- Smart Cards - Item or Case level tagging - Proximity Cards - Vicinity Cards
Very High Frequency (VHF) 433 MHz – Active Tags	Internal Custom Design	High Read Speed Large Amounts of Data	High 1-1000 feet	- Asset Tracking - Locationing - Container Tracking
Ultra High Frequency (UHF) 860 MHz – 960 MHz	Single or Double Dipole	High Read Speed Small to Medium amounts of data	Medium 1-50 feet	- Pallet or case level tagging - DOD & Walmart Mandates
Microwave Frequency 2.45 GHz & 5.4 GHz	Single Dipole	High Read Speeds Medium Amount of Data	High 1-300 feet	- Container Rail Car - Auto Toll Roads - Pallet Level Tracking

Fig. 2.10 Overview of RFID Tag Types Based on Frequency

More Info: For more information about Tag Frequency, visit our website at: http://rfid4u.com/rfid-basics-resources/how-to-select-a-correct-tag-frequency/

2.3.3 RFID Tag Types Based on Standards

There are many standards and protocols used by RFID tags, however, the most common are the following

- EPC Class 1 Gen 2 or ISO 18000-6C (passive UHF)
- ISO 18000-7 (active UHF)
- ISO 15693 (passive HF, NFC)
- ISO 14443 (passive HF, NFC)
- NFC Standards (NFC technology)

2.3.3.1 EPC Class 1 Gen 2

The electronic product code (EPC) Generation 2 protocol was released by EPCglobal in December 2004 and since then has had many updates and also has been ratified as ISO 18000-6C. It specifies the signaling layer of the communication link between tags and reader and defines UHF, passive-backscatter, interrogator-talks-first (ITF) air interface, and data structure standards. It operates within a frequency band of 860 to 960 MHz (and appropriate sub bands based on country regulations).

The EPC Generation 2 protocol provides the following capabilities:

- **Ability to change encoding according to the environment** - The reader changes the encoding method, the Miller sub-carrier or FM0, according to the noise in the environment. In a low-noise environment it may use FM0 encoding, which is faster, but as noise increases it may switch to Miller sub-carrier, which is designed to optimize performance in noisy and dense reader environments. This decreases the number of tags read per second but allows tags to be read in harsher environments.
- **Three modes for reader operation** - The reader may operate in single, multi, and dense environments. A dense reader environment is designed for enterprise deployments in which hundreds of readers are operating at the same time.
- Tag population management   Provides select, inventory, and access commands for efficient reading of tags—for example, a group of tags may be selected with a wild card pattern.
- **Longer kill and access passwords** - 32-bits-long access and kill passwords increase the level of security for the data on the tags.
- **Forward link data protection** -Tags provide a randomly generated number to the reader to encode the data sent by the reader to the tags.
- **Four sessions for tag inventory** - Tag may operate in four different sessions at the same time, so four different readers can communicate with the tag at the same time without interfering with each other.
- **More robust tag communication design** - Reduces potential for ghost reads and entry of erroneous data into the application.
- Faster data transmission rate up to 640 Kbps - This is five times faster than the previous standards.
- **Improved tag memory and programmability** - Tag memory is divided into four banks. A bank may have read-only, write once, and read/write parts within it. This provides better tag security and application flexibility.
- **Provides 96 to 256 bits of EPC memory** available on the tag and various sizes of User Memory.
- **Divides memory into 4 EPC banks**
  - Bank 0 – Reserved Memory – stores Kill and Access Passwords
  - Bank 1 – EPC Memory – stores the EPC number
  - Bank 2 – TID Memory – stores the Tag Identifier (from Manufacturer)
  - Bank 3 – User Memory – stores user data

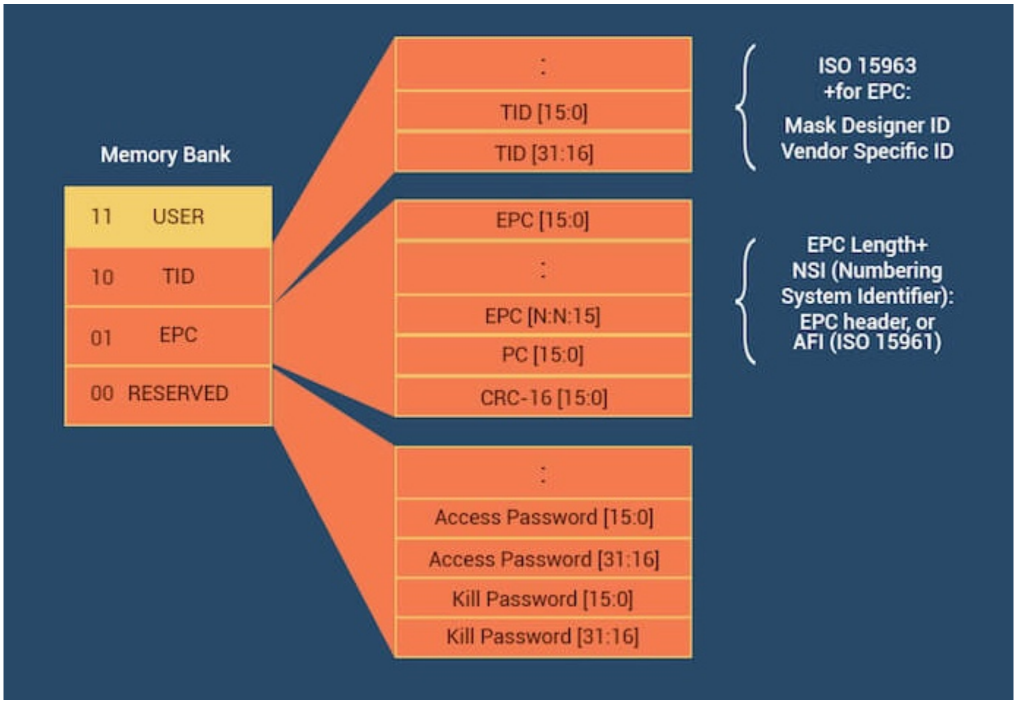


Fig 2.11. EPC Gen 2 Memory Layout

Upgrades to the Gen 2 included in the Gen 2 Version 2 provide:

- **Function for untraceability,** which allows to hide portions of data, restrict access privileges and reduce a tag's read range.
- Support for **cryptographic authentication of tags and readers**, to verify identity and provenance, as well as reduce the risk of counterfeiting and unauthorized access.
- **Enhanced User Memory** for supplementary encodings (such as maintenance logging) during a product's life cycle.
- **"Non-removable" tag** for embedded tagging of electronics and sewn-in tagging of apparel, to indicate that a tag cannot easily be removed without compromising the tagged product's intended functionality.

EPCglobal also provides data standards that govern the data encoding. Below is an example of an ECP General Identifier (GID). Other formats include SGTIN, SSCC, GLN, GRAI, GIAI and Airspace and DoD Identifier.

GID FORMAT

-	HEADER	GENERAL MANAGER NUMBER	OBJECT CLASS NUMBER	SERIAL NUMBER
Decimal capacity	0011 0101(actual value)	268,435,455	16,777,215	36 bits
GID-96	8 bits	28 bits	24 bits	24 bits

The standard also defines encoding of other numbering systems for 96 bits used in global trade.

Fig. 2.12. EPC General Identifier

2.3.3.2 ISO 18000-7

ISO 18000 Part 7 defines the air interface for RFID devices operating as an active RF tag in the 433 MHz band used in item management applications. Typical applications operate at ranges greater than 1 meter. It was developed for FCC-approved read/write active tags. These tags are used by US DoD and Universal Postal Union and have a read range in excess of 300 feet.

2.3.3.3 ISO 15693

ISO 15693 is an ISO standard for vicinity cards, which can be read from a greater distance compared to proximity cards defined by ISO 14443. ISO 15693 systems operate at the 13.56 MHz frequency, use near-field inductive coupling, and offer maximum read distance of 3 to 5 feet. This range makes them a good fit for applications such as physical access or controlling entry to a parking garage, also serves as the foundation for a variety of applications outside of contactless smart cards, such as airline baggage tracking and supply chain management. ISO 15693 is also a standard for NFC Mode 5.

2.3.3.4 ISO 14443

This standard defines identification cards operating at the 13.56 MHz frequency using near-field inductive coupling. The cards are usually called *proximity* cards. Typical applications include identity, security, payment, mass-transit, and access control. ISO 14443 systems are designed for a range of about 10 centimeters (3.94 inches), so they are a good fit for applications such as vending machines. This is also an NFC Standard.

2.3.3.5 NFC Standards

NFC is standardized by several organizations like ISO, ECMA and NFC Forum. Below is an overview of NFC standards. NFC technology uses 13.56 MHz (HF) and thus provides the same physical performance like HF. NFC standards enhance the standard HF technology to include various modes, authentication and encryption. NFC is often used for payment systems including contactless and contact systems and is now present in most current smart phones.

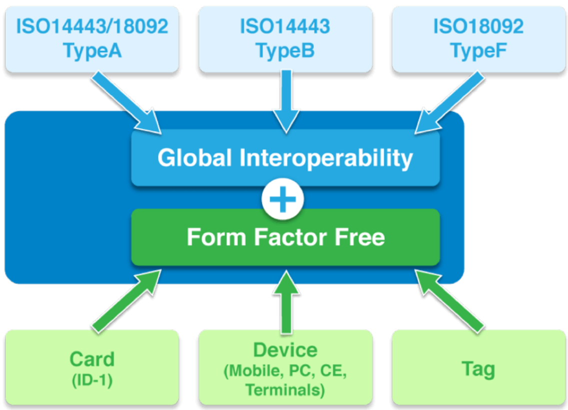


Fig. 2. 13. NFC Standards Interoperability

Tag Type	Use Case	Chip Examples	User Memory (bytes)*	UID Length (bytes)	Cost
Forum Type 1	Specialized	Innovision Topaz	90 - 454	4	$
Forum Type 2	Most common, low cost, single application like smart poster, personal label etc.	NXP MIFARE UL, MIFARE UL-C, NTAG 203, 210, 212 etc.	46 – 142	7	$
Forum Type 3	Specialized, Asian markets	Sony FeliCa (Lite)	224 – 3984	8	$$$
Forum Type 4	High memory applications, high security (in non NFC mode)	NXP MIFARE DESFire EV1 -2K, 4K, 8K, Inside Secure VaultIC 151/161, HID Trusted Tag™	1536 - 7678	7	$$$
Forum Type 5 (NFC-V / ISO 15693)	If longer read range is required, industrial rugged tags – added as forum tag type June 17, 2015.	NXP ICODE SLIx family, EM4233, Fujitsu FRAM MB89R118C, MB89R112, HID Vigo™	32 – 8192 (112 for ICODE SLIx)	8	$ - $$$
MIFARE Classic	Very common, high memory Not compatible to all devices!	NXP Mifare Classic 1K, 4K	716 - 3356	4 or 7	$$

Fig. 2. 14. NFC Forum NFC Tag Types

Factors that dictate performance are:

Factor	Description
Tag sensitivity	• The ability of a chip to be *energized* and to maximize the signal strength to send its identifier back to the reader. • The greater the chip sensitivity, the longer the read range.
Tag size	• Larger generally means longer range. • Size of the object dictates the size of the tag.
Antenna configurations	Different tag antenna configurations provide remarkably different levels of performance.
Number of tag antennas attached to the chip	Two dipole antennas attached to a single chip results in tag performance that is less sensitive to orientation. This is important for the environment where tag orientation is unpredictable.
Read speed	The rate at which a reader collects tag identifiers. RFID tags available today have read rates varying from as low as 20 tags per second to over 1000 tags per second. Rapid read rates: • Increase the reliability of tag reads. • Are less likely to impose burdens on business processes.
Tight tag stacking	• When stacked closely together, tags may interfere with one another. • There is a wide variation in tag performance in high-density environments. • The best tags available today work effectively even when situated within one-eighth of an inch of one another.
Interference	Well-designed tags and readers perform effectively in noisy RF environments.
Materials to which the tags are attached	• Some of the friendliest materials are cardboard, cloth and plastic. • Metal- and water-based materials are generally hostile to UHF, negatively effecting read range. However, this can be overcome by providing a small air gap between the tag and the material.

Fig. 2.15: Factors Affecting Tag Performance

When selecting the right tag for the application, consider the following criteria:

- Passive versus active
- Ability to write frequently
- Security requirements
- Frequency of operation
- Object material (such as plastic, paper, metal, liquid container, etc.)
- Read range (distance between tag and reader)
- Read speed (how fast tag moves relative to reader)
- Read rate (how many tags can be read per second)
- Size (object size may limit tag size)
- Mounting choice (such as stick on, embedded, etc.)
- Tag orientation (relative to reader antenna)
- Object manufacturing processes
- Standards-based (Interoperable)
- International usability
- Cost (relative to item cost)
- Compliance requirement

It's also essential to consider the environment in which the tags will be used, attached, and stored. Some of the considerations are motion, vibration, heat, cold, steam, water, corrosive chemicals, dirt, mud, metal surrounding, other RF sources in the vicinity, available space, manufacturing processes, etc.

More Info: For more information on EPC standards, please visit either our website: http://rfid4u.com/rfid-basics-resources/how-to-select-a-correct-rfid-tag-standards-mandates/ or the GS1/EPCglobal website: www.gs1.org

For more information on NFC review our blog posts: http://rfid4u.com/category/blog/nfc/

3. RFID Readers

The main function of the RFID tag reader, also called an RFID Interrogator, is to communicate with the tag, collect the data, and transfer the data to digital form. The reader also powers passive tag and are designed for various frequencies and protocols. Readers are connected to antenna. The antenna can be integrated inside the reader or it can be external to the reader. One or more external antennas can be connected to the reader. Usually more common varieties of UHF fixed readers have four antenna ports to connect external antennas. Readers may be powered by battery, AC, or via Ethernet.

Readers perform the following functions:

- Act on commands from application software.
- Supply power to passive tags to communicate with them.
- Interrogate tags and collect data from tags' memory.
- Write data to tags' memory.
- Perform conversion between analog radio waves and digital data.
- Store and/or transmit data to other devices with wired or wireless connection.
- Filter and/or aggregate data.

RFID readers effectively link external objects with business processes within the enterprise.

3.1 RFID Reader Construction

RFID reader has several components. **The Transmitter** sends the signal from the reader to the tag through an antenna and **the receiver** receives the signal from the tag also through the antenna.
The oscillator provides carrier signal to modulator (in transmitter) and a reference signal to demodulator (in receiver) circuits. The **Control Module** processes transmitted and received data, communicates with host, receives commands, holds memory, controls all reader components, etc.
Mono-static reader has an antenna with both transmitting and receiving functions. These are switched by a circulator. **Bi-static** reader has dedicated antenna ports (and therefore antennas) for separate transmit and receive functions. Some readers can be used in bi-static as well as mono-static mode.

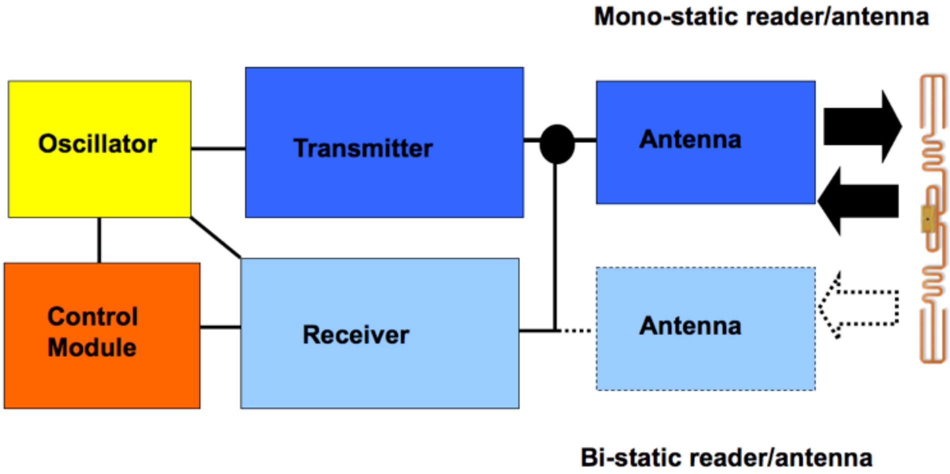


Fig. 3.1 RFID Reader Diagram

3.2 RFID Reader Form Factors

RFID Readers can come in various form factors. Although the main functions that facilitate reading and writing tags are identical to all, other features like power options, networking options, portability options are different.

3.2.1 Fixed Interrogators

Fixed interrogators are designed to be bolted to walls near doorways or attached to wire racks near doors, integrated into stands and dock door portals, and attached to conveyor portals and the like. Fixed readers can come with various number of ports, as well as option for GPIO devices and communication. Integrated RFID readers will have embedded antenna, so reader and antenna will be just one device. This is convenient for small spaces. RFID Readers are often embedded into portals, together with antennas, light stack and other IO devices. The portal is then installed on site and provides not just aesthetic but also protective value.

More Info: For more information on how to select an RFID reader, visit our site: http://rfid4ustore.com/blog/how-to-select-an-rfid-reader/

Fig. 3.2 Examples of Fixed RFID Readers and Portals

3.2.2 Vehicle-Mounted Interrogators

Vehicle-mounted interrogators, which can automate shipping and receiving of goods, are usually integrated into material handling devices such as forklifts, paper trucks, cargo trucks, and pallet jacks. These interrogators usually have a special shape for easier installation onto the vehicle and a rugged design to survive the vibrations and other environmental conditions.

3.2.3 Handheld Interrogators

If you cannot bring the asset to the reader like with a conveyor or a door portal processing, you have to bring the reader to the asset. Handheld readers are typically used for exception processing, asset tracking when asset is fixed, remote data collection, and in small scale installations. There are four main types of handheld readers:

Handheld Computers with RFID Capability – these devices have an onboard computer usually with Windows OS, display, keyboard and of course RFID antenna and reader. These devices are usually the most expensive, however, they pack the most functionality and usually can be custom configured with options based on your needs. For instance, you can add a 1D barcode scanner or 2D Imager, camera, Bluetooth communication, more memory and other options.

Fig. 3.3 Examples of Handheld Computers - Zebra 319Z and Alien 9011

Sled Handheld Readers – sleds are becoming increasingly popular, because instead of having a built-in computer on board, they utilize a smart phone. They only house the RFID reader, antenna, handle with a trigger and connection to the smart phone. The smart phone runs an app and communicates with the sled reader and with the network over Wi-Fi or Bluetooth. Because of using smart phone, Android, iOS or Windows apps can be easily utilized. Sleds can also have variations including barcode scanning. This option is also more cost effective.

Fig. 3.4 Examples of Sled Readers - Zebra RFD8500 and TSL 1128.

Bluetooth Handhelds – The third type (not really an official category) are small readers that are in form of a key fob or strap on your hand or belt. They usually don't have a display or maybe a very small LCD one, include RFID reader and antenna and communicate with your smart phone over a Bluetooth. These readers are perfect where space is an issue and users need small and light device. Such handhelds are usually the most cost effective, however, due to their small size, they usually have quite short read range and shorter battery life.

Fig. 3.5 Examples TSL 1062 (HF)/ TSL 1153 (UHF) and CAEN qID Mini Keyfob Reader

RFID Handheld Snap-Ons – this is a category of add-on modules that can be plugged into existing non-RFID handheld computers. These are often HF and LF frequency, but there are some UHF as well. This is a good option, if you already have handheld computers on-site that you use and you can enable them with RFID for a relatively low cost instead of replacing them. Good examples are TSL 1117 and 1101 snap-on readers, Zebra has also several options. The cost depends on whether the snap-on has its own battery therefore not draining the battery life of the handheld unit itself or whether it uses the handheld power.

Fig. 3.6 Examples of Snap-On Modules for Handhelds TSL 1117 and 1101

More Info: For more information on how to select an RFID Handheld, review our site: http://rfid4ustore.com/blog/how-to-select-an-rfid-handheld/

3.3 RFID Reader Types

Listed below are basic types of RFID tag readers:

- Fixed, handheld (mobile computer, sled, key fob, snap-on module), vehicle mount
- Single-protocol or multi-protocol - Note: Reader and tag protocols must match.
- Single-frequency or multi-frequency (this is sometimes implemented with LF and HF frequency) - Note: Reader and tag frequency bands must match
- Integrated antenna or External antenna (single, multiple)
- Powered by battery, alternating current (AC), or Ethernet (POE)
- Dumb or intelligent (depending on the processing and data handling capabilities)
- Data Connections: Serial, Ethernet (wired or wireless), USB, Bluetooth
- Based on number of antenna ports (zero to 16)

3.4 Reader to Reader Interference

The near-field readers (LF, HF, and UHF near field) use magnetic flux to communicate with the tags. The magnetic flux decays very rapidly and since the near-field readers are usually not installed very close to each other they do not interfere with each other.

Reader-to-reader interference is only an issue for ultra-high frequency (UHF) and microwave operating readers in far-field. Reader interference countermeasures include:

- Physical isolation
- Absorptive materials
- Shielding
- Reduced transmit power
- Frequency hopping
- Band separation

Reader operating environment is defined as a region within which a reader's RF transmissions are attenuated by less than 90dB (roughly a sphere with a one km radius).

When a reader and tag transmission share a channel, reader transmission is 100 dB larger than tag backscatter. The distant in-channel readers mask nearby tags. To solve this problem Generation 2 protocol provides three reader operation levels as follows:

- Level 1 – **Single Reader Mode**: A single reader operating in the environment.
- Level 2 – **Multiple Reader Mode**: The number of simultaneously active readers is less than the number of available channels (such as 10 readers operating in 50 available channels).
- Level 3 – **Dense Reader Mode**: The number of simultaneously active readers is equal to or greater than the number of available channels (such as 50 or more readers operating in 50 available channels in the US).

Don't Miss! The number of available channels for reader operation in the US is 50 while in Europe it is effectively 4 (within 865 to 868 MHz and 2W ERP).

So what happens is that the reader and tag transmissions are separated spectrally. The tags in the same read zone will collide with each other because they all operate at the same channel but they will not collide with other readers because other readers are operating at different channel. The tag collision will be taken care by anti-collision algorithm. Channel usage is governed by rules and regulations that include frequency hopping (US), Listen Before Talk and assigned channels for readers and tags (EU) and other methods used regionally. These functions are performed by the reader firmware.

4. RFID Antennas

A reader antenna is a converter between radiated waves and wired voltage. Antenna structures, used in radio frequency-identification (RFID) systems, may be used to both transmit and receive electromagnetic energy, particularly data modulated electromagnetic energy.

Antenna is the biggest and most obvious component of system and is most vulnerable to:

- Mechanical damage
- Thermal cycling, rain, snow, wind (if outdoors)
- Obstruction by metallic objects

4.1 Antenna Types

RFID antennas are necessary part of any RFID system. Unless the antenna is embedded into a reader (like Alien 9650 or CSL CS203), you will have to select and purchase the right antenna for your application. And there are a lot of options to select from.

Fig. 4.1 Antenna Examples (from the left Zebra, Laird, Impinj, CSL)

Frequency – this will depend on your tags – choose between LF, HF, UHF or Microwave frequency.

Frequency Region – this will depend on country of operation and will affect only the UHF frequency. As you know, due to regulations, the frequency bands for UHF RFID slightly differ for US, Europe and other regions. Most UHF antennas are specified as

global and they are tuned for operation between 860 to 960 MHz. You can also find antennas that are specifically tuned for each region, which slightly improves their performance in the particular region. For instance, 865 - 868 MHz antenna will perform better when deployed in Europe than a global antenna, although this may not be distinguishable in most applications. Global antenna will work well for most applications; however, you can choose region-specific antenna for difficult deployments (long read ranges, RF challenging environment) or where global is not available.

Read range and size – smaller antennas within the same frequency will have shorter read range and vice versa. The antennas with the shortest read range for UHF technology will be Near Field Antennas, that utilize near field as opposed to far field as regular UHF antennas. These are often used for item tracking and where short ranges are required for item singulation and/or security purposes.

Profile width – if you are short on space or for esthetic reasons, you may need to look for low profile antennas that have a side connector or a side pigtail.

Gain – gain affects read range and beamwidth. Antennas with higher gain will have longer read range but narrower beam. Antennas with lower gain will have shorter read range and wider beam width. Select antenna gain based on the shape of your interrogation zone and coverage needs. Most common gain is 6dBi but you can find antenna with 1 dBi (low gain) and also with 11 dBi (high gain).

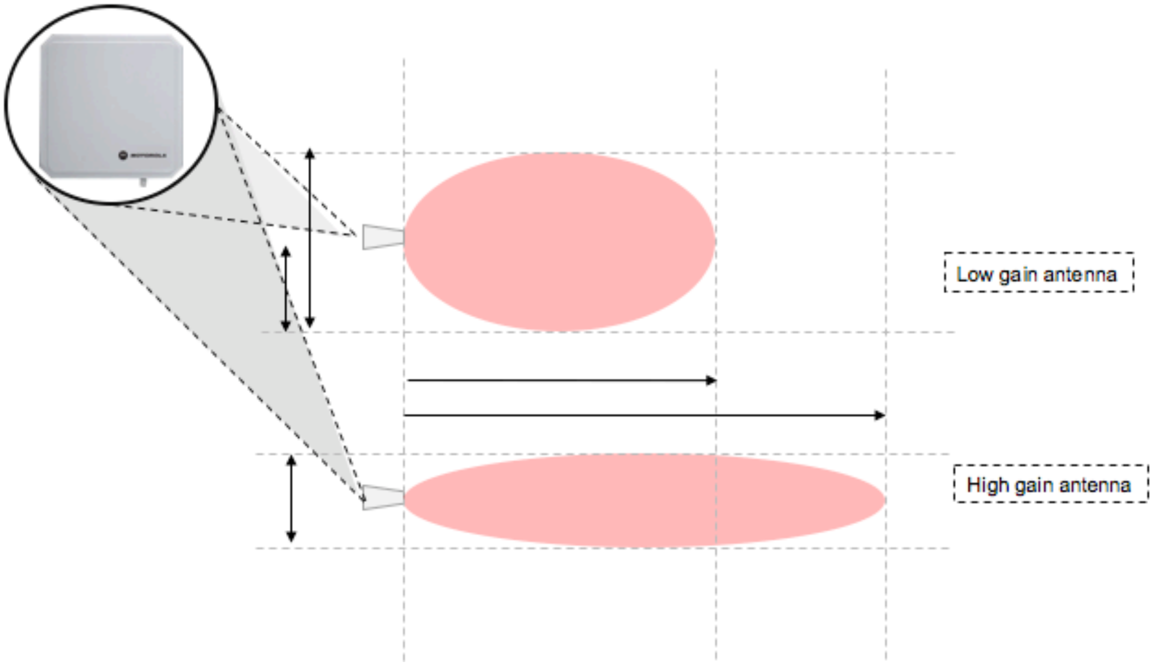


Fig. 4.2 Antenna Gain Diagram

Polarization – you can select between circular and linear polarization.

Circularly polarized antennas will have shorter read range but will be less orientation sensitive. You can select between right hand circularly polarized antennas (RHCP) or left hand circularly polarized antenna (LHCP). Sometimes you can see **dual circularly polarized** antennas that have both left hand and right hand polarization.

Linearly polarized antennas will provide longer read range and more focused beam but will read only tags that have antennas parallel to the plane of wave. If your tag orientation is not fixed, especially when using single dipole tag antennas (which are most common), you should select a **circularly polarized** antenna.

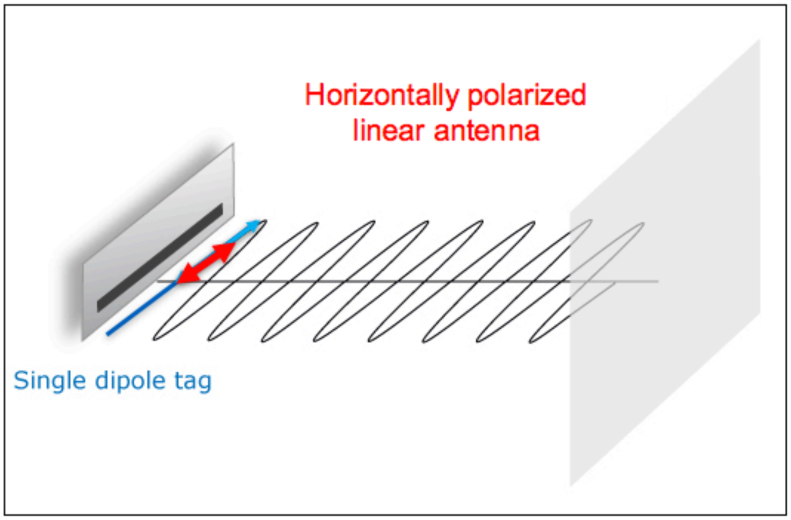


Fig. 4.3 Linear Polarization

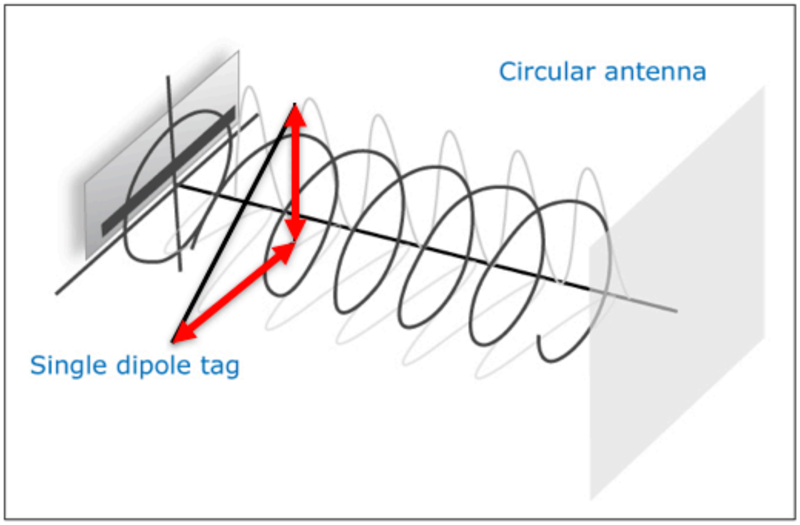


Fig. 4.4 Circular Polarization

VSWR – voltage standing wave ratio or also called return loss - Due to mismatches in impedance within the connector, some of the signal is reflected. The ratio of the input to the reflected signal is called the Voltage Standing Wave Ratio (**VSWR**). This ratio can also be measured in dB, and expressed as **Return Loss**. The VSWR signifies antenna design efficiency and the lower the VSWR the smaller the return loss and the better the antenna (ideal VSWR is 1:1).

Axial Ratio - The axial ratio is the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components of equal amplitude, which are 90 degrees out of phase. Because these components are of equal magnitude, the axial ratio is 1 or 0 dB. Axial ratios are often specified for circularly polarized antennas. The axial ratio tends to degrade away from the main beam of an antenna, therefore, in the spec sheet for an antenna, you can sometimes see information such as: “Axial Ratio: <3 dB for +-30 degrees from the main beam”. This indicates that the deviation from circular polarization is less than 3 dB over the specified angular range.

Beamwidth – select elevation beam width (vertical, up and down) and azimuth beam width (horizontal, left to right) based on the desired coverage of an interrogation zone. Wider beamwidth antennas will provide wider coverage without the need for additional antennas, however, the read range may be shorter (which is often desired as not to read tags outside the portal or door).

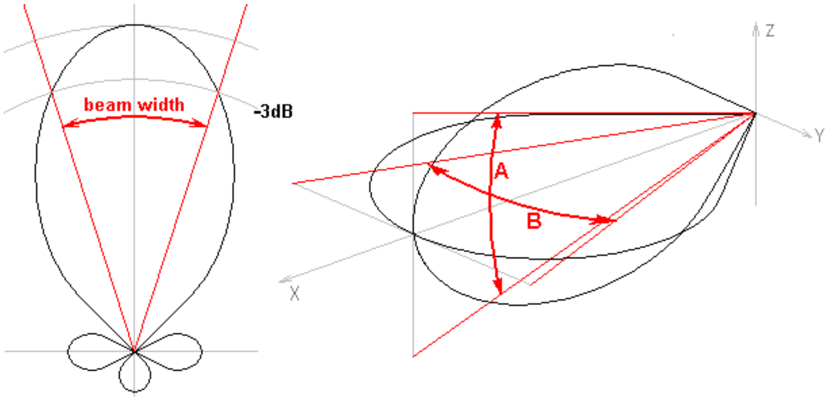


Fig. 4.5 Antenna Beamwidth

Antenna Connectors – there are several common types of connectors that are used with RFID antennas. They can be male or female and be regular or reverse polarity. Each manufacturer prefers certain connectors. In general, the connectors have no effect on performance, some are smaller and less bulky and therefore good for tight spaces or easier to hide and work better with thin cables. On the other hand, larger and bulkier connectors are sturdier and work with thicker cables and in harsher environments. You must know what connector your antenna has as well as your reader, so that you can purchase a cable that will pair with these. These connectors are most common: N-type, RP-TNC and SMA (the least bulky).

Don’t Miss! Don’t forget that you must pair female and male connectors.

Fig. 4.6 Antenna Connectors

Front to Back Ratio – this ratio indicates the ratio of forward and backward signal transmission. Most if not all antennas radiate also to the back of the main beam, which is often due to the signal bending from the main beam. You want this ratio to be as large as possible unless you plan to utilize also the back beam (this is not usual).

Environmental Protection and Ruggedness – select an antenna with a suitable IP rating and made of materials that will survive the environment it will be installed in. Most antennas are enclosed in hard plastic, but there are also all metal antennas (suitable for very harsh environments or where they will suffer impact) or antennas encased in rubber (for mounting on the ground).

4.2 Antenna Selection Criteria Review

1. **Frequency** – this will depend on your tags – choose between LF, HF, UHF or Microwave frequency.
2. **Frequency Region** – Global, USA, EU, country specific – use global or per region
3. **Read range and size** – smaller antennas within the same frequency will have shorter read range and vice versa.
4. **Profile width** – if you are short on space or for esthetic reasons, you may need to look for low profile antennas that have a side connector or a side pigtail.
5. **Gain** – gain affects read range and beamwidth. Antennas with higher gain will have longer read range but narrower beam. Antennas with lower gain will have shorter read range and wider beam width.

6. **Polarization** – Circular, Dual Circular, or Linear.
7. **VSWR** – look for VSWR as close to 1:1 as possible.
8. **Axial Ratio** – look for as close to 1 or 0 dB as possible.
9. **Beam Width** – based on your application and need for coverage.
10. **Antenna Connectors** –N-type, RP-TNC and SMA. Consider your space and mounting. Some are bulkier than others, SMA is the smallest.
11. **Front to Back Ratio** – You want this ratio to be as large as possible unless you plan to utilize also the back beam (this is not usual).
12. **Environmental Protection and Ruggedness** – select an antenna with a suitable IP rating and made of materials that will survive the environment it will be installed in.

5. RFID Regulations

Although the worldwide regulatory requirements are not unified, any radio-frequency (RFID) protocol must meet the *lowest common denominator* of competing national and international regulations. Each region or country has their own rules for RFID operations and they differ by frequency band used, allowed transmitted power, number of channels, channel usage and other parameters.

> ***Note**:* Normally, a user does not have to worry about the mechanics of the regulations as long as he/she uses a reader that is specified and certified for usage in the particular region.

Country	Governing bodies
USA	Federal Communications Commission (FCC)
Canada	Department of Communication (DOC)
Europe	• European Radiocommunications Office (ERO) • European Telecommunications Standards Institute (ETSI)
Japan	• Ministry of Public Management, Home Affairs, Post and Telecommunications (MPHPT) • Ministry of Internal Affairs and Communications
China	Standardized Administration of China (SAC)
Singapore	Infocomm Development Authority (IDA) of Singapore
Oceania	Australian Communication Authority, New Zealand Ministry of Economic Development

Fig. 5.1 Selection of Regional RFID Governing Bodies

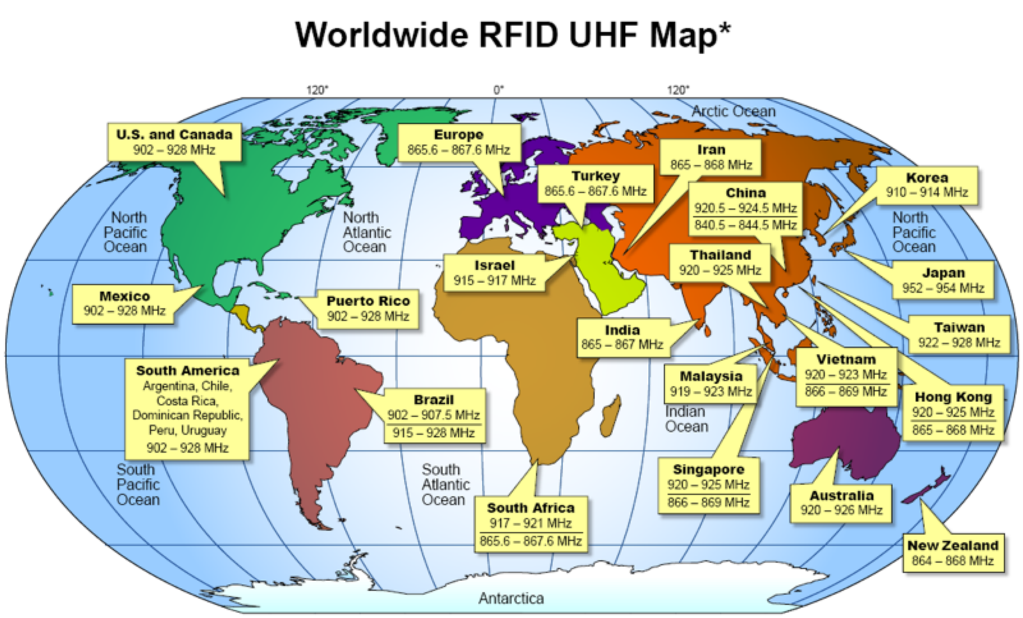


Fig. 5.2 Worldwide UHF RFID Map

Country	Regulators/ Regulations	Frequency	Bandwidth	Channel spacing	Maximum Power
USA	FCC Part 15, Section 247	902–928 MHz	26 MHz	52 channels of 500 kHz spacing	4 W EIRP FHSS
Europe	ETSI 302-208	865-868 MHz 915-921 MHz	3 MHz 6 MHz	15 channels 200kHz 14 channels 400kHz	2 W ERP 4 W ERP
Japan	MIC	952-956 MHz	2 MHz	Either LBT free with 4 x 200KHz channels for readers or LBT	4 W EIRP (Lic. Req.)
India	DOT	865-867 MHz	2 MHz	10 channels of 200kHz spacing	4 W EIRP
China	SRRC	840.5-844.5 MHz 920.5-924.5 MHz	2 MHz	20 channels 250 kHz spacing	2 W ERP FHSS

Fig. 5.3 Selection of Regional RFID Regulations Overview

5.1 US Regulations

In the United States, the Federal Communications Commission (FCC), Part 15, regulates the use of radio frequency devices. In the United States, UHF can be used unlicensed from 908 to 928 MHz, but restrictions exist for transmission power and channel usage.

Regulations require frequency hopping within 902 to 928 MHz. If the 20 dB bandwidth of the hopping channel is:

- Less than 250 kHz, the system uses at least 50 hopping frequencies and the average time of occupancy on any frequency is not be greater than 0.4 seconds within a 20-second period.
- 250 kHz or greater, the system uses at least 25 hopping frequencies and the average time of occupancy on any frequency is not be greater than 0.4 seconds within a 10-second period.

Don't Miss! The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz (50 channels).

In addition, FCC mandates that total power aka Effective Isotropic Radiated Power (EIRP) can be maximum of 4 Watts (36 dBm), which is based on the maximum allowed output from the reader must can adjust the reader power down and together it always has to be under 4 W/36 dBm EIRP. Cable loss also plays a factor in this equation.

EIRP = Power from the reader + antenna gain – cable loss = 36 dBm/4W max

dBm and Watt

dBm	Watt
36	4
33	2
30	1
27	0.5
24	0.25

dBm	Watt
50	100
40	10
30	1
20	0.1
10	0.01
0	0.001

Fig. 5.4 Quick Guide for Conversion of dBm and Watt

5.2 EU Regulations

In the EU, regulations for RFID are provided by ETSI. The standard that applies to RFID today is the ETSI 302 208, which governs communications in two bands, upper and lower (the upper band is not allowed in most countries due to interference).

The Lower Band (used by most ETSI RFID Readers) is specified as:

- 865.0 – 868.0 MHz
- 15 channels – 200 kHz each
- Only 4 channels usable w. 2W power – 4, 7, 10 and 13 for reader operations, remaining channels are left for use by the tags to send responses.
- Three sub-bands with different allowed ERP
- Up to 2 W ERP middle subband
- Required LBT

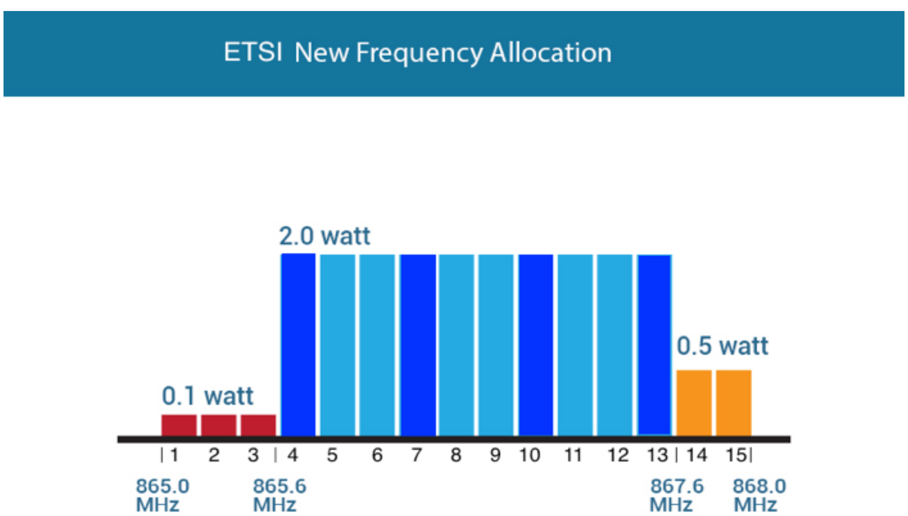


Fig. 5.5 ETSI RFID Regulations

The Upper Band (not allowed in most countries, only Russia so far) is specified as:

- 915 – 921 MHz
- 14 channels – 400 kHz each
- Only 4 channels usable for reader operations 3, 6, 9 and 12, rest used by the tags.
- Up to 4 W ERP
- Required LBT

As you can see, the power limits in the EU are specified in ERP (Effective Radiated Power).
Regulations expressed in effective/equivalent isotropic radiated power (EIRP) are based on the spherical radiation pattern of an isotropic emitter. Real antennas (such as dipoles) do not radiate uniformly in all directions (such as no power is radiated along the axis).

Effective radiated power (ERP) levels relate to the dipole antenna. The relationship between the gain of an isotropic and a dipole antenna is given by:

P(EIRP) = P(ERP) × 1.64 (approx 2.2 dB)

Don't Miss! The European limit of 2 W ERP is equivalent to 3.28 W EIRP. In the United States, it is 4 W EIRP.

More Info: For more information on RFID Regulations, visit our website: http://rfid4u.com/rfid-basics-resources/basics-rfid-regulations/.

6. RFID Mandates

Several large retailers (such as Wal-Mart, Target, BestBuy, etc.) and the Department of Defense (DoD) are requiring their suppliers to provide shipments with UHF radio-frequency identification (RFID) tags on pallets, and cases.

6.1 Walmart Mandate

Wal-Mart is in the industry leadership position with in passive radio-frequency identification (RFID) standards. The standards are:

- Cases and pallets must be tagged (that is, no individual items).
- Wal-Mart supports EPC Gen 2. Tag EPC size standard is 96 bit.
- Case and pallet shipments will require SGTIN-96 or SSCC-96.
- 100% read rate required as follows:
  - Dock Door–read distance up to 10 feet.
  - Conveyor–read at a speed of 600 FPM.
  - Hand Held–read distance of up to 6 to 8 feet.
- Advanced shipping notice (ASN)/electronic data interchange (EDI).
- No endorsed or mandated manufacturer. The companies should evaluate the technology for themselves.

***Note**: Companies should evaluate the technology for themselves.*

Performance Requirements:

- Tags on both pallets and cases, with returnable containers, shrink wrapped bundles, bags, and DSD delivery trays defined as cases.
- Pallet tags need to be read at a distance of up to 10 feet from the antenna a minimum of three times to be counted as a successful read.
- 100% tag read performance regardless of orientation.
- Individual cases read on conveyors operating at up to 600′ per minute (fpm) with a 6″ separation between cases.
- Current human readable and bar code.
- All product types

Case type	RFID Tag required	Tag Data
Single item and standard assortment stock keeping units (SKUs)	Yes	Global trade item number (GTIN)
Mixed SKU non-standard assortments (that is, custom pack)	Yes, if advanced shipping (shipment) notice (ASN) is sent.	Serial shipping container code (SSCC)
Masterpack cartons containers	Yes. Vendor packs carton	GTIN
Breakpack cases	No	N/A (GTIN)

Pallet type	RFID Tag required	Tag Data
Single item and standard assortment SKUs	Yes	GTIN
Mixed SKU non-standard assortments (that is, custom pack)	Optional	SSCC

Fig. 6.1 Walmart RFID Mandate Tagging Requirements

6.2 DoD Mandate

The DoD standards include:

- Cases and pallets.
- DoD will support EPC Gen 2 - 96 bit.
- Case and pallet shipments will require SGTIN-96 or SSCC-96.
- 100% read rate required:
    - Portal–read distance up to 3 meters at a speed of 10 miles per hour (mph).
    - Conveyor– read distance up to 1 meter at a speed of 600 feet per minute (fpm).
- All RFID tagged shipments also require an advanced shipping (that is, shipment) notice (ASN) be submitted through the DoD's electronic commerce capability called Wide Area Work Flow (WAWF).
- Electronic data interchange (EDI)
- Web based.
- User-defined format.

More Info: For more information on RFID Standards and Mandates, visit our website: http://rfid4u.com/rfid-basics-resources/how-to-select-a-correct-rfid-tag-standards-mandates/.

7. Site Inspection and Planning

Before you can start designing an RFID system you must first perform a site inspection. This is one of the most important parts of any implementation and one that should not be skipped.

Don't Miss! A careful evaluation and documentation of environment including its RF properties as well as the business processes is essential to guiding system design, equipment selection and installation. It also helps vendors and customers set realistic performance expectations as well as helps the rest of the deployment team (if external) visualize the site.

7.1 Physical Site Inspection

During the site survey, the following should be examined and documented:

- **Type of facility** – the equipment installed must fit esthetically as well as survive the conditions. In certain facilities, there are special requirements on safety of the system as well as workers including installers. There will be different requirements for hospitals, manufacturing facilities, oil and gas platforms, etc.
- **Building layout** –will help determine hardware locations as well as physical process flows. Specifically note entries, exits, dock doors, fixed assets and machinery, storage areas, power outlets, network outlets and measure spaces where your equipment will be potentially mounted and distances where the tags will travel and potential reader location.
- **Types of equipment and machinery used** – will affect the ruggedness of the hardware, its installation and protection or can create possible interference.
- **Environmental conditions** – the hardware has to survive and dust, steam, water, corrosive liquids or gasses can damage the equipment; presence of metal and liquids will affect RF performance. This will affect what type of hardware and protection you will choose (reader, tags, antennas, portals, NEMA boxes). Note:
    - Will the tags be under physical stress? (Impact, tearing, etc.)
    - Will the tags be under environmental stress? (Chemicals, steam, water, etc.)
    - What will be the temperature variations of the environment?
    - What will be the temperature variations of the assets tagged?
- **IT Infrastructure** – what kind of infrastructure is present. Is there a server for the software deployment? Cloud Server? Internet, LAN or Wi-Fi? This will affect the communication from your readers to the middleware and the back end system.
- **Electrical Infrastructure** - Power outlet location, wiring whether there a reliable power available 24/7.
- **Surrounding area** – nearby operations can provide interference.
- **Workflow and business processes** (such as how material and personnel moves around, production line schedules, receiving and shipping schedules, etc.) – very

important for system design, especially hardware selection and placement and software logic.

- **Local regulations** (such as local radio frequencies) – this is especially important if this is in a different country or region than you are familiar with
- **Company regulations and policies** - such as safety equipment, security, etc.
- **Union policies** - who can perform which work.
- **RF site assessment of the facility** – important to learn about potential interference.

***Note**:* Best practice is to take photos of the facility, tagged product and everything you can.

7.2 RF Site Assessment

There are electromagnetic waves and radio frequency (RF) signals already in your environment that can and will interfere with your radio-frequency identification (RFID) system.

Some sources of radio-frequency (RF) interference include:

- Conveyor belts, electronic motors on lift trucks, electric pallet jacks, heavy machinery, etc.
- Wireless networks, short-range radios, cordless phones, etc.
- Everything from bug zappers to old 900MHz wireless local area network (LAN) equipment to neon lights
- Adjacent facility or one above or below

These RF signals may be intentional or unintentional from internal or external sources. The competing frequencies can cause many of the tags to be missed because the RFID reader is also picking up other frequencies than just those being sent from the RFID tags. This may interfere with reading the tags.

To identify the sources of interference you should use **a spectrum analyzer**. It uses a broad frequency spectrum antenna to identify all frequencies present, their strength, and their direction. This tells you what frequencies will cause the most trouble operating your RFID system. Similarly, it also indicates if your new RFID system interferes with your existing wireless communication systems or other RF sensitive devices. In difficult environments you can perform further analysis, such as:

Full Faraday Cycle Analysis (FFCA) over a full operational business cycle which typically is a minimum of 24 to 48 hours. It is conducted over a period of time and considers the how the RF environment might vary over time.

RF Path Loss Contour (PLC) analysis at the planned locations of your radio-frequency identification (RFID) interrogation zones. Considers space and how the RF environment varies over the area that you are trying to serve.

This information is critical to properly define deployment variables such as antenna direction and location, power setting, and field strength. The RF Site Survey not only maps the area as far as RF signal, it also provides insight into how readers should be configured for optimal performance with minimal RF coverage and helps define the blueprint for optimal tuning of interrogation zones.

7.3 Planning

The result of the Site Inspection and Site Survey is the radio-frequency identification (RFID) network architecture plan that includes topological specifications such as:

- Location and set-up of readers and peripheral equipment.
- Equipment specifications, such as reader and tag selection.
- Reader configuration settings such as power and interrogation rates and connectivity specifications governing how readers communicate and inter-operate.

It helps develop a plan to shield the RFID readers and helps modify configuration or layout to ensure a consistent performance. The information required to design a RFID network architecture includes:

- Environmental variables from site survey
- Product material
- Business process and objectives

The following information must be documented:

- Radio-frequency (RF) characteristics of the facility
- RF shielding requirements
- Number, type, and location of read points
- Number and type of readers, antennas, printers, and sensors
- Readers, antenna, printers, and sensor locations for each read point
- Computer location
- Cabling/Wiring requirements and route
- Cable lengths
- Identify power requirements
- Document planned points of connectivity into existing network
- Handheld readers required
- Any modification required to the facility

Radio-frequency identification (RFID) site assessments are very different from those conducted for wireless fidelity (WiFi) implementations. While they may employ similar testing equipment, the objectives are totally different.

- WiFi installations seek to maximize coverage by blanketing an area with radio frequency (RF).
- RFID systems try to minimize and contain RF coverage within a small read zone.

Items to consider when placing an antenna include:

- Placed at inlets, branches, storage locations, etc.
- Location is influenced by tag placement and orientation.
- Large area (such as a dock) may require multiple antennas.
- For slow moving or stationary items, multiple antennas per reader may be used.
- For fast moving items (such as boxes on conveyor), a single antenna per reader may be required.
- Must be protected from damage by environment and moving equipment.

Some variables affecting tag reads:

- Product density and moisture content
- Tag and antenna configuration
- Tag and antenna placement and orientation
- Conveyor or forklift travel speeds
- Environmental conditions
- Tag abuse (such as pressure, cuts, scrapes, etc.)
- Tag/label substrate materials
- Packaging and shrink wrap material

8. Installation

A RFID system requires installation of:

- RFID Antennas
- RFID Readers
- RF Cables
- Peripherals (RFID Printers, I/O Devices, Barcode Scanners, etc.)

Types of installations include:

- Portals (door and dock door portals)
- Conveyor
- Encoding station
- Vehicle Mount (Forklift)

Since antenna installation is the most complex part, we will discuss it first.

8.1 RFID Antenna Installation

Antenna is the most important component in a portal design. It's important to know an antenna's radiation pattern, read zone, and footprint. Antenna radiation pattern can be estimated from its datasheets.

Antenna Installation Do's:

- Connect an antenna to a reader only when it's powered off.
- Protect antenna installations with a bollard or a guard (or embed into portal or both).
- Install antennas with an adjustable swivel mount for adjustment of the antenna height and angle to modify the read zone.
- Visually inspect the possibility of interference from multipath reflections (such as from ground, other nearby antennas, etc.). If interference exists, cover all surfaces with electromagnetic interference (EMI) shielding.
- Make sure that the facing (and/or with overlapping read zones) antennas in the same portal are connected to the same reader. As reader cycles through antennas in a round robin fashion and does not allow simultaneous transmission on more than one antenna at a time.
- Is there are antennas of two nearby portals (connected to different readers) mounted in the same structure, make sure their radiation patterns do not interfere with each other (angling, shielding, different polarization).
- In case of bistatic operation (separate transmit and receive antennas), the corresponding RX and TX antenna pairs should be collocated and view the same region.
- If two antennas connected to different readers face each other, they should both have the opposite polarization – one LHCP and the other RHCP (which will reduce interference.

- Angle the antennas to increase the dwell time (the time tag spends in the read zone when traveling through).
- Use circularly polarized antennas when tag orientation is random (most of the time in supply chain).
- Consider how high and low will the tag travel (single vs. double stacked pallets, small vs. large tagged objects) and adjust the read zone accordingly (angle or possibly add antennas).
- Consider speed of travel, if necessary add antennas with the direction of travel to increase the size of the read zone.
- It may also be important to establish the **direction of travel of a tagged object** if the same portal is used for both entering and leaving the facility. This can be done by using sensors (light break sensors) or by antennas (based on which antenna registered the tag first and which one second, the antennas must be within different read zones) and configured within the middleware to determine direction.
- When using circularly polarized antennas facing each other, they should have the same polarization in order not to interfere with each other. Because they are

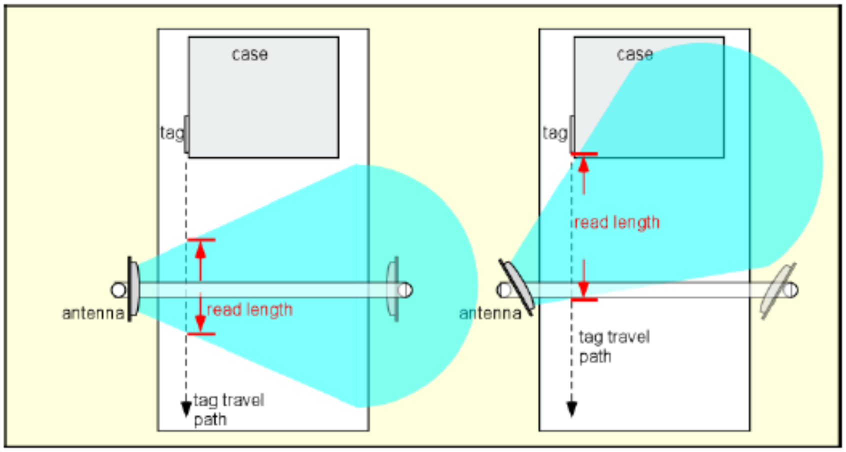


Fig 8.1 Angle your antennas to achieve longer read zone

Antenna Installation Don'ts:

- Do not disconnect the antenna when the reader is on or when the *read* is on.
- Do not mount the antenna close to ground potential. For ultra-high frequency (UHF) patch antennas keep a minimum height of 12″ to 18″.
- Don't place tags too close to the antenna. The near field region of the antenna has complex radiation patterns which are difficult to calculate and unless the tag is designed to read well in the Near Field, it may not be read. Near Field for UHF frequency is approximately within 1 foot (30 cm) from an antenna.
- Do not obstruct operations and safety zones (entries and exits must have certain clearance around).

Portals

Portals are typically sets of readers, antennas and cables that are mounted and encapsulated for installation by the entries, exits, dock doors and other areas.
A portal reader configuration is intended to identify objects with RFID tags as they pass through a doorway entering or leaving a facility (such as a warehouse, distribution center, etc.). Typically, portals use ultra-high frequency (UHF) technology due to the read range.

The objects are often cases mounted on pallets or within cages and the pallets or cages themselves. The height of pallets can vary considerably, from less than 3′ for heavy objects to 10′ for large cases with lighter less dense objects. Usually, no tag writing is done at portals.

Considerations include:

- Typically, not able to read 100% of cases on pallet.
- Cases identification only through aggregation (based on pallet tag).
- Size of door (width and height).
- Pallet movement and truck loading patterns.
- Speed of travel.
- Expected maximum amount of tags to be read per pallet.
- Physical robustness.
- Wiring configuration (such as readers, antennas, etc.).

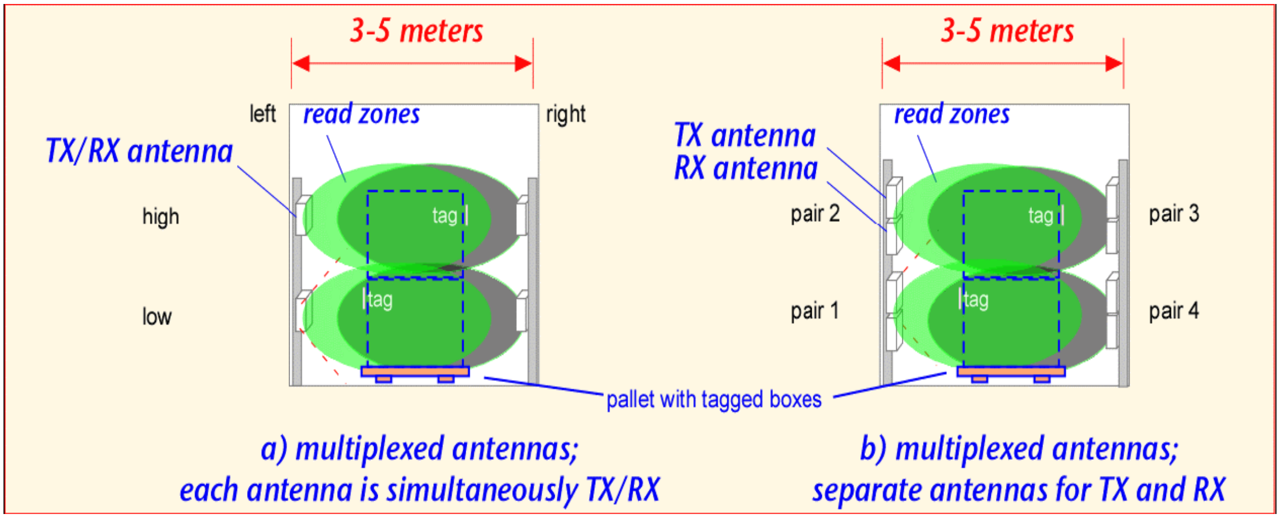


Fig. 8.2 RFID Portal Configuration

It’s not unrealistic to expect reads of 100% accuracy. Performance measures for portal are:

- **Percentage of tags read:**
  - The likelihood of reading a tag on an object passing through the portal.
  - This is formally a measure of false negatives. Tags that should have been read but were not.
- **Spurious tags read:**
  - The likelihood of reading a tag that is not within the target portal.
  - A measure of false positives. Tags that should not have been read but were read.

Spurious reads can result when

- Tagged objects are staged for transport too near the portal.
- A reflecting object passes close to an antenna.
- People walk by carrying tagged objects.
- Tags passing through neighboring portal are read.

In order to minimize spurious tag reads, it is clearly desirable to use **directional antennas** (i.e. antennas with high gain and a well-defined primary beam) so that we can create a well-defined main read zone. However, regulatory restrictions typically prevent the use of very high gains. In the United States, an antenna connected to a one-watt reader is limited to a gain of 6 dBi for unlicensed operation. A very popular antenna for this range of gain is the patch or panel antenna with:

- Typical gain of approximately 6 to 8 dBi.
- Most of the radiated power in a well-defined beam around 90° to 100° wide, perpendicular to the front face of the antenna.
- Typically 8 to12 inches on a side with adjustable mount.
- Have short cable 8 to15 feet.
- Can be linearly or circularly polarized.

***Note**:* In portal installation, four inward-facing antennas are typically used with the overlap of the read zones. This ensures good coverage of the interior region of the portal with considerations for possible variations in pallet height.

Read Zone Height

Read zone height can be figured out based on the beamwidth provided by the antenna specifications. For a carton, at a distance of approximately a half meter from the antenna, you can calculate the height of the read zone from the diagram. If a tag is placed higher or lower than the estimated height, it is likely that the tag cannot not be read.

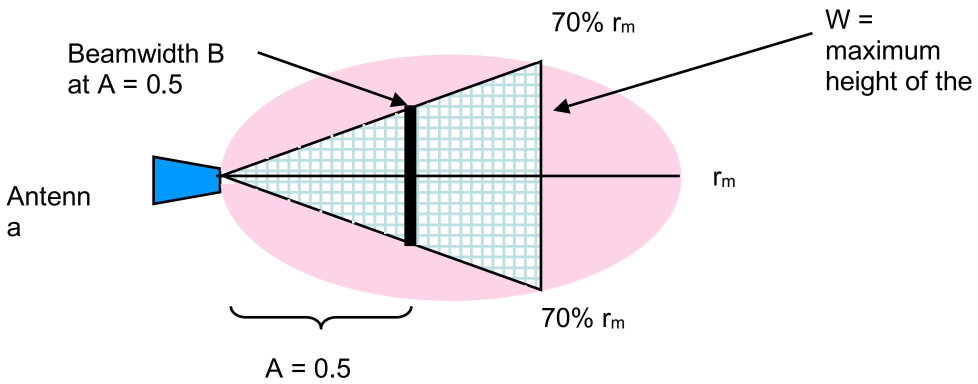


Fig. 8.3 Antenna Read Zone Height

Antenna Gain
Antenna gain is limited by regulations. An increase in gain implies an increase in the ellipsoid length. Therefore, you have an increase in read distance but a narrower zone. An increase in antenna gain may lead to more interference and reads from tags passing through neighboring portals/doors. The higher gain antenna may be used if reader power is reduced. With operational trials, decide on the antenna gain.

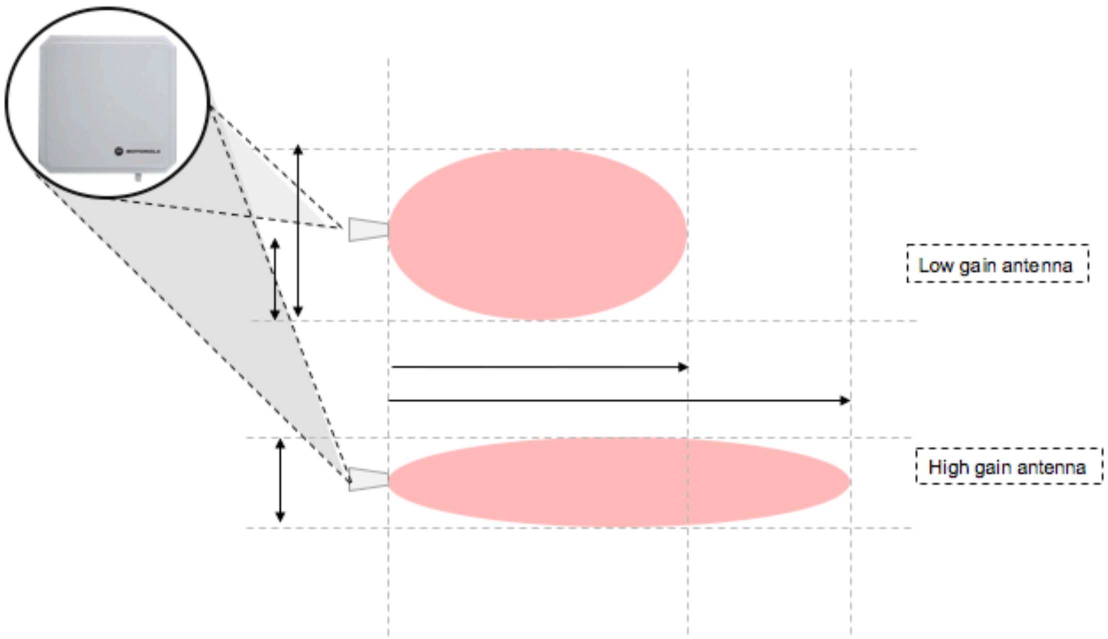


Fig. 8.4. Antenna Gain Diagram

8.2 RFID Reader Installation

Reader itself can be mounted anywhere, as long as it is in proximity of power and the antennas and easily accessible for troubleshooting.

Reader Installation Do's:

- Mount readers securely so that they are not disturbed, bumped, or damaged.
- As a rule of thumb leave five to six inches of clearance on all sides of a reader for access and ventilation.
- Place/orient readers correctly, according to the recommendations of manufacturers.
- Some readers may have environmental enclosures for protection. Place them accordingly.
- Protect your readers from environmental damage.
- Place readers so that its status indicator lights or light emitting diode (LEDs) are easily visible to an operator.
- Reader ports that are not in use should be terminated with appropriate connectors (50-ohm dummy load). Check with manufacturer's instructions, this is often built in.
- Do a reader power-on test.
- Determine if the reader is connected to host systems correctly (local area network [LAN]/Ethernet, etc.).
- Verify reader configuration parameters.
- When read is a success, is the green light on?
- Ground your readers (power outlet if fixed readers, to the chassis if vehicle mount).
- Use UPS (Uninterruptible Power Supply) to ensure surge protection and uninterrupted operation.
- Make sure that if you are using POE readers, that the facility has POE enabled. Otherwise you will have to use additional power supply to power the readers and plug them into an AC power outlet.
- Configure readers for Single, Multiple or Dense Reader Mode based on the environment.

Reader Installation Don'ts:

- Never power up a port when it is not in use (i.e. antenna is not connected).
- Don't disconnect antennas when the reader is on.
- Don't use other than manufacturer recommended power supplies.
- Don't forget to ground the reader, especially when attached to vehicles (ground to the chassis).

Multiple readers operating on the same portal may interfere with one another. A number of techniques can help limit these unwanted effects:

- Direct antennas of different readers away from each other.
- Connect antennas whose read zone overlap to the same reader.

- Use photo-cell triggering to initiate reading and don't have the reader transmit without having a tag nearby.
- Set reader power and duty cycle correctly (based on calculating gain, cable losses, etc.).
- Limit the number of tags in a reader's field (based on speed of travel).
- Shield between antennas of different readers (that is within the same portal) with absorptive material. Use low density materials or metal mesh.

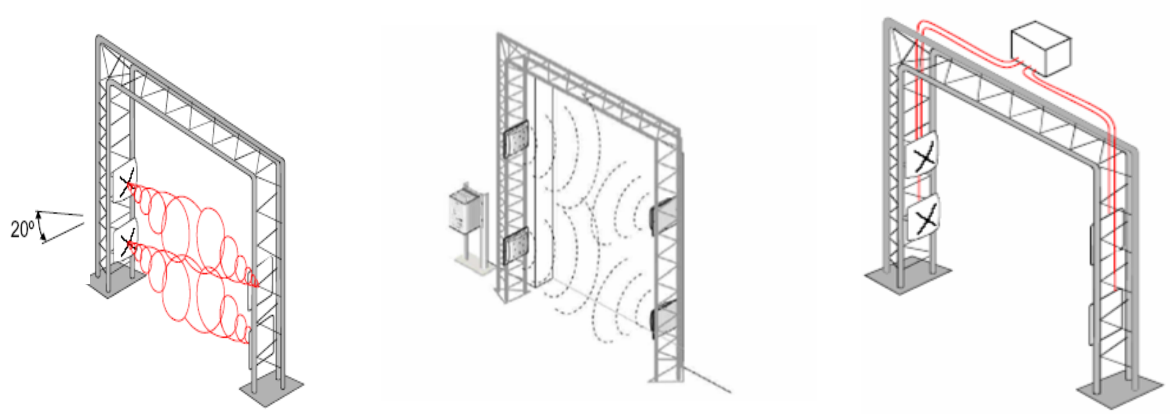


Fig. 8.5 RFID Portals

8.3 RF Cable Installation

Cables are very important part of the system as they connect the antennas to the interrogators. There are several best practices to follow when installing RF cables.

Cable Installation Do's:

- Cable lengths from one reader to pairs of antennas should be equal (to ensure that the attenuation is equal).
- Select RF cables with low attenuation.
- Know cable attenuation in dB/m.
- The thicker the cable the lower the loss/attenuation but less flexible and more expensive the cable is.
- The thinner the cable, the higher the loss but more flexible and cheaper.
- If RF cables are stiff/inflexible, secure them correctly so that they are not under mechanical stress.
- Coil up extra cable lengths.
- Common cables used for RFID antennas are LMR-195, LMR-240 and LMR-400 (from the thinnest to the thickest).
- Make sure the cable connectors match your reader and antenna port connectors (i.e. pair SMA Female with SMA Male, RP-TNC Male with RP-TNC Female, etc.).

Cable Installation Don’ts:
- Don’t bend the cables in sharp angles
- Avoid excessive cable lengths (over 25 ft)
- Don’t strip or damage the cable insulation

8.4 RFID Tag Placement and Installation

- Ensure that the tagged item does not travel too close to an antenna or too far from the antenna.
- Avoid antenna near fields. For ultra-high frequency (UHF), this is about 1 ft or 30 cm.
- Place markers/guards accordingly, near the antenna positions.
- Ensure that the tag and the reader have direct line of sight for UHF operations as much as possible.
- Position the tags on the outside of the pallet load. Avoid overlapping or stacking labels.

8.5 Peripherals Installation

Whether you are installing triggering devices, notification devices, or RFID printers encoders, there are some best practices to follow:

- When there is a need to determine direction of travel, place two sets of **photo eyes,** one before and one after the read zone.
- To save on power and reduce RF noise, especially in operations when the tags pass the read zone infrequently, use **triggering devices**, such as **photo eyes** or **proximity sensors** to turn on the reader. Make sure they are configured correctly in order to trigger the reading in time.
- Use **light stack** for notifications on read status – green – successful read, orange – reader on, red – reader error. You can also use **audible indicators** where light indicators are not sufficient.
- Install an **RFID Printer Encoder** based on manufacturer’s specifications. Ensure enough space is for ventilation, connections and to open the media door for media and ribbon replacement. You will need power and network connections in order to run the printer. Don’t forget to calibrate the printer for the particular media before you start printing and encoding.

8.6 General Installation Check List

- Check correct placement and function of photo sensors and proximity sensors
- Check functions of I/O devices and their correct placement.
- Visually inspect the installed AC outlets and Ethernet cable runs.
- Visually inspect radio-frequency (RF) cables.
- Perform a RF Spectrum Analysis to see the level of *noise* interference in the UHF band after installation.

Fig. 8.6 Examples of RFID Portal Installations

9. Testing and Troubleshooting

RFID systems are not plug and play and even with careful planning, design and installation, the system performance can have problems. What are the factors that affect the system performance the most?

- Varying readability of the tag from location to location or even at the same location at different times.
- Cost of the tag relative to the object.
- Object material to which the tags are attached (such as the size and shape of object relative to the tag, absorptive or reflective material, etc.).
- Environment where the system is deployed.
- Lack of availability of plug-N-Play hardware (HW) and (SW).
- Hard to establish industry standard practices as each system, environment and tagged product is different.

9.1 Challenges

There are many factors affecting tag readability within the RFID system. These include tag design and what condition it is in, what objects are tagged and what they are made of, RF characteristics of the read zones and the whole environment as well as the system design and configuration.

The Tag Design and Condition

- Tag types (such as frequency, communication protocols, tag antenna configuration, etc.).
- Tag chip sensitivity
- Tag substrates, including electrical and mechanical properties.
- Tag placement and orientation relative to reader antenna and at pallet, case, or item levels.
- Tag abuse (such as pressure, cuts, scrapes, etc.).

Tagged Objects and Packaging

- RF absorbing water/liquid content in objects being tagged.
- RF absorbing water content in corrugated cardboard packaging, with added variability due to changing relative humidity of indoor/outdoor climates.
- RF reflecting and/or RF shielding metal content in both goods and packaging, even foils and metallic inks.

The RF Characteristics of the Read Zone

RF fields are like Swiss cheese, as they have many holes. Holes are the areas where the RF field is weak and tags in that area may not be read or the read distance may be low. All of these holes are caused by reflections (such as a filing cabinet, forklift, floor, etc.). Additionally, the shape of RF field changes from location to location. The shape and location of holes within the field may change from location to location or even at the same location at different times, due to external events, such as:

- Signal interference from other RF devices.
- The reflective and/or shielding characteristics of read zone surroundings.
- Electromagnetic interference from electric motors.
- Interference from power lines.
- Hidden structural elements, such as the amount of rebar or wiring placed in the floors or walls of a building.
- Interference from neon lights.

System Design
System design and configuration variables affecting RFID system include:

- Tag and reader antenna distance and the inverse correlation of distance to the readability.
- Number of reader antennas and their configuration and location.
- Reader protocols (that is, depending on the manufacturer).
- Single, Multiple, or Dense Reader Mode and correct reader configuration.
- Tolerances between readers and tags and their performance specifications.
- Throughput speeds of pallets, cartons or items on forklifts, pallet jacks, or conveyors.
- Number of tags in the read zone at any time.
- Type and speed of the label/tag applicator mechanism.
- Data network architecture, efficiency, and robustness.
- Software device and data management architecture, efficiency, and robustness.
- Degree of automation and efficiency of business processes in handling exceptions.

9.2 Troubleshooting

Radio-frequency (RF) field problem resolution is addressed by:

- Using spectrum analyzer to identify types of radio-frequency (RF) noise in the read zone.
- Installing RF shields to prevent RF interference from other readers or RF devices.
- Relocating antenna, changing orientation, or replacing with different design.
- Using directional antenna.
- Using an antenna with higher or lower gain.
- Increasing or reducing reader power.

- Synchronizing readers.
- Using Multiple or Dense Reader Mode.
- Changing tag orientation and location vs. the reader antenna to avoid RF holes and wrong orientation
- Read tags in motion to prevent shadowing
- Changing business processes.
  - Eliminating the use of interfering hardware (often obsolete or damaged hardware can create interference).
  - Changing the routes of moving heavy machinery or generate alarms to not use handheld radio-frequency identification (RFID) readers while they are in the vicinity.

Consider some of the following solution scenarios for portal installation:

- To sense the direction of movement, use portal motion detectors and indicator lights.
- When you're unable to read all the cases on the pallet, inner case tags may not be read, a pallet tag may keep list of all the cases on it.
- If shrink wrap is intact and the pallet tag can be read then accept that all the cases on the pallet are received.
- Get the list of cases from the backend information technology (IT) system.

The photo below is an example of a portal reader installation.

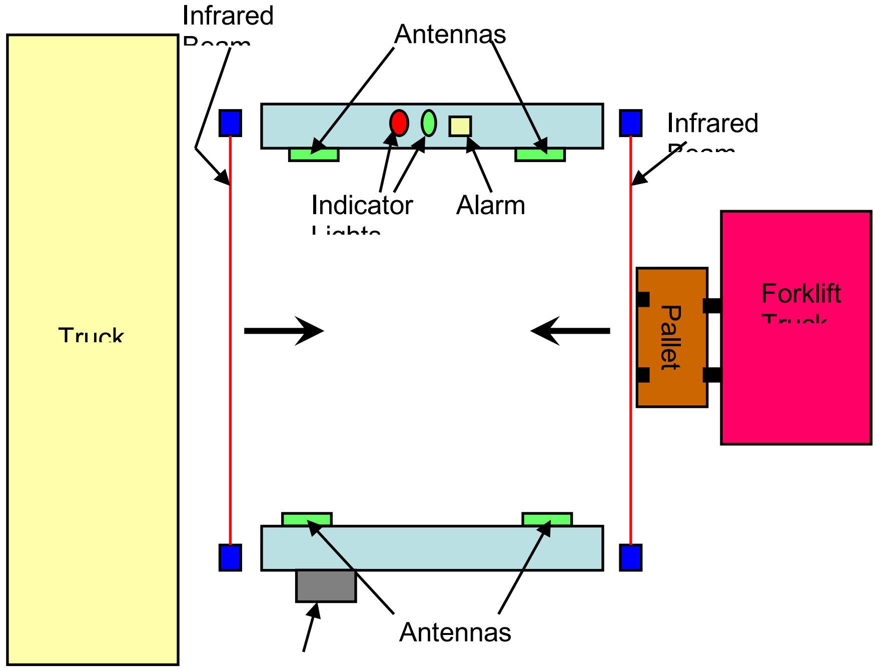


Fig. 9.1 Diagram of an Interrogation Zone

Detecting Missed Reads

Most of the time, at the receiving portals, you don't know the details of what you are receiving. This means you don't know what you didn't read. Proper coordination among all parties involved will greatly reduce this problem. This requires business process modification.

- Compare with what you are expecting. You can use an advanced shipping (that is, shipment) notice (ASN) or some other form of report indicating what you are supposed to receive and compare it with what you read.
- Compare several reads at different places in your processes and update your read.
- Check for association between items and get the missed read data.

Randomly Missed Reads

Randomly missed reads occur when readers hop pseudo-randomly from one channel to another between available frequencies (902 to 928 MHz in the United States). Tag responses vary slightly with this small change in frequency, but with many metal components around reflecting radio waves, it may affect read performance of the tag.

Since frequency varies randomly as the reader hops, a good read may be delayed while waiting for a favorable hop frequency. This may give rise to unpredictable missed reads at high speeds for instance on high-speed conveyors.

Conveyor Belt Reading

Conveyor belts are used to move boxes and totes around within the facility. The items moved may be of any size and may have tag on any side. Thus, the tag must be reliably read regardless of location, orientation, or angle of the object on the conveyor. In addition, conveyors are made of metal which can detune or block the RF signal, however, they don't require long read ranges and only small amount of tags is present in the read zone at one time.

- Use circularly polarized antennas directed at 45º angle to elongate the read zone and read tags at various orientations.
- Use more than one antenna or a metal plate opposite to utilize the RF reflections.
- Realize that circularly polarized waves from bottom antenna become linearly polarized after passing through metal rollers.
- If possible, replace metal rollers with plastic ones at the read point help resolve reflection and detuning problem.
- Install non-metallic guards or bumpers to prevent tag to touch the metal side of the conveyor in the read zone to prevent tag detuning and blocking of RF.
- Install radio-frequency (RF) shielding and absorbing material to make sure antennas do not reach other read zones.

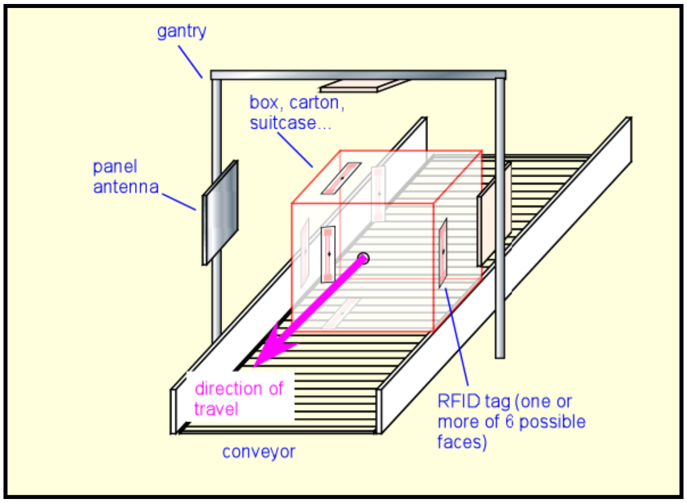


Fig. 9.2 Conveyor Reading

Tag Reading Problems Due to Product and Packaging

It is difficult to tag many **liquid products**, because water absorbs electromagnetic radiation at ultra-high frequencies (UHF). UHF waves bounce off of **metal**, making it difficult to read tags on canned goods, items in foil wrapping, and other products made of metal or contained in metal packaging.

Other materials that can cause problems:

- RF energy is absorbed by containers made with **carbon fibers**, which are often used in the electronics industry to prevent electrical components from being damaged by electrostatic discharges.
- Electronic parts are often shipped in bags that may look like a clear plastic, but are actually **conductive packages**. Created to prevent static discharge from damaging the parts, they may very well block RF.
- RF energy is also absorbed by containers designed to be used in microwave ovens.
- Frozen foods can be a problem because the tags are detuned by the frost and condensation.

How to mitigate these issues:

- When deciding on tag placement on a box, choose a location on the case where the tag is not affected by the contents of the case. Utilize air gaps.
  - For example, when tagging a case of wine, a tag would be very difficult to read if it were placed on the case where the bottles touch the corrugated box. However, a tag placed in front of air gaps created by the necks of the bottles would be easy to read.
- Consider how cases typically travel on conveyors in your facilities and how they are stacked on pallets.

- If cases are always stacked the same way, then it makes sense to put the tag on the side of the case that faces outward when it's on a pallet.
- If the orientation of tag is unpredictable, install multiple antennas at the read zone. That way, you can read the tag from any side of the box. This helps read the boxes with radio frequency (RF) reflecting or absorbing material inside.
- Use tags that are specifically tuned for performance on certain materials. Use tags for metals, liquids and moist products, wood, cardboard and other materials.
- Use dual-dipole antenna tags that have unpredictable orientation as this increases chance of being energized by RF waves.

There is plenty of air around the necks of wine bottles

Gillette puts a tag where there's an air gap in the case

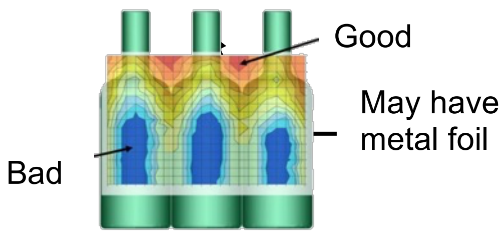


Fig. 9.3 Tag Placement on Product

Problem Resolution Checklist

When no tags are read:
- Is the reader on?
- Is the reader's error light on?
- Is AC power connected and functional?
- Is the network or serial port functional?
- Is the RF cable in good condition, unbent, properly connected?
- Is the antenna connected?

Slow reads (that is, takes longer to read all tags).
- Is the network too slow or overloaded?
- Are too many tags in the field for reader capacity?
- Reader may have to try several times to read a tag due to RF interference.
- Check all settings of reader configuration.

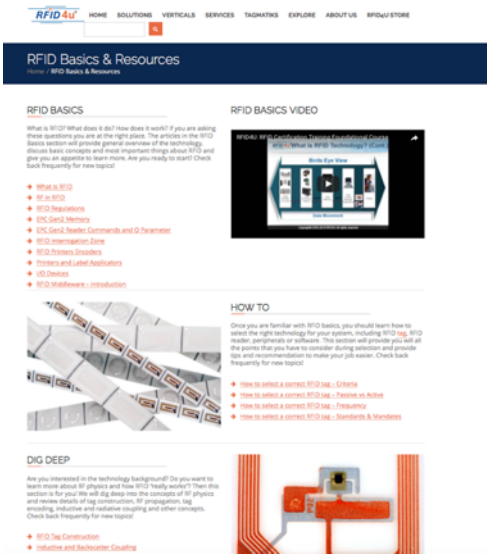
Intermittent missed reads

- Is there RF interference?
- Are there reflections from passing objects?
- Check for poor or loose connectors.
- Power level at the tag may be too low or marginal for the tag distance.
- Incomplete RF coverage of the read zone.
- Reader may not be able to keep up with the number of tags passing through its field.
- Too many antennas or protocols to cycle through.
- Too many tags moving too fast.

Spurious reads

- Is there another reader or tag located within reader range?
- Has a tag passed by?

10. Resources



For more resources, please visit our website https://www.rfid4u.com/.

We have prepared an Explore Portal that provides a lot of information about RFID technology, from basics to the depth. https://rfid4u.com/rfid-basics-resources/

Part of our Explore Portal is also the RFID Certification Prep page that helps prepare for the RFID Certification by RFID Professional Institute but also provides a great overview of all RFID Basics. https://rfid4u.com/explore/rfid-certification-prep/

You should also visit our Blog that covers technology applications and news. https://rfid4u.com/category/blog/

And last but not least, check out the Training Schedule for upcoming training classes for RFID Certification, AIT, NFC and other topics! https://rfid4u.com/services/training/training-schedule/