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The Basics of RFID Technology

There are many different types of radio frequency identification technology. This article explains the difference between active and passive tags and between low-, high- and ultra-high frequency systems.

Radio frequency identification is the next wave in the evolution of computing. Essentially, it's a technology that connects objects to Internet, so they can be tracked, and companies can share data about them. The concept is simple: Place a transponder—a microchip with an antenna—on an item and then use a reader—a device with one or more antennas—to read data off of the microchip using radio waves. The reader passes the information to a computer, so that the data can be used to create business value.

There are many different types of RFID systems, and installing them and using them to generate data that can be used to cut costs or boost efficiency is challenging. It's important to choose the right type of RFID system for a particular application. It's also important to work with an experienced systems integrator to make sure the system is installed and configured properly.

The purpose of this article is to introduce you to the basics of RFID technology. We present a lot of technical information. It's not critical that you grasp it all. Understanding the major differences between the various types of systems will help you choose the right systems integrator and work with the integrator to choose the right RFID technology for your needs.

Active tags can broadcast a signal over long distances

The vast majority of RFID tags or transponders (the tags are often used interchangeably) use a silicon microchip to store a unique serial number and usually some additional information (for information on systems that don't use microchips, see our FAQs). There are two broad categories of RFID systems—*passive* and *active* systems. Passive RFID tags do not have a transmitter; they simply reflect back energy (radio waves) coming from the reader antenna. Active tags have their own transmitter and a power source, usually—but not always—a battery (active tags could draw energy from the sun or other sources). They broadcast a signal to transmit the information stored on the microchip. (There are also semi-passive and battery-assisted RFID tags, which are suitable for specific applications. These are covered in our FAQs and Glossary.)

Active RFID Systems
Active tags are used on large assets, such as cargo containers, rail cars and large reusable containers, which need to be tracked over long distances (in a distribution yard, for example). They usually operate at 455 MHz, 2.45 GHz, or 5.8 Ghz, and they typically have a read range of 60 feet to 300 feet (20 meters to 100 meters).

Broadly speaking, there are two types of active tags: transponders and beacons. Active transponders are woken up when they receive a signal from a reader. These are used in toll payment collection, checkpoint control and other systems. When a car with an active transponder approaches a tollbooth, a reader at the booth sends out a signal that wakes up the transponder on the car windshield. The transponder then broadcasts its unique ID to the reader. Transponders conserve battery life by having the tag broadcast its signal only when it is within range of a reader.

Beacons are used in most real-time locating systems (RTLS), where the precise location of an asset needs to be tracked. In an RTLS, a beacon emits a signal with its unique identifier at pre-set intervals (it could be every three seconds or once a day, depending on how important it is to know the location of an asset at a particular moment in time). The beacon's signal is picked up by at least three reader antennas positioned around the perimeter of the area where assets are being tracked. RTLS are usually used outside, say, in a distribution yard (see Logistics Gets Cheaper by the Yard), but automakers use the systems in large manufacturing facilities to track parts bins (see RFID Revs Up Hummer Plant).

Active tags have a read range of up to 300 feet (100 meters) and can be read reliably because they broadcast a signal to the reader (some systems can be affected by rain). They generally cost from $10 to $50, depending on the amount of memory, the battery life required, whether the tag includes an on-board temperature sensor or other sensors, and the ruggedness required. A thicker, more durable plastic housing will increase the cost.

Passive RFID Systems

Passive RFID tags have no power source and no transmitter. They are cheaper than active tags (20 cents to 40 cents) and require no maintenance, which is why retailers and manufacturers are looking to use passive tags in their supply chains. They have a much shorter read range than active tags (a few inches to 30 feet).

A passive RFID transponder consists of a microchip attached to an antenna. The transponder can be packaged in many different ways. It can be mounted on a substrate to create a tag, or sandwiched between an adhesive layer and a paper label to create a printable RFID label, or smart label. Transponders can also be embedded in a plastic card, a key fob, the walls of a plastic container, and special packaging to resist heat, cold or harsh cleaning chemicals. The form factor used depends on the application, but packaging the transponder adds significantly to the cost.

Tags come in many form factors

Passive tags can operate at low frequency, high frequency and ultra-high frequency. Low-frequency systems generally operate at 124 kHz, 125 kHz or 135 kHz. High-frequency systems use 13.56 MHz, and ultra-high frequency systems use a band anywhere from 860 MHz to 960 MHz. Some systems also use 2.45 Ghz and other areas of the radio spectrum.

Radio waves behave differently at each of these frequencies, which means the different frequencies are suitable for different applications. We'll explain a little bit about the different frequencies, but it's useful to think of low frequency waves as the waves that reach your radio. They can penetrate walls well, but can't go through metal. Low-frequency tags are ideal for applications where the tag needs to be read through material or water at close range (more about read range in a minute).

As you increase the frequency of radio waves they start to behave more like light. They can't penetrate materials as well and tend to bounce off many objects. Waves in the UHF band are also absorbed by water. The big challenge facing companies using UHF systems is being able to read RFID tags on cases in the center of a pallet, or on materials made of metal or water.

Inductive vs. Propagation Coupling

So why are companies eager to use UHF passive systems in the supply chain, rather than low-frequency and high-frequency systems? One reason is some vendors in the UHF market have offered simple, low cost tags. Another reason is read range. Companies need to be able to read tags from at least 10 feet (3.3 meters) for RFID to be useful in a warehouse. That's because there is no way to read a tag on a pallet going through a dock door from less than 10 feet. At closer distances, the reader begins to interfere with the normal operation of forklifts and other equipment. Low-frequency tags can usually be read from within 12 inches (0.33 meter). High frequency tags can be read from up to 3 feet (1 meter), and UHF tags can be read from 10 feet or more.

Read range is determined by many factors, but one of the most important is the method passive tags use to transmit data to the reader. Low- and high-frequency tags use *inductive coupling.* Essentially, a coil in the reader antenna and a coil in the tag antenna form an electromagnetic field. The tag draws power from the field, uses the power to run the circuitry on the chip and then changes the electric load on the antenna. The reader antenna senses the change in the magnetic field and converts these changes into the ones and zeros that computers understand. Because the coil in the tag antenna and the coil in the reader antenna must form a magnetic field, the tag must be fairly close to the reader antenna, which limits the read range of these systems.

Passive UHF systems use *propagation coupling.* A reader antenna emits electromagnetic energy (radio waves). No electromagnetic field is formed. Instead, the tag gathers energy from the reader antenna, and the microchip uses the energy to change the load on the antenna and reflect back an altered signal. This is called backscatter.

UHF tags can communicate ones and zeroes in three different ways. They can increase the amplitude of the wave coming back (amplitude shift keying), shift the wave so it's out of phase (phase shift keying) or change the frequency (frequency shift keying). The reader picks up the signal and converts the altered wave into a one or a zero. That information is then passed on to a computer that converts the binary data into a serial number or the data stored on the tag.

Factors that affect performance

It's not necessary to understand the intricacies of the communication methods used, but end users do need to understand the basic characteristics of the different systems and what affects their performance.

Reading tags on liquid products is a challenge

Because low- and high-frequency systems use inductive coupling, the size of the reader field is smaller and can be more easily controlled. Ultra-high frequency systems that use propagation coupling are harder to control, because energy is sent over long distances. The waves can bounce off surfaces and reach tags you never expected them to reach; you might even read tags you don't want to read.

Low- and high-frequency systems also work better than UHF systems around metal and water. The radio waves don't bounce off metal and cause false reads. And they are better able to penetrate water; UHF radio waves are absorbed by water.

In fact, the problem with reading tags reliably is mainly an issue with UHF systems. Here are some additional issues that end users have to cope with.

Detuning the antenna: With propagation coupling, the antenna is tuned to receive waves of a particular frequency. When an antenna is placed on an object or product packaging that is not "RF friendly," the antenna can be detuned, making it difficult for the tag to receive enough energy to reflect back a signal. There are several ways to deal with this issue. Products with a lot of water and metal are particularly challenging to tag, and some antennas can be specially designed to be in tune when close to water or to couple with the metal to improve the ability to read the tag. Another way is to create an air gap between the tag and the object. In the case of metal, an air gap can increase performance if done correctly, because waves will reflect off the metal and provide more power to the tag.

Signal attenuation: Attenuation in RFID usually refers to the reduction in energy emitted by the reader or in the energy reflected back by the tag. If less energy is able to reach the tag, then the tag must be closer to the reader to be read. The energy emitted by the reader naturally decreases with distance; the rate of decrease is proportional to the inverse square of the distance. Passive UHF RFID tags (those with no batteries) reflect back a signal at very low power levels. A tag's reflected signal decreases as the inverse fourth power of the distance between tag and reader. In other words, the signal emitted by the reader attenuates natural with distance, and the signal reflected by a passive tag attenuates at a much faster rate.

Signal attenuation can also be caused by the way a system is installed or external factors, such as the items tagged. Many readers have one or more external antennas that emit radio waves. These are connected to the reader by coaxial cables. As the energy travels from the reader, through the cable, to the reader antenna, the signal attenuates, so placing reader antennas too far from the reader can cause poor performance.

Water, carbon and other materials absorb UHF energy, so products with high water content, such as fruit and soft drinks, or products made of carbon, such as batteries, can attenuate the signal reaching the tags on these products.

Electromagnetic interference: EMI is essentially noise that makes it harder to get a clear signal back from the UHF tag. It can be caused by a wide variety of machines. Motors emit EMI and may need to be shielded to prevent interference with RFID systems. Conveyors with nylon belts cause interference, as do most robots on manufacturing lines.

Interference can also be caused by other RF-based systems operating in a warehouse or other areas where RFID is used. For instance, many older wireless local area networks use the UHF frequency band. These interfere with UHF RFID systems and need to be upgraded to the 802.11 standard. Cordless phones, wireless computer terminals and other devices can also interfere with RFID systems.

The Department of Defense is combing passive and active systems

Combining Passive and Active RFID

The goal of using RFID in open supply chains is to gain "visibility"—that is to be able to "see" where your products are in real time. Visibility, however, is often lost once products are shipped. It's possible to combine active and passive systems to record which container goods are in and when a container has left a distribution yard on a truck. And with Global Positioning System technology, it's possible to track goods even while in transit. (This kind of system is expensive to implement today and is usually used only when a company is looking to reduce theft in the supply chain.)

The U.S. Department of Defense plans to combine passive RFID tagging of pallets, cases and some high-value items with the active tagging system it already uses to track many containers being shipped to bases and units overseas. The DOD will scan the passive tags on cases of meals ready to eat and other items and associate the EPCs on those cases with a pallet tag. As pallets are loaded onto a container, the case and pallet tag information will be written to an active tag on the container.

A test done last year validated the concept (subscribers, see Vendor to Foxhole Tracking). When a truck left a DOD depot, the active tag on the container was read and the fact that it left was uploaded to the military's Total Asset Visibility system, a global database for tracking goods. When the truck arrived at a train station, airport or port, the tag was read again and its location updated. Readers at ports, airports and depots have been installed overseas to give the DOD better visibility.

GPS transmitters on trucks can provide real-time location of trucks on the road. The benefits of such a system is the company can insure that high-value goods are not diverted in transit. In the future, a supply chain manager might be able to dynamically manage deliveries. For example, a potential out-of-stock situation could be averted by rerouting a truck to a store dangerously low on a given item.

It's clear that RFID has the potential to dramatically improve supply chain efficiencies, but the same technology can be used for many other applications, from securing buildings and ensuring the safety of workers to improving asset utilization and reducing manufacturing errors. The most common applications for RFID will be explained in RFID Business Applications. First, we'll explain the RFID System Components and Costs.