What is RFID? | The Beginner's Guide to How RFID Systems Work

What is RFID?

RFID is an acronym for Radio Frequency Identification which means RFID is the wireless, non-contact use of radio frequency waves to transfer data and identify objects, animals, or humans. RFID systems are usually comprised of an RFID reader, RFID tags, and antennas. RFID is widely used in industries like healthcare, retail, hospitality, and manufacturing - just to name a few. RFID is just like barcodes but is not restricted by line-of-sight. In this RFID beginner's guide, we will walk you through the most common questions about RFID, like what is RFID, what is the meaning of RFID technology, how does RFID work, and what is RFID used for.

Welcome to the Beginner's Guide to How RFID Systems Work! This guide is ideal for those new to RFID and who want to find answers to what is RFID, what's the meaning of RFID technology, how RFID is used, what are the different types of RFID, and how to build RFID systems?

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How Does RFID Work?

Tagging items with RFID tags allows users to automatically and uniquely identify and track inventory and assets. RFID uses radio waves sent via an RFID antenna to RFID tags in the surrounding area. RFID readers amplify energy, modulate it with data, and send the energy at a certain frequency out to an RFID antenna cable to the connected RFID antenna. To learn more about the physics of RFID, take a look at our article - RF Physics: How Does Energy Flow in an RFID System?

The ability to identify each individual RFID tag being read is all thanks to a unique identifier (unique information) in the RFID tag's memory. This unique identifier enables two physically identical items to be easily distinguished from one another by a simple read.

RFID takes auto-ID technology to the next level by allowing tags to be read without line of sight and up to 30+ meters away.

RFID has come a long way from its first application of identifying airplanes as friend or foe in World War II back in the 1930s. Not only does the technology continue to improve year over year, but the cost of implementing and using an RFID system continues to decrease, making RFID more cost-effective and efficient. For more information about how RFID is continuing to improve, check out our article - RFID Failed You in the Past? It May Have Improved More Than You Think.

What is RFID Used For?

Examples of applications that benefit from RFID are endless. Applications extend from broad areas like inventory tracking to supply chain management and can become more specialized depending on the company or industry. Types of RFID applications can span from IT asset tracking to textile tracking and even into specifics like rental item tracking.

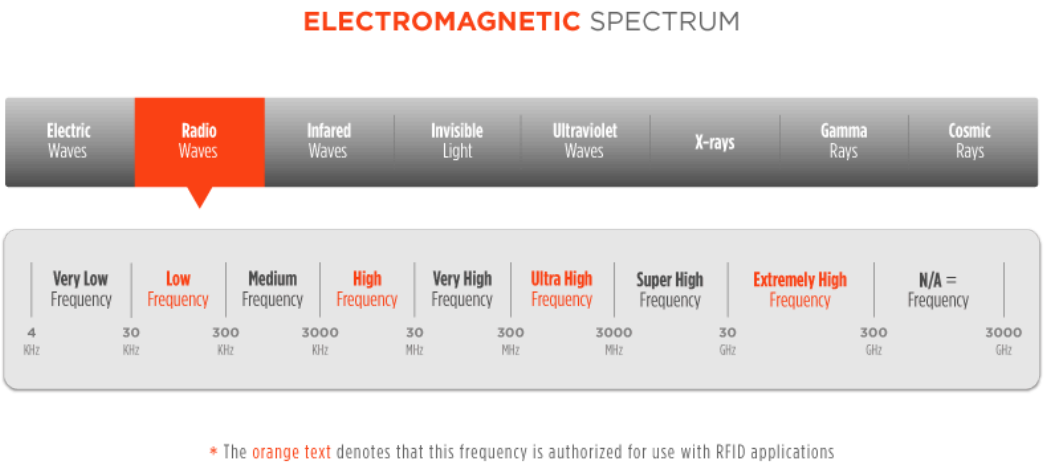
What sets a potential RFID application apart from applications that can use other types of systems is the need to uniquely identify individual items quickly and more efficiently where traditional systems fall short. Below are a few applications that are successfully using RFID technology.

- Race Timing
- Supply Chain Management
- Pharmaceutical Tracking
- Inventory Tracking
- IT Asset Tracking
- Laundry & Textile Tracking

- File Tracking
- Returnable Transit Item (RTI) Tracking
- Event & Attendee Tracking
- Access Control
- Vehicle Tracking
- Tolling
- Hospital Infant Tracking
- Animal Tracking
- Tool Tracking
- Jewelry Tracking
- Retail Inventory Tracking
- Pipe and Spool Tracking
- Logistics Tracking (Materials Management)
- DVD Kiosks
- Library Materials Tracking
- Marketing Campaigns
- Real-Time Location Systems

Types of RFID Frequencies

When learning about RFID technology, it is important to note that there are three main areas or frequencies that all have different read ranges and specifications.Within the Electromagnetic Spectrum, there are three primary frequency ranges used for RFID transmissions – Low Frequency RFID (LF RFID), High Frequency RFID (HF RFID), and Ultra-High Frequency RFID (UHF RFID).



Low Frequency

- General Frequency Range: 30 - 300 kHz
- Primary Frequency Range: 125 - 134 kHz
- LF RFID Read Range: Contact - 10 Centimeters
- Average Cost Per LF RFID Tag: $0.75 - $5.00
- Applications: Animal Tracking, Access Control, Car Key-Fob, Applications with High Volumes of Liquids and Metals
- Pros: Works well near Liquids & Metals, Global Standards
- Cons: Very Short Read Range, Limited Quantity of Memory, Low Data Transmission Rate, High Production Cost

High Frequency

- Primary Frequency Range: 13.56 MHz
- HF RFID Read Range: Near Contact - 30 Centimeters
- Average Cost Per HF RFID Tag: $0.20 - $10.00
- Applications: DVD Kiosks, Library Books, Personal ID Cards, Poker/Gaming Chips, NFC Applications
- Pros: NFC Global Protocols, Larger Memory Options, Global Standards
- Cons: Short Read Range, Low Data Transmission Rate

Ultra-High Frequency

- General Frequency Range: 300 - 3000 MHz
- Primary Frequency Ranges: 433 MHz, 860 - 960 MHz

There are two types of RFID that reside within the Ultra High Frequency range: Active RFID and Passive RFID.

Ultra-High Frequency: What are the Differences between Passive vs. Active RFID?

What is Active RFID?

- Primary Frequency Range: 433 MHz, (Can use 2.45 GHz - under the Extremely High-Frequency Range)
- Active RFID Read Range: 30 - 100+ Meters
- Average Cost Per Active RFID Tag: $15.00 - $50.00

- Applications: Vehicle Tracking, Auto Manufacturing, Mining, Construction, Asset Tracking, Cargo Container Tracking, Construction Tools
- Pros: Very Long Read Range, Lower Infrastructure Cost (vs. Passive RFID), Large Memory Capacity, High Data Transmission Rates
- Cons: High Per Tag Cost, Shipping Restrictions (due to batteries), Complex Software may be Required, High Interference from Metal and Liquids; Few Global Standards

What is Passive RFID?

- Primary Frequency Ranges: 860 - 960 MHz
- Passive RFID Read Range: Near Contact - 25 Meters
- Average Cost Per UHF RFID Tag: $0.08 - $20.00
- Applications: Manufacturing, Pharmaceuticals, Tolling, Inventory Tracking, Race Timing, Asset Tracking, Supply Chain Management, IT Asset Tracking, Tool Tracking, Laundry Tracking, Library Management, Access Control, User Experience
- Pros: Long Read Range, Low Cost Per Tag, Wide Variety of Tag Sizes and Shapes, Global Standards, High Data Transmission Rates
- Cons: High Equipment Costs, Moderate Memory Capacity, High Interference from Metal and Liquids

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Passive RFID Focus

Primary Subsets of Passive RFID

The relatively wide range of 860 - 960 MHz is recognized as the ‘Global Standard’ for UHF Passive RFID; however, its late adoption led to the range being further divided into two primarily subsets – 865 – 868 MHz and 902 - 928 MHz. RFID tags and equipment can either operate on one of these subsets, or on the global range, depending on the manufacturer and the region of operation for the RFID system.

865 - 868 MHz - ETSI

The European Telecommunications Standards Institute (ETSI) is the governing body in Europe that sets and upholds country-wide standards for communicating via multiple channels, including Radio Waves. By ETSI’s regulations, RFID equipment and tags are only allowed to communicate on the smaller frequency range of 865 - 868 MHz because other types of radio communications are allocated to subsets of the larger range of 860 - 960 MHz.

Because ETSI sets the standards for Europe, when purchasing tags and equipment, the standard can be called either ETSI or EU denoting Europe.

902 - 928 MHz - FCC

The Federal Communications Commission (FCC) is the governing body in the United States that sets and upholds country-wide standards for electromagnetic communication via multiple channels including those used for RFID. The FCC regulations state that RFID tags and equipment can only operate between 902 - 928 MHz, because, like Europe, other communication types are allocated to the remaining portions of the larger range of 860 - 960 MHz.

RFID Equipment or Tags that are FCC certified or on the North American Frequency Range, or NA, can be used throughout North America.

Other Radio Frequencies

Because both ETSI and FCC were the first major standards to be approved, many countries either adopted one or the other, or created their own standards* within a subset of either frequency range. For example, Argentina chose to adopt the FCC range of 902 – 928 MHz, while Armenia chose to implement its own, smaller band of 865.6 – 867.6 MHz within the ETSI range.

Although regional radio frequency regulations like FCC and ETSI are typically discussed using frequency ranges, there are other specifics that each country regulates such as the amount of radiated power (ERP or EIRP). Certain countries are stricter and regulate where RFID can be used, the amount of frequency "hopping" that must be used, or that a license is required to use RFID. For more information on each country's regulations – read " How to Conform to Regional Regulations when using RFID".

*Every region requires its own regional operating frequency, to find yours, visit GS1.org.

What is in an RFID System?

While each system will vary in terms of device types and complexity, traditional (fixed) RFID systems contain at least the following four components:

- Readers
- Antennas
- Tags

- Cables

The exception to that rule is when a system uses a mobile/handheld/USB reader or other integrated reader which combines the reader, antenna, and cabling.

A mobile handheld RFID reader (with an integrated antenna) and RFID tags make up the simplest RFID system, while more complex systems are designed using multi-port readers, antenna hubs (https://www.atlasrfidstore.com/rfid-insider/antenna-multiplexers-save-thousands-of-dollars/), GPIO boxes, additional functionality devices (e.g. stack lights), multiple antennas and cables, RFID tags, and a complete software setup.

What is an RFID Tag?

An RFID tag in its most simplistic form, is comprised of two parts – an antenna for transmitting and receiving signals, and an RFID chip (or integrated circuit, IC) which stores the tag's ID and other information. RFID tags are affixed to items in order to track them using an RFID reader and antenna.

RFID tags transmit data about an item (contained on the RFID chip) through radio waves to the antenna/reader combination. RFID tags typically do not have a battery (unless specified as Active or BAP tags); instead, they receive energy from the radio waves generated by the reader. When the RFID tag receives the transmission from the reader/antenna, the energy runs through the internal antenna to the tag's chip. The energy activates the RFID chip, which modulates the energy with the desired information, and then transmits a signal back toward the antenna/reader.

On each RFID chip, there are four memory banks – EPC, TID, User, and Reserved. Each of these memory banks contains information about the item that is tagged or the tag itself depending on the bank and what has been specified. Two of the four memory banks, the EPC and User, can be programmed with a unique number or

information for identifying the item on which it's placed. The TID bank cannot be updated because it contains information about the tag itself as well as the unique tag identifier. The RFID tag's Reserved memory bank is used for special tag operations, like locking the tag or expanding its available EPC memory.

Hundreds of different RFID tags are available in many shapes and sizes with features and options specific to certain environments, surface materials, and applications. It's important to choose the ideal tag for the specific application, environment, and item material in order to get the best performance out of your tag. To learn more about how to choose RFID tags for your application and then how to test them, check out our webinar - How to Select an RFID Tag and our article The Importance of Testing RFID Solutions.

Learn more about RFID Tags, checkout our free, easy-to-read guide - A Guide to UHF RFID Tags

Types of RFID Tags

Because there is a wide variety of RFID applications, there is also a wide variety of RFID tags and ways to categorize them. A common way to divide tags into types is inlays vs. hard tags. Inlays are cheaper, typically varying between $0.09 - $1.75 depending on the features on the tags. Hard tags are generally more rugged and weather resistant and vary between $1.00 - $20.00.

Form Factor – Inlay, Label, Card, Badge, Hard Tag

Frequency Type– LF, NFC, HF, UHF Passive (902 – 928 MHz, 865 – 868 MHz, or 865 – 960 MHz), BAP, Active

Environmental Factors– Water resistant, Rugged, Temperature resistant, Chemical resistant

Customizable– Shape, Size, Text, Encoding

Specific Features/Applications– Laundry Tags, Sensor Tags, Embeddable Tags, Autoclavable Tags, Vehicle Tags, High Memory Tags

Specific Surface Materials– Metal mount tags, Glass mount tags, Tags for Liquid-filled items

How much do RFID Tags Cost?

Tag pricing depends on the type of tag and the quantity ordered. As mentioned previously, inlays typically vary between $0.09 - $1.75 and hard tags can vary between $1.00 - $20.00. The higher the level of customization or the more specialized the tag, the more expensive it will be in comparison to typical off-the-shelf tags. For instance, if your application requires a tag with more memory than the average 96 - 128 bits, that tag could cost more due to a different IC being needed to accommodate the higher memory requirement.

How to Select an RFID Tag

- What type of surface will you be tagging? On metal, plastic, wood, etc.?
- What read range do you desire?
- Size limitations (i.e. the tag can be no larger than x by y by z inches)?
- Any excessive environmental conditions to consider? Excessive heat, cold, moisture, impact, etc.?
- Method of attachment? Adhesive, epoxy, rivets/screws, cable ties, etc.?
- The key to choosing a tag is thorough testing of a variety of tags in your environment on the actual items you wish to tag. RFID tag sample packs can be customized for your application so that you can narrow down the tags that are right for your application.

To read a full list of questions for selecting an RFID tag, check out our RFID Buyer's Guide.

What is an RFID Reader?

An RFID reader is the brain of the RFID system and is necessary for any system to function. Readers, also called interrogators, are devices that transmit and receive radio waves in order to communicate with RFID tags. RFID readers are typically divided into three distinct types in terms of mobility/flexibility – Fixed RFID Readers, Mobile RFID Readers, and USB Readers.

Fixed readers stay in one location and are typically mounted on walls, on desks, into portals, or in other stationary locations. Fixed RFID Readers typically have external antenna ports that can connect anywhere from one additional antenna to up to eight different antennas. With the addition of one or more multiplexers, some readers can connect to up to 64 RFID antennas. The number of antennas connected to one reader depends on the area of coverage required for the RFID application. Some desktop applications, like checking files in and out, only need a small area of coverage, so one antenna works well. Other applications with a larger area of coverage, such as a finish line in a race timing application typically require multiple antennas to create the necessary coverage zone.

Mobile readers are handheld devices that allow for flexibility when reading RFID tags while still being able to communicate with a host computer or smart device. Most mobile devices are cordless and rely on a battery for a power source and Wi-Fi or Bluetooth for data transmission. There are two primary categories of Mobile RFID readers – readers with an onboard computer, called Mobile Computing Devices, and readers that use a Bluetooth or Auxiliary connection to a smart device or tablet, called Sleds.

A common subset of fixed or mobile readers is integrated readers. Most mobile readers are integrated readers, but fixed readers are available as lone devices or as integrated devices. An integrated RFID reader is a reader with a built-in antenna that does not have to be connected to an external antenna. Integrated readers are usually aesthetically pleasing and designed to be used for indoor applications without a high traffic of tagged items.

USB Readers are a unique subset of RFID readers because, while they are fixed to a computer, they are not fixed to a wall outlet, allowing them to have more mobility than a typical fixed RFID reader. USB readers are incredibly popular for any desktop applications or specifically for reading and writing individual RFID tags.

Learn more about RFID Readers – An Intro to RFID Readers: Basic Options and Features

Types of RFID Readers

The most common way to categorize readers is to classify them based on their mobility. Other ways to differentiate between RFID readers include categories like connectivity, available utilities, features, processing capabilities, power options, antenna ports, etc.

- Frequency Range - US/FCC 902 – 928 MHz, EU/ETSI 865 – 868 MHz
- Mobility – Fixed Readers, Mobile Readers, USB Readers
- Connectivity Options – Wi-Fi, Bluetooth, LAN, Serial, USB, Auxiliary Port
- Available Utilities – HDMI, GPS, USB, Camera, GPS, GPIO, 1D/2D Barcode, Cellular Capabilities
- Processing Capabilities – OnBoard Processing, No OnBoard Processing
- Power Options – Power Adapter, PoE, Battery, In-Vehicle, USB
- Available Antenna Ports – No External Ports, 1-Port, 2-Port, 4-Port, 8-Port, 16-Port

How much do RFID Readers Cost?

A reader will usually be the most expensive component in an RFID system. RFID readers can vary from around $500 to up to $3,000 or more depending on the features and capabilities required. One of the less-expensive classes of readers is USB readers, which have an average price point of around $500 - $600. USB readers generally have short read ranges and are used for desktop applications. Handheld readers and fixed readers vary greatly in pricing depending on the features and functionality offered.

How to Choose an RFID Reader

- How much read range do you require for your application?

- Any excessive environmental conditions to consider? Excessive heat, cold, moisture, impact, etc.?
- Will you be adding the reader to a network?
- Where will the reader be placed? Fixed location, or on a vehicle?
- Does the reader need to be mobile?
- How many read points/read zones will you need?
- How many tags might need to be read at one time?
- How quickly will the tags be moving through the read zone? For example, is this a slow-moving conveyor belt or fast-moving race?

To read a full list of questions for selecting an RFID reader, check out our RFID Buyer's Guide - https://www.atlasrfidstore.com/a-guide-to-buying-rfid-tags-equipment/

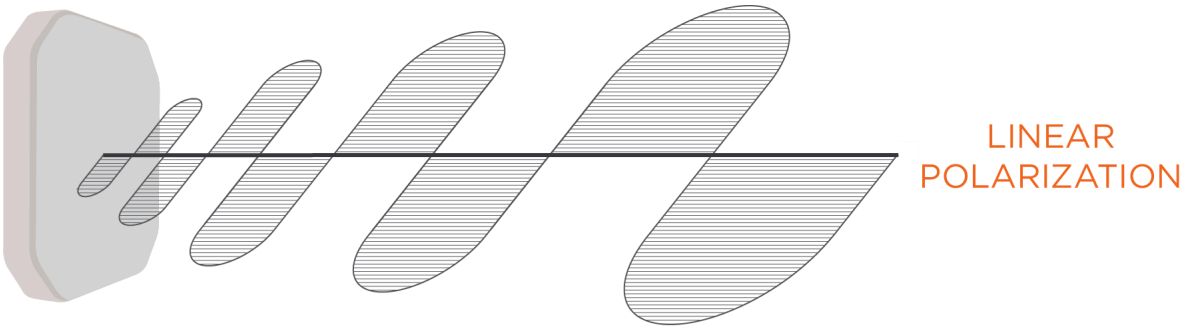
What is an RFID Antenna?

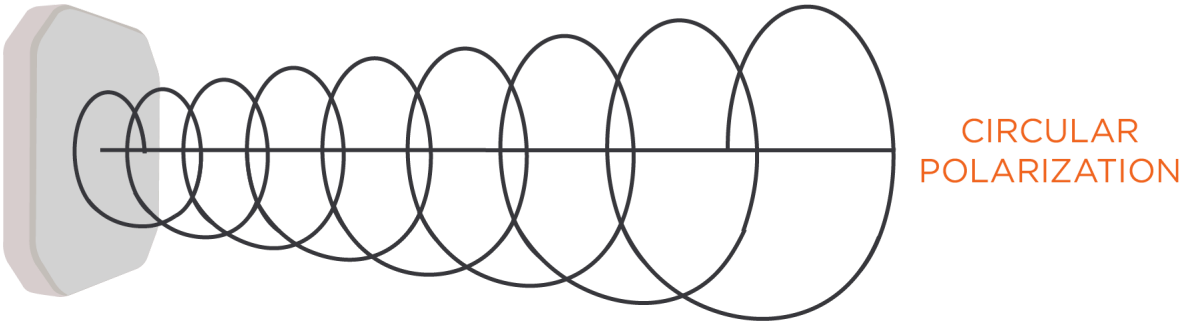
RFID Antennas are necessary elements in an RFID system because they convert the RFID reader's signal into RF waves that can be picked up by RFID tags. Without some type of RFID antenna, whether integrated into the reader or external, the RFID reader cannot properly send and receive signals to RFID tags.

Unlike RFID readers, RFID antennas are called "dumb devices" for a couple of reasons - the first being that they cannot power on or retain power individually, and the second being that RFID antennas do not have any computing power. When the reader's energy is transmitted to the antenna, the antenna generates an RF field and, subsequently, an RF signal is transmitted to the tags in the vicinity. The

antenna's efficiency in generating waves in a specific direction is known as the antenna's gain. To put it simply, the higher the gain, the more powerful, and further-reaching RF field an antenna will have.

The most common way to categorize RFID antennas is based on how they transmit RF waves which is called their polarity. Linearly polarized RFID antennas transmit RF waves on a plane, either vertical or horizontal, while circularly polarized RFID antennas transmit RF waves in a circular pattern **(see images below).**





Linearly-Polarized Antennas

Linearly polarized RFID antennas give off RF waves along a horizontal or vertical plane. If the RF field is a horizontal plane, is it described as horizontally linear, and the same principle applies to an RFID antenna that emits waves on a vertical plane.

If you are using a linear antenna, the polarity can have a significant impact on a system's read range. The key to maximizing read range is to ensure an antenna's polarity aligns with the polarity of the RFID tag. If these do not match up, for instance, a vertical linearly-polarized antenna and a tag with a horizontal linearly-polarized antenna, the read range will be severely reduced. An RFID tag's antenna polarity can be determined by simply looking at the way the tag's antenna is placed in relation to the antenna - typically the longer portion of the tag is either horizontal or vertical. Determining the linear RFID antenna's emitting plane is usually

done with testing, but some antennas include an indicator for the linear plane being used.

While this is key to receiving the best read range possible, determining horizontal or vertical linear polarity is not important during purchase, only during equipment setup because the antenna or tag can simply be rotated 90 degrees to match either polarization option. To learn more about RFID Antenna Polarization, read our article - Circular Polarization vs. Linear Polarization: Which is the Right RFID Antenna?

Circularly-Polarized Antennas

A circularly-polarized antenna transmits RF waves that continually rotate between horizontal and vertical planes in order to give an application enhanced flexibility. This flexibility allows for RFID tags to be read in multiple orientations. However, because the energy is divided between two planes, a circularly-polarized antenna's read range is shorter versus a similar gain linear antenna.

Learn more about RFID Antennas – 9 Tactics For Choosing an RFID Antenna

Types of Antennas

RFID Antennas, like most RFID equipment, can be divided into different categories that help to narrow down the best antenna for an application. Even though antennas are grouped by a few different factors, the most common groupings for RFID Antennas are polarity (circular vs linear) and ruggedness (indoor vs. outdoor).

- Frequency Range – US/FCC 902 – 928 MHz, EU/ETSI 865 – 868 MHz, Global 860 – 960 MHz
- Polarity – Circular, Linear
- Ruggedness – Indoor IP Rated, Outdoor IP Rated
- Read Range – Proximity (Near-Field), Far-Field
- Mounting Type – Shelf Antenna, Ground Antenna, Panel Antenna, Portal Antenna

How much do RFID Antennas Cost?

Most RFID antennas are typically priced between $50 and $300 per antenna, but there are a few that cost more because of key, application-specific factors, such as ground/mat antennas. These antennas are specialized for applications such as race timing and must be rugged enough to survive and perform well while people, bikes, or even go-carts run over them. Specialized antennas can increase a system's cost significantly but are also an investment that can make a big impact on an application.

Selecting an RFID Antenna

- How much read range do you need?
- Is it possible to always know or control the orientation of the RFID tag relative to the antenna's position in your application?
- Any excessive environmental conditions to consider? Excessive heat, cold, moisture, impact, etc.?
- Will the antenna be mounted indoors or outdoors?
- Size limitations (i.e. the antenna can be no larger than x by y by z inches)?

To read a full list of questions for selecting an RFID antenna, check out our RFID Buyer's Guide - https://www.atlasrfidstore.com/a-guide-to-buying-rfid-tags-equipment/

RFID Facts and Frequently Asked Questions

What is RFID's Return on Investment (ROI)?

When considering purchasing and deploying any new system, two of the most important questions to answer are if and when the company will see a return on its investment. Fixed costs, recurring costs, as well as the cost of switching in terms of labor costs, all must be evaluated before implementing a new system.

Before implementing an RFID system, both Application Feasibility and Cost Feasibility should be assessed.

What is RFID Application Feasibility

Application Feasibility refers to the process of determining if the application is suitable for use with RFID. Like all technology, RFID has limitations. Environmental constraints, read range limitations, and asset material composition are just a few of the different aspects that can severely impact how effective an RFID system is for a specific application. The Application Feasibility process should entail scoping of the project and the project's environment as a starting point, and then determining if RFID (or another technology) is the right fit for the application. Some applications need more advanced features, like real-time tracking, which can be accomplished by a type of Real-Time Location System, or RTLS. An RTLS system can be put together with a variety of different technologies including RFID. Learn more about RTLS systems in our RTLS guide. (https://www.atlasrfidstore.com/what-is-rtls-an-introduction-to-real-time-location-systems/)

What is RFID Cost Feasibility

Cost Feasibility refers to assessing if implementing an RFID system is achievable from a monetary perspective. Cost Feasibility includes not just if an ROI is possible, but also includes working with current numbers and prospective numbers to determine the estimated timeline for a return on investment. RFID systems can be expensive. They require an initial investment for testing and working with different types of equipment and tags (which may be a sunk cost for the company if the technology doesn't pan out). After the testing phase, deployment costs begin (Read more about Fixed vs. Recurring Costs below). Only after a system has been implemented and is working properly can the timeline begin for seeing a return on the investment.

What are the Fixed vs. Recurring Costs of RFID Systems

Grouping costs by fixed (initial) or recurring will help to paint a more accurate picture of expected yearly costs and return on investment of a system.

Fixed Costs

Fixed costs are one-time costs that are associated with getting started. In an RFID deployment, a fixed cost is typically associated with hardware like readers, antennas, and cables needed to setup the system. Fixed costs do not necessarily mean that you will not ever purchase that item again, it just means that the item is not used once and then discarded or consumed during the application. If you plan to set up an initial system and then expand that system later, hardware will still be considered a Fixed Cost. RFID tags are only considered to be a fixed cost when they are continually reused throughout the system – e.g. access control RFID fobs that are assigned and redistributed as needed to employees.

Recurring Costs

Recurring costs are attributed to items that are used once and then discarded or consumed during the application. An RFID inlay or label is a common example of a recurring cost in an RFID system. Because of their low-cost, these tags are frequently applied once and kept on an item for its lifespan (or discarded after use). If an RFID printer is used, then printer ribbon would also be a recurring cost. If a software license renews annually or is purchased as a SaaS (Software as a Service) product, then it too should be factored as a recurring cost.

Up Next

Even though this guide is filled with RFID knowledge, it is just the tip of the iceberg when it comes implementing RFID technology. The great news is that we have many different ways to learn more:

RFID Insider – The goal of this blog is to keep you well-informed and up-to-date with the latest developments in the RFID industry. Whether you're an industry veteran or a new-comer to the RFD world, we plan on creating original content covering a wide range of topics for all levels of RFID expertise.

YouTube channel – Discover tutorials, interviews, and more on atlasRFIDstore's channel. We'll be discussing radio frequency identification and its various applications across a wide range of industries.

eBooks & resources – We have additional guides similar to this one that discuss the main components of an RFID systems, RFID applications, and even information in deploying a system. Other resources like infographics, customer profiles, and whitepapers are also available in our RFID resources section.

For additional information and questions, feel free to contact us.