Radio-frequency identification

Radio-frequency identification (RFID) is a technology that uses communication via electromagnetic waves to exchange data between a terminal and an object, like products, animals, or human for the objective of identification and tracking. Some tags can be read from several meters away and beyond the line of sight of the reader. Radio-frequency identification involves interrogators (also known as readers), and tags (also known as labels).

Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, modulating and demodulating a radio-frequency (RF) signal, and other specialized functions. The other is an antenna for receiving and transmitting the signal.

There are three types of RFID tags: passive RFID tags, which have no power source and require an external electromagnetic field to initiate a signal transmission, active RFID tags, which contain a battery and can transmit signals once an external source ("Interrogator") has been successfully identified, and battery assisted passive (BAP) RFID tags, which require an external source to wake up but have significant higher forward link capability providing greater range.

There are a variety of groups defining standards and regulating the use of RFID, including: International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), ASTM International, DASH7 Alliance, EPCglobal. (Refer to Regulation and standardization below.)

RFID has many applications; for example, it is used in enterprise supply chain management to improve the efficiency of inventory tracking and management.

History and technology background

In 1945 Léon Theremin invented an espionage tool for the Soviet Union which retransmitted incident radio waves with audio information. Sound waves vibrated a diaphragm which slightly altered the shape of the resonator, which modulated the reflected radio frequency. Even though this device was a covert listening device, not an identification tag, it is considered to be a predecessor of RFID technology, because it was likewise passive, being energized and activated by electromagnetic waves from an outside source.\(^1\)

Similar technology, such as the IFF transponder invented in the United Kingdom in 1915, was routinely used by the allies in World War II to identify aircraft as friend or foe. Transponders are still used by most powered aircraft to this day. Another early work exploring RFID is the landmark 1948 paper by Harry Stockman, titled "Communication by Means of Reflected Power" (Proceedings of the IRE, pp 1196–1204, October 1948). Stockman predicted that "... considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored."

Mario Cardullo's device in 1973 was the first true ancestor of modern RFID, as it was a passive radio transponder with memory.\(^2\) The initial device was passive, powered by the interrogating signal, and was demonstrated in 1971 to the New York Port Authority and other potential users and consisted of a transponder with 16 bit memory for use as a toll device. The basic Cardullo patent covers the use of RF, sound and light as transmission media. The original business plan presented to investors in 1969 showed uses in transportation (automotive vehicle identification, automatic toll system, electronic license plate, electronic manifest, vehicle routing, vehicle performance monitoring), banking (electronic check book, electronic credit card), security (personnel identification, automatic gates, surveillance) and medical (identification, patient history).\(^3\)
An early demonstration of reflected power (modulated backscatter) RFID tags, both passive and semi-passive, was performed by Steven Depp, Alfred Koelle, and Robert Freyman at the Los Alamos National Laboratory in 1973. The portable system operated at 915 MHz and used 12-bit tags. This technique is used by the majority of today's UHFID and microwave RFID tags.

The first patent to be associated with the abbreviation RFID was granted to Charles Walton in 1983.

The largest deployment of active RFID is the US Department of Defense use of Savi active tags on every one of its more than a million shipping containers that travel outside of the continental United States. The largest passive RFID deployment is the Defense Logistics Agency (DLA) deployment across 72 facilities implemented by ODIN who also performed the global roll-out for Airbus consisting of 13 projects across the globe.

**Miniaturization**

RFIDs are easy to conceal or incorporate in other items. For example, in 2009 researchers at Bristol University successfully glued RFID microtransponders to live ants in order to study their behavior. This trend towards increasingly miniaturized RFIDs is likely to continue as technology advances.

Hitachi holds the record for the smallest RFID chip, at 0.05mm x 0.05mm. The Mu chip tags are 64 times smaller than the new RFID tags. Manufacture is enabled by using the silicon-on-insulator (SOI) process. These dust-sized chips can store 38-digit numbers using 128-bit Read Only Memory (ROM). A major challenge is the attachment of the antennas, thus limiting read range to only millimeters.

Potential alternatives to the radio frequencies (0.125–0.1342, 0.140–0.1485, 13.56, and 840–960 MHz) used are seen in optical RFID (or OPID) at 333 THz (900 nm), 380 THz (788 nm), 750 THz (400 nm). The awkward antennas of RFID can be replaced with photovoltaic components and IR-LEDs on the ICs.

**Current uses**

In 2010 three key factors drove a significant increase in RFID usage: decreased cost of equipment and tags, increased performance to a reliable 99.9% and a stable international standard around UHF passive. At RFID Journal Live 2010 in Orlando, Airbus detailed 16 active projects being conducted by ODIN technologies, IBM and - most recently added to the team - CSC. The two other areas of significant use are financial services for IT asset tracking and healthcare with more than 60% of the top medical device companies using passive UHF RFID in 2010. RFID is becoming increasingly prevalent as the price of the technology decreases. The Japanese HIBIKI initiative aims to reduce the price to 5 Yen (4 eurocents). In January 2009 Envego announced a 5.9 cent tag, and in March 2010 a Korean laboratory successfully created a printed chip using carbon nanotubes that would halve the price of a passive UHF RFID tag to about three cents by late 2011.

**Payment by mobile phones**

Since summer 2009, two credit card companies have been working with Dallas, Texas-based DeviceFidelity to develop specialized microSD cards. When inserted into a mobile phone, the microSD card can be both a passive tag and an RFID reader. After inserting the microSD, a user's phone can be linked to bank accounts and used in mobile payment.

Dairy Queen in conjunction with Vivotech has also begun using RFIDs on mobile phones as part of their new loyalty and rewards program. Patrons can ask to receive an RFID tag to place on their phone. After activation, the phone can receive promotions and coupons, which can be read by Vivotech's specialized NFC devices.

Similarly, 7-Eleven has been working alongside MasterCard to promote a new touch-free payment system. Those joining the trial are given a complimentary Nokia 3220 cell phone – after activation, it can be used as an RFID-capable MasterCard credit card at any of 7-Eleven's worldwide chains.
Nokia's 2008 device, the 6212, has RFID capabilities also. Credit card information can be stored, and bank accounts can be directly accessed using the enabled handset. The phone, if used as a vector for mobile payment, has added security in that users would be required to enter a passcode or PIN before payment is authorized.[17]

**Transportation payments**

Governments use RFID applications for traffic management, while automotive companies use various RFID tracking solutions for product management. Many of these solutions may work together in the future, though privacy regulations prevent many initiatives from moving forward at the same pace that technology allows.

**Car-sharing**

The Zipcar car-sharing service uses RFID cards for locking and unlocking cars and for member identification.

**Season parking tickets**

Following a successful pilot, Housing & Development Board (HDB) Singapore called two tenders in 2006 to implement RFID to replace the paper Season Parking Ticket (SPT). The successful tenderers have distributed RFID tags to SPT holders since March 2007.[18]

**Toll roads**

- RFID is being used for e–tolling in Motorways, implemented by NADRA.
- In Dubai, UAE, RFID is being used for e–tolling – SALIK in Motorways, implemented by RTA.
- In Turkey, RFID has been used in the motorways and bridges as a payment system since Nov 2008; it is also used in public transportation systems in Istanbul, Çanakkale, Izmir and Denizli.
- RFID is used in Malaysia's Touch 'n Go. As the system's name indicates, the card is designed to only function as an RFID card when the user touches it.
- In Norway, all public toll roads are equipped with an RFID payment system known as AutoPASS.
- In Italy, all public toll roads are equipped with an optional RFID payment system named Telepass.
- In Ireland, the eToll system uses RFID tags for payments on all road tolls, including the barrier-free M50 toll between exits 6 and 7.
- In Singapore, public transportation buses and trains employ passive RFID cards known as EZ-Link cards. Traffic into crowded downtown areas is regulated by variable tolls imposed using an active tagging system combined with the use of stored-value cards (known as CashCards).
- In Ontario, Canada, Electronic Road Pricing systems are used to collect toll payments on Ontario Highway 407.
- RFID tags are used for electronic toll collection at toll booths with Georgia's Cruise Card, California's FasTrak, Colorado's E-470, Illinois' I-Pass, Oklahoma's Pikepass, the expanding eastern states' E-ZPass system (including Massachusetts's Fast Lane, Delaware, New Hampshire Turnpike, Maryland, New Jersey Turnpike, Pennsylvania Turnpike, West Virginia Turnpike, New York's Thruway system, Virginia, the Maine Turnpike, and Rhode Island's Newport Bridge); Central Florida also utilizes this technology, via its E-PASS System. E-PASS and Sunpass are mutually compatible. Florida's SunPass, various systems in Texas including D/FW's NTTA TollTag, the Austin metro TxTag and Houston HC Tra EZ Tag (which as of early 2007 are all valid on any Texas toll road), Kansas's K-Tag, The "Cross-Israel Highway" (Highway 6), Philippines South Luzon Expressway E-Pass, Brisbane's Queensland Motorways GoVia tag (previously called E-Toll) System in Australia, Autopista del Sol (Sun's Highway), Autopista Central (Central Highway), Autopista Los Libertadores, Costanera Norte, Vespucio Norte Express and Vespucio Sur urban Highways and every forthcoming urban highway (in a "Free Flow" modality) concessioned to private investors in Chile, all toll tunnels in Hong Kong (Autotoll) and all highways in Portugal (Via Verde, the first system in the world to span the entire network of tolls), France (Liber-T system), Italy (Telepass), Spain (VIA-T), Brazil (Sem Parar - Via Fácil). The tags, which are usually the active type, are read remotely as vehicles pass through the booths, and tag information is used to debit the toll amount from a
Radio-frequency identification

prepaid account. The system helps to speed traffic through toll plazas as it records the date, time, and billing data for the RFID vehicle tag. The plaza- and queue-free 407 Express Toll Route, in the Greater Toronto Area, allows the use of a transponder (an active tag) for all billing. This eliminates the need to identify a vehicle by license plate.

Public transit (bus, rail, subway)

• Throughout Europe, and in particular in Paris (system started in 1995 by the RATP), Lyon, Bordeaux, Grenoble, Nancy and Marseilles in France, in the whole of the Portuguese highway system and in many Portuguese public car parks, Milan, Turin, Naples and Florence in Italy, and Brussels in Belgium, RFID passes conforming to the Calypso international standard are used for public transport systems. They are also used now in Canada (Montreal), Mexico, Israel, Bogotá and Pereira in Colombia, Stavanger in Norway, Luxembourg, Gävle in Sweden, etc.

• In South Korea, T-money cards can be used to pay for public transit. It can also be used in most convenience stores and vending machines in subways as cash. 90% of cabs in Seoul accept card payment, including most major credit cards and the T-money card. T-money replaced Upass, first introduced for transport payments in 1996 using MIFARE technology.

• In Hong Kong, mass transit is paid for almost exclusively through the use of an RFID technology, called the Octopus Card. Originally it was launched in September 1997 exclusively for transit fare collection, but has grown to be similar to a cash card, and can still be used in vending machines, fast-food restaurants and supermarkets. The card can be recharged with cash at add-value machines or in shops, and can be read several centimetres from the reader. The same applies for Delhi Metro, the rapid transit system in New Delhi, capital city of India.

• In Shanghai the Shanghai Public Transportation Card allows the user to credit money in advance and to be debited according to the distance travelled, as determined by the check-in and check-out stations. The card can also be used to pay taxi drivers, and some shops offer card readers as well.

• The Moscow Metro, the world's second busiest, was the first system in Europe to introduce RFID smart cards in 1998. [19]

• The Washington Metro rail became the first U.S. urban mass-transit system to use RFID technology when it introduced the SmarTrip card in 1999.

• JR East in Japan introduced SUICA (Super Urban Intelligent Card) for transport payment service in its railway transportation service in November 2001, using Sony's FeliCa (Felicity Card) technology. The same Sony technology was used in Hong Kong's Octopus card, and Singapore's EZ-Link card.

• Since 2002, in Taipei, Taiwan the transportation system uses RFID operated cards as fare collection. The Easy Card is charged at local convenience stores and metro stations, and can be used in Metro, buses and parking lots. The uses are planned to extend all throughout Taiwan in the future.

• In the United States, the Chicago Transit Authority has offered the Chicago Card and the Chicago Card Plus for rail payments across the entire system since 2002 and for bus payments since 2005. The MBTA introduced the RFID enabled CharlieCard across Boston's subway, streetcar, and bus system in 2006, replacing the decades-old token based fare collection system.

• The New York City Metropolitan Transportation Authority conducted an RFID trial that utilized PayPass by MasterCard. The trial primarily took place on the IRT Lexington Avenue Line with several busier stations on other lines also included. The trial ended on May 31, 2009, however the option of using PayPass may be reintroduced on a wider scale at a later date. The MTA is also studying the possibility of accepting SmartLink (introduced by PATH) for fare payment on the New York City Subway and Buses, and as an eventual replacement for the MetroCard.
• In the UK, operating systems for prepaying for unlimited public transport have been devised, making use of RFID technology. The design is embedded in a creditcard-like pass, that when scanned reveals details of whether the pass is valid, and for how long the pass will remain valid. The first company to implement this is the NCT company of Nottingham, where the general public affectionately refer to them as "beep cards". It has since been successfully implemented in London, where "Oyster cards" allow for pay-as-you-go travel as well as passes valid for various lengths of time and in various areas.

• In Canada, Metrobus in St. John's adopted RFID on December 1, 2006. In the Greater Toronto and Hamilton areas, under Metrolinx, full implementation of the RFID farecard Presto began in November 2009, and will be rolled out in stages across the network. OC Transpo in Ottawa is also in the process of implementing Presto, with completion expected in late 2011.

• In Oslo, Norway, the upcoming public transport payment is to be entirely RFID-based. The system was slated for introduction around spring 2007.

• The Transperth public transport network in Perth, Western Australia uses RFID technology its SmartRider ticketing system, allowing passengers to "tag on" and "tag off" and be charged automatically, according to how many zones they have travelled.

• In Atlanta, MARTA (Metropolitan Atlanta Rapid Transit Authority) has transitioned its bus and rail lines from coin tokens to the new Breeze Card system which uses RFID tags embedded in disposable paper tickets. More permanent plastic cards are available for frequent users.

• In Rio de Janeiro, "RioCard" passes can be used in buses, ferries, trains and subway. There are two types, one you cannot recharge, the other one can be recharged if it's been bought by the company you work for, if they provided it (only in Brazil).

• In Santiago (Chile) the subway system Metro and the recently implemented public transportation system Transantiago use an RFID card called "Bip" or "Multivia".

• In Medellín (Colombia) the recently-implemented card system for the Metro system uses an RFID card called Cívica.

• In Dubai, (United Arab Emirates) drivers through Sheikh Zayed Road and Garhoud Bridge pay tolls using RFID tags called Salik (road toll). Dubai has also initiated a public transportation card named Nol (which means fare in Arabic) for use in the metro, bus, and waterbus. It was introduced to service on 9 September 2009, the day of the official launch of the Dubai Metro.

• In San Diego, California, Metropolitan Transit Systems (MTS), North County Transit District (NCTD), and The San Diego Association Of Governments (SANDAG) use a re-writable RFID smart card referred to locally as the Compass Card, to store daily, weekly, or monthly passes or cash value, making the boarding of buses and trains quicker and simpler.

• In Finland, the RFID travel card system used in the Greater Helsinki region is the largest of systems in Europe that cover all modes of traffic (busses, trams, commuter train units, metros and ferry terminals) operation since 2001. RFID travel card system in Tampere has been in operation since 1995.

• In Cali (Colombia) the recently-implemented card system for the Masivo Integrado de Occidente(MIO) system uses an RFID card.

• In Dublin (Ireland) the LUAS light rail system has been using an RFID enabled 'smart card' system since March 2005.

• In Seattle the Orca Card was introduced in 2009 for fares on buses, ferries, light rail, a street car, and commuter trains. In Tacoma, Washington, a sticker tag is used for paying the toll of the Tacoma Narrows Bridge.

• In Osijek RFID cards have been used to pay for public transportation (buses and trams) since 2008.
• In Buenos Aires (Argentina), Monedero is an RFID card used in all metro lines and, since May 2009, on some bus lines as an experimental program. The card can also be used to pay, as a debit card in some small shops and in toll roads. The Monedero card could be prepaid or linked to a credit card.[25]

• Since 2010, bus transit in Ljubljana (Slovenia) is payable only by RFID with pre-paid city card named Urbana which can be re-filled with monthly passes or cash value on Urbanomats scattered all over the city.

• In Gothenburg (Sweden), public transportation has used RFID cards since 2006.

Asset management and retail sales

RFID combined with mobile computing and Web technologies provide a way for organizations to identify and manage their assets. Initially introduced to major retail by Craig Patterson, Knoxville, TN. Mobile computers, with integrated RFID readers, can now deliver a complete set of tools that eliminate paperwork, give proof of identification and attendance. This approach eliminates manual data entry.

Web based management tools allow organizations to monitor their assets and make management decisions from anywhere in the world. Web based applications now mean that third parties, such as manufacturers and contractors can be granted access to update asset data, including for example, inspection history and transfer documentation online ensuring that the end user always has accurate, real-time data. Organizations are already using RFID tags combined with a mobile asset management solution to record and monitor the location of their assets, their current status, and whether they have been maintained.

RFID is being adopted for item-level retail uses. Aside from efficiency and product availability gains, the system offers a superior form of electronic article surveillance (EAS), and a superior self checkout process for consumers. The first commercial, public item-level RFID retail system installation is believed to be in May 2005 by Freedom Shopping, Inc. in North Carolina, USA.

2009 witnessed the beginning of wide-scale asset tracking with passive RFID. Wells Fargo and Bank of America made announcements that they would track every item in their data centers using passive RFID. Most of the leading banks have since followed suit. The Financial Services Technology Consortium[26] (FSTC) hired RFID specialty company ODIN technologies to set a technical standard for tagging IT assets[27] and other industries have used that standard as a guideline. For instance the US State Department is now tagging IT assets with passive RFID using the ISO/IEC 18000-6 standard.[28]

Product tracking

RFID use in product tracking applications begins with plant-based production processes, and then extends into post-sales configuration management policies for large buyers.

IT asset tracking

In 2008 more than a dozen new passive UHF RFID tags emerged to be specifically mounted on metal. ODIN technologies of Ashburn, Virginia, produced a benchmark which showed varying performance of metal mount tags, with the greatest read distance being just over 25 feet in real-world conditions. In 2010 there are more than 60 metal mount specific RFID tags. Members of the financial service industry, including Wells Fargo, Bank of America, Morgan Stanley, Citigroup, Fidelity and others, are purported to have tagged more than one million assets.

At the same time new integrated circuits (ICs) were introduced by Alien, Impinj and NXP (formerly Philips) which proved much better performance and use of the IT asset tracking application increased. The largest adopter to date appear to be Bank of America and Wells Fargo – each with more than 100,000 assets across more than a dozen data centers.[29]

• High-frequency RFID or HFID/HighFID tags are used in library book or bookstore tracking, jewelry tracking, pallet tracking, building access control, airline baggage tracking, and apparel and pharmaceutical items tracking.
High-frequency tags are widely used in identification badges, replacing earlier magnetic stripe cards. These badges need only be held within a certain distance of the reader to authenticate the holder. The American Express Blue credit card now includes a HighFID tag. In Feb 2008, Emirates Airline started a trial of RFID baggage tracing at London and Dubai airports.\(^{[30]}\)

- BGN has launched two fully automated Smartstores that combine item-level RFID tagging and SOA to deliver an integrated supply chain, from warehouse to consumer.
- UHF, Ultra-HighFID or UHFID tags are commonly used commercially in case, pallet, and shipping container tracking, and truck and trailer tracking in shipping yards.
- In May 2007, Bear River Supply began utilizing Intelleflex Corporation's ultrahigh-frequency identification (UHFID) tags to help monitor their agricultural equipment.\(^{[31]}\)
- In Colombia, "Federación Nacional de Cafeteros" uses an RFID solution to trace the coffee.
- Purdue Pharma currently uses RFID to track shipments of the painkiller OxyContin.\(^{[32]}\)
- In Berlin, Germany, the Berliner Wasserbetriebe (water treatment facility) Uses RFID systems from Psion Teklogix and Elektroniksystem-und-Logistik-GmbH (ESG) to identify and track its 60,000 assets.\(^{[33]}\)

**Transportation and logistics**

- Logistics and transportation are major areas of implementation for RFID technology. For example, yard management, shipping and freight and distribution centers are some areas where RFID tracking technology is used. Transportation companies around the world value RFID technology due to its impact on the business value and efficiency.
- The North American railroad industry operates an automatic equipment identification system based on RFID. Locomotives and rolling stock are equipped with two passive RFID tags (one mounted on each side of the equipment); the data encoded on each tag identifies the equipment owner, car number, type of equipment, number of axles, etc. The equipment owner and car number can be used to derive further data about the physical characteristics of the equipment from the Association of American Railroads' car inventory database and the railroad's own database indicating the lading, origin, destination, etc. of the commodities being carried.\(^{[34]}\)
- Aerospace applications that incorporate RFID technology are being incorporated into Network Centric Product Support architecture. This technology serves to help facilitate more efficient logistics support for systems maintenance on-board commercial aircraft.
- Baggages passing through the Hong Kong International Airport are individually tagged with "HKIA" RFID tags as they navigate the airport's baggage handling system, which improves efficiency and reduces misplaced items.
- In the Netherlands, the Dutch Government sponsors an RFID project in which Cargobox Europe tests an intelligent air cargo container. The container has a passive tag and can be followed by a series of fixed and handheld readers that will be used in the warehouses of several shippers. The intelligence is in the RFID tags but also in the GPS, GSM and airplane detection module that switches off the tag and sensors when the container is airborne.\(^{[35]}\)
Radio-frequency identification

Animal identification

RFID tags for animals represent one of the oldest uses of RFID technology. Originally meant for large ranches and rough terrain, since the outbreak of mad-cow disease, RFID has become crucial in animal identification management.

An implantable variety of RFID tags or transponders can also be used for animal identification. The transponders are more well-known as passive RFID technology, or simply "chips" on animals.[36]

RFID tracking and tracing for meatpackers

The Canadian Cattle Identification Agency[37] began using RFID tags as a replacement for barcode tags. The tags are required to identify a bovine's herd of origin and this is used for tracing when a packing plant condemns a carcass. Currently CCIA tags are used in Wisconsin and by US farmers on a voluntary basis. The USDA is currently developing its own program.

Inventory systems

An advanced automatic identification technology such as the Auto-ID Labs system based on the Radio Frequency Identification (RFID) technology has significant value for inventory systems. Notably, the technology provides an accurate knowledge of the current inventory. In an academic study[38] performed at Wal-Mart, RFID reduced Out-of-Stocks by 30 percent for products selling between 0.1 and 15 units a day. Other benefits of using RFID include the reduction of labor costs, the simplification of business processes, and the reduction of inventory inaccuracies.

In 2004, Boeing integrated the use of RFID technology to help reduce maintenance and inventory costs on the Boeing 787 Dreamliner. With the high costs of aircraft parts, RFID technology allowed Boeing to keep track of inventory despite the unique sizes, shapes and environmental concerns. During the first six months after integration, the company was able to save $29,000 in labor.[39]

In 2007, Recall Corporation integrated the use of RFID to help organizations track and audit their records, to support compliance with regulations such as the Sarbanes-Oxley Act and HIPAA.[40]

Hospital operating rooms

In 2008, ClearCount Medical introduced the SmartSponge System,[41] the first RFID-based system approved for use in the operating room. The system, consisting of an electronic reader and high frequency RFID-tagged disposable gauze, sponges, and towels, is designed to improve patient safety and O.R. efficiency. The system aims to reduce or eliminate the most common and costly surgical "never event", unintentionally retained foreign objects in surgery. The system automatically provides a device-reconciled count by directly matching the unique identifier on each tagged item both entering into and then out of the surgical case. The system also provides a reusable wand which may be used to scan the patient as an additional safety measure or to assist in locating misplaced sponges.
Radio-frequency identification

RFID mandates

Wal-Mart and the United States Department of Defense have published requirements that their vendors place RFID tags on all shipments to improve supply chain management. Due to the size of these two organizations, their RFID mandates impact thousands of companies worldwide. The deadlines have been extended several times because many vendors face significant difficulties implementing RFID systems. In practice, the successful read rates currently run only 80%, due to radio wave attenuation caused by the products and packaging. In time it is expected that even small companies will be able to place RFID tags on their outbound shipments.

Wal-Mart mandate

In January 2005, Wal-Mart required its top 100 suppliers to apply RFID labels to all shipments. To meet this requirement, vendors use RFID printer/encoders to label cases and pallets that require EPC tags for Wal-Mart. These smart labels are produced by embedding RFID inlays inside the label material, and then printing bar code and other visible information on the surface of the label.

In October 2005 the University of Arkansas' Information Technology Research Institute released a report on its preliminary study of the impact of RFID on reducing retail out-of-stocks and concluded that RFID reduced OOS by 21% over non-RFID based stores.\[42]\n
Two years later the Wall Street Journal published an article titled "Wal-Mart's Radio-Tracked Inventory Hits Static." The articles stated that the RFID plan set forth by Wal-Mart was "showing signs of fizzling" due to a lack of progress by Wal-Mart executives to introduce the technology to its stores and to the non-existent incentives for suppliers.

In October 2007 Wal-Mart announced new focus areas for its RFID implementation:

- Shipments going to Sam's Club
- Promotional displays and products going to Wal-Mart stores
- Tests to see RFID's impact in improving category management in select areas

Another Wal-Mart division, Sam's Club, has also moved in this direction. It sent letters dated Jan. 7, 2008 to its suppliers, stating that by Jan. 31, 2008, every full single-item pallet shipped to its distribution center in DeSoto, Texas, or directly to one of its stores served by that DC, must bear an EPC Gen 2 RFID tag. Suppliers failing to comply will be charged a service fee.\[43]\n
However, in January 2009 Sam's Club drastically lowered the penalty for failure to tag pallets from $2 a pallet to just 12 cents a pallet. The 12 cents a pallet is what Wal-Mart estimated it would cost Sam's to do the tagging itself. Sam's also announced that pallet-level tagging is expected to be introduced throughout the entire chain in 2010 while the deadline for tagging individual items was "under review."

In February 2009 Procter & Gamble stated it was ending its promotional program with Wal-Mart after Procter & Gamble "validated" benefits of the RFID program in merchandising and promotional displays. This implied Wal-Mart was not acting on the information to improve store execution.\[44\]
Department of Defense mandate

The DoD requirements for RFID tags on packages is prescribed in the Defense Federal Acquisition Regulations Supplements (DFARS) 252.211-7006 [45]. Positioning of the tag needs to be completed in accordance with the clause and definitions in MIL STD 129 and as of 1 March 2007, EPC Global tags must comply with EPCglobal Class 1 Generation 2 specification [46],[47]

Promotion tracking

Manufacturers of products sold through retailers promote their products by offering discounts for a limited period on products sold to retailers with the expectation that the retailers will pass on the savings to their customers. However, retailers typically engage in forward buying, purchasing more product during the discount period than they intend to sell during the promotion period. Some retailers engage in a form of arbitrage, reselling discounted product to other retailers, a practice known as diverting. To combat this practice, manufacturers are exploring the use of RFID tags on promoted merchandise so that they can track exactly which product has sold through the supply chain at fully discounted prices.[48]

Libraries

Among the many uses of RFID technology is its deployment in libraries. This technology has slowly begun to replace the traditional barcodes on library items (books, CDs, DVDs, etc.). The RFID tag can contain identifying information, such as a book's title or material type, without having to be pointed to a separate database (but this is rare in North America). The information is read by an RFID reader, which replaces the standard barcode reader commonly found at a library's circulation desk. The RFID tag found on library materials typically measures 50×50 mm in North America and 50×75 mm in Europe. It may replace or be added to the barcode, offering a different means of inventory management by the staff and self service by the borrowers. It can also act as a security device, taking the place of the more traditional electromagnetic security strip.[49]

While there is some debate as to when and where RFID in libraries first began, it was first proposed in the late 1990s as a technology that would enhance workflow in the library setting. Singapore was certainly one of the first [50] to introduce RFID in libraries and Rockefeller University in New York may have been the first academic library in the United States to utilize this technology, whereas Farmington Community Library [51] in Michigan may have been the first public institution, both of which began using RFID in 1999. In Europe, the first public library to use RFID was the one in Hoogezand-Sappemeer, the Netherlands, in 2001, where borrowers were given an option. To their surprise, 70% used the RFID option and quickly adapted, including elderly people.

Worldwide, in absolute numbers, RFID is used most in the United States (with its 300 million inhabitants), followed by the United Kingdom and Japan. It is estimated that over 30 million library items worldwide now contain RFID tags, including some in the Vatican Library in Rome.[52] At the time of 2010, the largest RFID implementation in academic library is the University of Hong Kong Libraries which have over 1.20 million library items contain RFID tags,[53] whereas the largest implementation for public institution has been installed in Seattle Public Library in the United States.

RFID has many library applications that can be highly beneficial, particularly for circulation staff. Since RFID tags can be read through an item, there is no need to open a book cover or DVD case to scan an item. This could reduce...
Radio-frequency identification. Where the books have a barcode on the outside, there is still the advantage that borrowers can scan an entire pile of books in one go, instead of one at a time. Since RFID tags can also be read while an item is in motion, using RFID readers to check-in returned items while on a conveyor belt reduces staff time. But, as with barcode, this can all be done by the borrowers themselves, meaning they might never again need the assistance of staff. Next to these readers with a fixed location there are also portable ones (for librarians, but in the future possibly also for borrowers, possibly even their own general-purpose readers). With these, inventories could be done on a whole shelf of materials within seconds, without a book ever having to be taken off the shelf.\footnote{In Umeå, Sweden, RFID is being used to assist visually impaired people in borrowing audiobooks.} In Malaysia, Smart Shelves are used to pinpoint the exact location of books in Multimedia University Library, Cyberjaya.\footnote{In the Netherlands, handheld readers are being introduced for this purpose.} The Dutch Union of Public Libraries ('Vereniging van Openbare Bibliotheeken') is working on the concept of an interactive 'context library', where borrowers get a reader/headphones-set, which leads them to the desired section of the library (using triangulation methods, rather like GPS) and which they can use to read information from books on the shelves with the desired level of detail (e.g. a section read out loud), coming from the book’s tag itself or a database elsewhere, and get tips on alternatives, based on the borrowers’ preferences, thus creating a more personalised version of the library. This may also lead them to sections of the library they might not otherwise visit. Borrowers could also use the system to exchange experiences (such as grading books). This is already done by children in the virtual realm at mijnstempel.nl, but the same could be done in physical form. Borrowers can grade the book at the return desk.

However, as of 2008 this technology remains too costly for many smaller libraries, and the conversion period has been estimated at 11 months for an average-size library. A 2004 Dutch estimate was that a library which lends 100,000 books per year should plan on a cost of €50,000 (borrow- and return-stations: 12,500 each, detection porches 10,000 each; tags 0.36 each). RFID taking a large burden off staff could also mean that fewer staff will be needed, resulting in some of them getting fired,\footnote{RFID would complicate or nullify this respect of readers' privacy. Further, another non-library agency could potentially record the RFID tags of every person leaving the library without the library administrator's knowledge or consent. One simple option is to let the book transmit a code that has meaning only in conjunction with the library's database. Another step further is to give the book a new code every time it is returned. And if in the future readers become ubiquitous (and possibly networked), then stolen books could be traced even outside the library. Tag removal could be made difficult if the tags are so small that they fit invisibly inside a (random) page, possibly put there by the publisher.} but that has so far not happened in North America where recent surveys have not returned a single library that cut staff because of adding RFID. In fact, library budgets are being reduced for personnel and increased for infrastructure, making it necessary for libraries to add automation to compensate for the reduced staff size. Also, the tasks that RFID takes over are largely not the primary tasks of librarians. A finding in the Netherlands is that borrowers are pleased with the fact that staff are now more available for answering questions.

A concern surrounding RFID in libraries that has received considerable publicity is the issue of privacy. Because RFID tags can -depending on the RFID transmitter & reader- be scanned and read from up to 350 feet or 100 m (e.g. Smart Label RFID's), and because RFID utilizes an assortment of frequencies (both depending on the type of tag, though), there is some concern over whether sensitive information could be collected from an unwilling source. However, library RFID tags do not contain any patron information,\footnote{Also, libraries have always had to keep records of who has borrowed what, so in that sense there is nothing new. However, many libraries destroy these records once an item has been returned. RFID would complicate or nullify this respect of readers' privacy. Further, another non-library agency could potentially record the RFID tags of every person leaving the library without the library administrator's knowledge or consent. One simple option is to let the book transmit a code that has meaning only in conjunction with the library's database. Another step further is to give the book a new code every time it is returned. And if in the future readers become ubiquitous (and possibly networked), then stolen books could be traced even outside the library. Tag removal could be made difficult if the tags are so small that they fit invisibly inside a (random) page, possibly put there by the publisher.} and the tags used in the majority of libraries use a frequency only readable from approximately ten feet.
Passports

The first RFID passports ("E-passport") were issued by Malaysia in 1998. In addition to information also contained on the visual data page of the passport, Malaysian e-passports record the travel history (time, date, and place) of entries and exits from the country.

Other countries that insert RFID in passports include Norway (2005), Japan (March 1, 2006), most EU countries (around 2006) including Spain, Ireland and the UK, Australia, Hong Kong and the United States (2007), Serbia (July 2008), Republic of Korea (August 2008), Taiwan (December 2008), Albania (January 2009), The Philippines (August 2009), Republic of Macedonia (2010).

Standards for RFID passports are determined by the International Civil Aviation Organization (ICAO), and are contained in ICAO Document 9303, Part 1, Volumes 1 and 2 (6th edition, 2006). ICAO refers to the ISO/IEC 14443 RFID chips in e-passports as "contactless integrated circuits". ICAO standards provide for e-passports to be identifiable by a standard e-passport logo on the front cover.

In 2006, RFID tags were included in new US passports. The US produced 10 million passports in 2005, and it has been estimated that 13 million will be produced in 2006. The chips inlays produced by Smartrac will store the same information that is printed within the passport and will also include a digital picture of the owner. The US State Department initially stated the chips could only be read from a distance of 10 cm (4 in), but after widespread criticism and a clear demonstration that special equipment can read the test passports from 10 meters (33 ft) away, the passports were designed to incorporate a thin metal lining to make it more difficult for unauthorized readers to "skim" information when the passport is closed. The department will also implement Basic Access Control (BAC), which functions as a Personal Identification Number (PIN) in the form of characters printed on the passport data page. Before a passport's tag can be read, this PIN must be entered into an RFID reader. The BAC also enables the encryption of any communication between the chip and interrogator.

Security expert Bruce Schneier has suggested that a mugger operating near an airport could target victims who have arrived from wealthy countries, or a terrorist could design an improvised explosive device which functioned when approached by persons from a particular country if passengers did not put their cards in an area close to their body (high liquid and saline content) or in a foil-lined wallet.

Some other European Union countries are also planning to add fingerprints and other biometric data, while some have already done so.

Schools and universities

School authorities in the Japanese city of Osaka are now chipping children's clothing, back packs, and student IDs in a primary school. A school in Doncaster, England is piloting a monitoring system designed to keep tabs on pupils by tracking radio chips in their uniforms. St Charles Sixth Form College in west London, England, started September, 2008, is using an RFID card system to check in and out of the main gate, to both track attendance and prevent unauthorized entrance. Similarly, Whitcliffe Mount School in Cleckheaton, England uses RFID to track pupils and staff in and out of the building via a specially designed cards. In the Philippines, some schools already use RFID in IDs for borrowing books and also gates in those particular schools have RFID ID scanners for buying items at a school shop and canteen, library and also to sign in and sign out for student and teacher's attendance. These schools are Claret School of Quezon City, Colegio de San Juan de Letran, San Beda College, University of Santo Tomas and other private schools.
Museums

RFID technologies are now also implemented in end-user applications in museums. An example was the custom-designed temporary research application, "eXspot," at the Exploratorium, a science museum in San Francisco, California. A visitor entering the museum received an RF Tag that could be carried as a card. The eXspot system enabled the visitor to receive information about specific exhibits. Aside from the exhibit information, the visitor could take photographs of themselves at the exhibit. It was also intended to also allow the visitor to take data for later analysis. The collected information could be retrieved at home from a "personalized" website keyed to the RFID tag.\[65\]

Social retailing

When customers enter a dressing room, the mirror reflects their image and also images of the apparel item being worn by celebrities on an interactive display. A webcam also projects an image of the consumer wearing the item on the website for everyone to see. This creates an interaction between the consumers inside the store and their social network outside the store. The technology in this system is an RFID interrogator antenna in the dressing room and Electronic Product Code RFID tags on the apparel item.\[66\]

Race timing

Many forms of RFID race timing have been in use for timing races of different types since the early 1990s. The practice began with pigeon racing, introduced by a company called deister electronic GmbH of Barsinghausen, Germany. It is used for registering race start and end timings for animals or individuals in large running races or multi-sport races where it is impossible to get accurate stopwatch readings for every entrant.

In the race, the racers wear passive or active tags that are read by antennae placed alongside the track or on mats across the track. UHF based tags instead of low or high frequency last-generation tags provide accurate readings with specially designed antennas. Rush error, lap count errors and accidents at start time are avoided since anyone can start and finish any time without being in a batch mode.

Lap scoring

Passive and active RFID systems are used in off-road events such as Orienteering, Enduro and Hare and Hounds racing. Riders have a transponder on their person, normally on their arm. When they complete a lap they swipe or touch the receiver which is connected to a computer and log their lap time. The Casimo Group Ltd sells such a system, as does Sweden's SportIdent\[68\] and Japan's Micro Talk Systems Corp.\[69\] which sells the J-Chip system shown in the photo left.

RFID is being adapted by many recruitment agencies which have a PET (Physical Endurance Test) as their qualifying procedure especially in cases where the candidate volumes may run into millions (Indian Railway Recruitment Cells, Police and Power sector).
Ski resorts

A number of ski resorts, particularly in Scandinavia, the French Alps and in the Spanish and French Pyrenees, have adopted RFID tags to provide skiers hands-free access to ski lifts. Skiers do not have to take their passes out of their pockets. The Vail Resorts in Colorado have been using RFID equipped season passes. In 2010, Vail announced that it will be collecting information – vertical feet skied, number of runs taken, lifts used, etc – and all the information will be available to the user online. They are calling this new system EpicMix.\(^{[70]}\)\(^{[71]}\)

Human implants

Implantable RFID chips designed for animal tagging are now being used in humans. An early experiment with RFID implants was conducted by British professor of cybernetics Kevin Warwick, who implanted a chip in his arm in 1998. In 2004 Conrad Chase offered implanted chips in his night clubs in Barcelona\(^{[72]}\) and Rotterdam to identify their VIP customers, who in turn use it to pay for drinks.

In 2004, the Mexican Attorney General's office implanted 18 of its staff members with the Verichip to control access to a secure data room.\(^{[73]}\)

Security experts have warned against using RFID for authenticating people due to the risk of identity theft. For instance a man-in-the-middle attack would make it possible for an attacker to steal the identity of a person in real-time. Due to the resource constraints of RFIDs it is virtually impossible to protect against such attack models as this would require complex distance-binding protocols.\(^{[74]}\)\(^{[75]}\)\(^{[76]}\)\(^{[77]}\)

Privacy advocates have protested against implantable RFID chips, warning of potential abuse and denouncing these types of RFID devices as "spychips", and that use by governments could lead to an increased loss of civil liberties and would lend itself too easily to abuse. One such case of this abuse would be in the microchip's dual use as a tracking device. Such concerns were justified in the United States, when the FBI program COINTELPRO was revealed to have tracked the activities of high profile political activist and dissident figures. There is also the possibility that the chip's information will be available to those other than governments, such as private business, thus giving employers highly personal information about employees. In addition, privacy advocates state that the information contained in this chip could easily be stolen, so that storing anything private in it would be to risk identity theft.

According to the US Food and Drug Administration (FDA), implantation of an RFID chip poses potential medical downsides. Electrical hazards, MRI incompatibility, adverse tissue reaction, and migration of the implanted transponder are just a few of the potential risks associated with the Verichip ID implant device, according to an October 12, 2004 letter issued by the FDA.\(^{[78]}\)

It has been argued that RFID chipping of sex offenders in the US could be politically feasible, and allowable under the U.S. Constitution.\(^{[79]}\)
Potential uses

RFID can be used in a variety of applications,[80][81] such as:

- Access management
- Tracking of goods and RFID in retail
- Tracking of persons and animals
- Toll collection and contactless payment
- Machine readable travel documents
- Smartdust (for massively distributed sensor networks)
- Location-based services
- Tracking sports memorabilia to verify authenticity
- Airport baggage tracking logistics[82]

Complement to barcode

RFID tags are often a complement, but not a substitute, for UPC or EAN barcodes. They may not ever completely replace barcodes, due in part to their higher cost and the advantage of multiple data sources on the same object. Also, unlike RFID labels, barcodes can be generated and distributed electronically, e.g. via e-mail or mobile phone, for printing and/or display by the recipient. An example is airline boarding passes. The new EPC, along with several other schemes, is widely available at reasonable cost.

The storage of data associated with tracking items will require many terabytes. Filtering and categorizing RFID data is needed to create useful information. It is likely that goods will be tracked by the pallet using RFID tags, and at package level with Universal Product Code (UPC) or EAN from unique barcodes.

The unique identity is a mandatory requirement for RFID tags, despite special choice of the numbering scheme. RFID tag data capacity is large enough that each individual tag will have a unique code, while current bar codes are limited to a single type code for a particular product. The uniqueness of RFID tags means that a product may be tracked as it moves from location to location, finally ending up in the consumer's hands. This may help to combat theft and other forms of product loss. The tracing of products is an important feature that gets well supported with RFID tags containing a unique identity of the tag and also the serial number of the object. This may help companies to cope with quality deficiencies and resulting recall campaigns, but also contributes to concern about tracking and profiling of consumers after the sale.

It has also been proposed to use RFID for POS store checkout to replace the cashier with an automatic system which needs no barcode scanning. In the past this was not possible due to the higher cost of tags and existing POS process technologies. However, Industry Standard, a couture shop and recording studio in Ohio has successfully implemented a POS procedure that allows faster transaction throughput.[83]

An FDA-nominated task force concluded, after studying the various technologies currently commercially available, which of those technologies could meet the pedigree requirements. Amongst all technologies studied including bar coding, RFID seemed to be the most promising and the committee felt that the pedigree requirement could be met by easily leveraging something that is readily available. (More details see RFID-FDA-Regulations[84])
Telemetry

Active RFID tags also have the potential to function as low-cost remote sensors that broadcast telemetry back to a base station. Applications of tagometry data could include sensing of road conditions by implanted beacons, weather reports, and noise level monitoring.\(^{[85]}\)

Passive RFID tags can also report sensor data. For example, the Wireless Identification and Sensing Platform is a passive tag that reports temperature, acceleration and capacitance to commercial Gen2 RFID readers.

It is possible that active or semi-passive RFID tags used with or in place of barcodes could broadcast a signal to an in-store receiver to determine whether the RFID tag (product) is in the store.

Identification of patients and hospital staff

In July 2004, the US Food and Drug Administration issued a ruling that essentially begins a final review process that will determine whether hospitals can use RFID systems to identify patients and/or permit relevant hospital staff to access medical records. Since then, a number of U.S. hospitals have begun implanting patients with RFID tags and using RFID systems, usually for workflow and inventory management.\(^{[86]}\) There is some evidence, as well, that nurses and other hospital staff may be subjected to increased surveillance of their activities or to labor intensification as a result of the implementation of RFID systems in hospitals.\(^{[87]}\) The use of RFID to prevent mixups between sperm and ova in IVF clinics is also considered.\(^{[88]}\)

In October 2004, the FDA approved USA’s first RFID chips that can be implanted in humans. The 134 kHz RFID chips, from VeriChip Corp. can incorporate personal medical information and could save lives and limit injuries from errors in medical treatments, according to the company. The FDA approval was disclosed during a conference call with investors. Shortly after the approval, authors and anti-RFID activists Katherine Albrecht and Liz McIntyre discovered an FDA Warning Letter that spelled out serious health risks associated with the VeriChip.\(^{[89]}\) According to the FDA, these include "adverse tissue reaction", "migration of the implanted transponder", "failure of implanted transponder", "electrical hazards" and "magnetic resonance imaging [MRI] incompatibility."

St. Clair Hospital in Pittsburgh has deployed an RFID and barcode based bedside medication verification system that improves patient safety by reducing medication errors. Nurses use a PDA equipped with a portable RFID reader and barcode scanner to check patient ID and medications before administering any drugs, including drugs delivered through IV pumps.\(^{[90]}\)

To combat home health fraud, the Centers for Medicare & Medicaid Services recently announced heightened scrutiny of the home health care industry. In March, 2009, Elite Medical Supply, a durable medical equipment supplier in New York were one of the first to sign on to combat Medical fraud. They selected CYBRA's EdgeMagic RFID and Bar Code Software to rollout the process.\(^{[91]}\)

Regulation and standardization

There is no global public body that governs the frequencies used for RFID. In principle, every country can set its own rules for this. The main bodies governing frequency allocation for RFID are:

- USA: FCC (Federal Communications Commission)
- Canada: Industry Canada - Spectrum Management Branch
- Europe: ERO, CEPT, ETSI, and national administrations (note that the national administrations must ratify the usage of a specific frequency before it can be used in that country)
- Malaysia: Malaysian Communications and Multimedia Commission (MCMC)\(^{[92]}\)
- Japan: MIC (Ministry of Internal Affairs and Communications)
- China: Ministry of Information Industry
- Taiwan: NCC (National Communications Commission)
- South Africa: ICASA\(^{[93]}\)
Radio-frequency identification

- South Korea: Ministry of Knowledge Economy
- Australia: Australian Communications and Media Authority.
- New Zealand: Ministry of Economic Development
- Singapore: Infocomm Development Authority of Singapore
- Brazil: Anatel (Agência Nacional de Telecomunicações)

Low-frequency (LF: 125–134.2 kHz and 140–148.5 kHz) (LowFID) tags and high-frequency (HF: 13.56 MHz) (HighFID) tags can be used globally without a license. Ultra-high-frequency (UHF: 868–928 MHz) (Ultra-HighFID or UHFID) tags cannot be used globally as there is no single global standard. In North America, UHF can be used unlicensed for 902–928 MHz (±13 MHz from the 915 MHz center frequency), but restrictions exist for transmission power. In Europe, RFID and other low-power radio applications are regulated by ETSI recommendations EN 300 220 and EN 302 208, and ERO recommendation 70 03, allowing RFID operation with somewhat complex band restrictions from 865–868 MHz. Readers are required to monitor a channel before transmitting ("Listen Before Talk"); this requirement has led to some restrictions on performance, the resolution of which is a subject of current research. The North American UHF standard is not accepted in France as it interferes with its military bands. For China and Japan, there is no regulation for the use of UHF. Each application for UHF in these countries needs a site license, which needs to be applied for at the local authorities, and can be revoked. For Australia and New Zealand, 918–926 MHz are unlicensed, but restrictions exist for transmission power.

These frequencies are known as the ISM bands (Industrial Scientific and Medical bands). The return signal of the tag may still cause interference for other radio users.

Some standards that have been made regarding RFID technology include:

- ISO 14223 – Radiofrequency identification of animals – Advanced transponders
- ISO/IEC 14443: This standard is a popular HF (13.56 MHz) standard for HighFIDs which is being used as the basis of RFID-enabled passports under ICAO 9303. The Near Field Communication standard that lets mobile devices act as RFID readers/transponders is also based on ISO/IEC 14443.
- ISO/IEC 15693: This is also a popular HF (13.56 MHz) standard for HighFIDs widely used for non-contact smart payment and credit cards.
- ISO/IEC 18000: Information technology — Radio frequency identification for item management:
  - Part 1: Reference architecture and definition of parameters to be standardized
  - Part 2: Parameters for air interface communications below 135 kHz
  - Part 3: Parameters for air interface communications at 13.56 MHz; MODE 1 and MODE 2.
  - Part 4: Parameters for air interface communications at 2.45 GHz
  - Part 6: Parameters for air interface communications at 860–960 MHz
  - Part 7: Parameters for active air interface communications at 433 MHz
- ISO 18185: This is the industry standard for electronic seals or "e-seals" for tracking cargo containers using the 433 MHz and 2.4 GHz frequencies.

Groups concerned with standardization are:

- DASH7 Alliance: international industry group formed in 2009 to promote standards and interoperability among extensions to ISO/IEC 18000-7 technologies[94]
Radio-frequency identification

- EPCglobal – this is the standardization framework that is most likely to undergo International Standardisation according to ISO rules as with all sound standards in the world, unless residing with limited scope, as customs regulations, air-traffic regulations and others. Currently the big distributors and governmental customers are pushing EPC heavily as a standard well-accepted in their community, but not yet regarded as for salvation to the rest of the world.

**EPC Gen2**

EPC Gen2 is short for *EPCglobal UHF Class 1 Generation 2*.

EPCglobal (a joint venture between GS1 and GS1 US) is working on international standards for the use of mostly passive RFID and the EPC in the identification of many items in the supply chain for companies worldwide.

One of the missions of EPCglobal was to simplify the Babel of protocols prevalent in the RFID world in the 1990s. Two tag air interfaces (the protocol for exchanging information between a tag and a reader) were defined (but not ratified) by EPCglobal prior to 2003. These protocols, commonly known as Class 0 and Class 1, saw significant commercial implementation in 2002–2005.

In 2004 the Hardware Action Group created a new protocol, the Class 1 Generation 2 interface, which addressed a number of problems that had been experienced with Class 0 and Class 1 tags. The EPC Gen2 standard was approved in December 2004, and is likely to form the backbone of passive RFID tag standards moving forward. This was approved after a contention from Intermec that the standard may infringe a number of their RFID-related patents. It was decided that the standard itself does not infringe their patents, but that it may be necessary to pay royalties to Intermec if the tag is to be read in a particular manner. The EPC Gen2 standard was adopted with minor modifications as ISO 18000-6C in 2006.

The lowest cost of Gen2 EPC inlay is offered by SmartCode at a price of $0.05 apiece in volumes of 100 million or more. Nevertheless, further conversion (including additional label stock or encapsulation processing/insertion and freight costs to a given facility or DC) and of the inlays into usable RFID labels and the design of current Gen 2 protocol standard will increase the total end-cost, especially with the added security feature extensions for RFID Supply Chain item-level tagging.

Here is the full list of the update on UHF Gen2 Regulation around the world. The list is updated at 2009 January.

**Problems and concerns**

**Data flooding**

Each tag generating a message each time when passing a reader may be a desired outcome. However, event filtering is required to reduce this data inflow to a meaningful depiction of moving goods passing a threshold. Various concepts have been designed, mainly offered as middleware performing the filtering from noisy and redundant raw data to significant processed data.

**Global standardization**

The frequencies used for RFID in the USA are currently incompatible with those of Europe or Japan. Furthermore, no emerging standard has yet become as universal as the barcode.

To address international trade concerns, it is necessary to utilize a tag that is operational within all of the international frequency domains. An example of such a tag is a Sentry-M WW from RCD Technology. This mount on metal asset tag provides typical read range of 2 meters (6 ft.). It is functional across the worldwide UHF frequency bands between 860–960 MHz. It exceeds the Financial Services Technology Consortium RFID Basic Functional Requirements for Data Center Assets in the North American, European and Japanese frequency bands. As a mount on metal solution, the Sentry-M WW is used for tracking many metal assets, such as IT Assets, tools or...
Security concerns

A primary RFID security concern is the illicit tracking of RFID tags. Tags, which are world-readable, pose a risk to both personal location privacy and corporate/military security. Such concerns have been raised with respect to the United States Department of Defense's recent adoption of RFID tags for supply chain management. More generally, privacy organizations have expressed concerns in the context of ongoing efforts to embed electronic product code (EPC) RFID tags in consumer products.

EPCglobal Network, by design, is also susceptible to DoS attacks. Using similar mechanism with DNS in resolving EPC data requests, the ONS Root servers become vulnerable to DoS attacks. Any organization planning to embark on EPCglobal Network may cringe upon discovering that the EPCglobal Network infrastructure inherits security weaknesses similar to DNS.

A second class of defense uses cryptography to prevent tag cloning. Some tags use a form of "rolling code" scheme, wherein the tag identifier information changes after each scan, thus reducing the usefulness of observed responses. More sophisticated devices engage in Challenge-response authentications where the tag interacts with the reader. In these protocols, secret tag information is never sent over the insecure communication channel between tag and reader. Rather, the reader issues a challenge to the tag, which responds with a result computed using a cryptographic circuit keyed with some secret value. Such protocols may be based on symmetric or public key cryptography. Cryptographically-enabled tags typically have dramatically higher cost and power requirements than simpler equivalents, and as a result, deployment of these tags is much more limited. This cost/power limitation has led some manufacturers to implement cryptographic tags using substantially weakened, or proprietary encryption schemes, which do not necessarily resist sophisticated attack. For example, the Exxon-Mobil Speedpass uses a cryptographically-enabled tag manufactured by Texas Instruments, called the Digital Signature Transponder (DST), which incorporates a weak, proprietary encryption scheme to perform a challenge-response protocol for lower cost. Still other cryptographic protocols attempt to achieve privacy against unauthorized readers, though these protocols are largely in the research stage. One major challenge in securing RFID tags is a shortage of computational resources within the tag. Standard cryptographic techniques require more resources than are available in most low cost RFID devices. RSA Security has patented a prototype device that locally jams RFID signals by interrupting a standard collision avoidance protocol, allowing the user to prevent identification if desired. Various policy measures have also been proposed, such as marking RFID-tagged objects with an industry standard label. RFID security is a very active research field for a few years, with more than 400 scientific papers published since 2002. An extensive list of references in this field can be found at the RFID Security and Privacy Lounge.

Exploitation

Ars Technica reported in March 2006 an RFID buffer overflow bug that could infect airport terminal RFID databases for baggage, and also passport databases to obtain confidential information on the passport holder.

Passports

In an effort to make passports more secure, several countries have implemented RFID in passports. However, the encryption on UK chips was broken in under 48 hours. Since that incident, further efforts have allowed researchers to clone passport data while the passport is being mailed to its owner. Where a criminal used to need to secretly open and then reseal the envelope, now it can be done without detection, adding some degree of insecurity to the passport system.
Shielding

A number of products are available on the market that will allow a concerned carrier of RFID-enabled cards or passports to shield their data. In fact the United States government requires their new employee ID cards to be delivered with an approved shielding sleeve or holder. There are contradicting opinions as to whether aluminum can prevent reading of RFID chips. Some people claim that aluminum shielding, essentially creating a Faraday cage, does work. Others claim that simply wrapping an RFID card in aluminum foil only makes transmission more difficult and is not completely effective at preventing it.

Shielding is again a function of the frequency being used. Low-frequency LowFID tags, like those used in implantable devices for humans and pets, are relatively resistant to shielding, though thick metal foil will prevent most reads. High frequency HighFID tags (13.56 MHz — smart cards and access badges) are sensitive to shielding and are difficult to read when within a few centimetres of a metal surface. UHF Ultra-HighFID tags (pallets and cartons) are difficult to read when placed within a few millimetres of a metal surface, although their read range is actually increased when they are spaced 2–4 cm from a metal surface due to positive reinforcement of the reflected wave and the incident wave at the tag. UHFID tags can be successfully shielded from most reads by being placed within an anti-static plastic bag.

Temperature Exposure

Currently, RFID tags are created by gluing an integrated circuit (IC) to an inlay. This poses a problem as vibration and high temperatures will loosen the connection. If the IC loses connection with the inlay, the RFID tag will no longer transmit. A new design was filed for patent (currently pending approval) where the IC is soldered to a circuit board and the circuit board is then soldered to the inlay. This process replaces the adhesive with solder which is much more durable and temperature resistant.

Controversies

[Logo of the anti-RFID campaign by German privacy group FoeBuD.]
Privacy

"How would you like it if, for instance, one day you realized your underwear was reporting on your whereabouts?"

—California State Senator Debra Bowen, at a 2003 hearing

The use of RFID technology has engendered considerable controversy and even product boycotts by consumer privacy advocates. Katherine Albrecht and Liz McIntyre, co-founders of CASPIAN (Consumers Against Supermarket Privacy Invasion and Numbering), are two prominent critics of the technology who refer to RFID tags as "spychips". The two main privacy concerns regarding RFID are:

- Since the owner of an item will not necessarily be aware of the presence of an RFID tag and the tag can be read at a distance without the knowledge of the individual, it becomes possible to gather sensitive data about an individual without consent.
- If a tagged item is paid for by credit card or in conjunction with use of a loyalty card, then it would be possible to indirectly deduce the identity of the purchaser by reading the globally unique ID of that item (contained in the RFID tag). This is only true if the person doing the watching also had access to the loyalty card data and the credit card data, and the person with the equipment knows where you are going to be.

Most concerns revolve around the fact that RFID tags affixed to products remain functional even after the products have been purchased and taken home and thus can be used for surveillance and other purposes unrelated to their supply chain inventory functions.

The concerns raised by the above may be addressed in part by use of the Clipped Tag. The Clipped Tag is an RFID tag designed to increase consumer privacy. The Clipped Tag has been suggested by IBM researchers Paul Moskowitz and Guenter Karjoth. After the point of sale, a consumer may tear off a portion of the tag. This allows the transformation of a long-range tag into a proximity tag that still may be read, but only at short range — less than a few inches or centimeters. The modification of the tag may be confirmed visually. The tag may still be used later for returns, recalls, or recycling.

However, read range is both a function of the reader and the tag itself. Improvements in technology may increase read ranges for tags. Having readers very close to the tags makes short range tags readable. Generally, the read range of a tag is limited to the distance from the reader over which the tag can draw enough energy from the reader field to power the tag. Tags may be read at longer ranges than they are designed for by increasing reader power. The limit on read distance then becomes the signal-to-noise ratio of the signal reflected from the tag back to the reader. Researchers at two security conferences have demonstrated that passive Ultra-HighFID tags, not of the HighFID type used in US passports, normally read at ranges of up to 30 feet, can be read at ranges of 50 to 69 feet using suitable equipment.

In January 2004 privacy advocates from CASPIAN and the German privacy group FoeBuD were invited to the METRO Future Store in Germany, where an RFID pilot project was implemented. It was uncovered by accident that METRO "Payback" customer loyalty cards contained RFID tags with customer IDs, a fact that was disclosed neither to customers receiving the cards, nor to this group of privacy advocates. This happened despite assurances by METRO that no customer identification data was tracked and all RFID usage was clearly disclosed.

During the UN World Summit on the Information Society (WSIS) between the 16th to 18 November 2005, founder of the free software...
movement, Richard Stallman, protested the use of RFID security cards. During the first meeting, it was agreed that future meetings would no longer use RFID cards, and upon finding out this assurance was broken, he covered his card with aluminum foil, and would only uncover it at the security stations. This protest caused the security personnel considerable concern, with some not allowing him to leave a conference room in which he had been the main speaker, and the prevention of him entering another conference room, where he was due to speak.\[117]\[118]

In 2004-2005 the Federal Trade Commission Staff conducted a workshop and review of RFID privacy concerns and issued a report recommending best practices.\[119]

RFID was one of the main topics of 2006 Chaos Communication Congress (organized by the Chaos Computer Club in Berlin) and triggered a big press debate. Topics included: electronic passports, Mifare cryptography and the tickets for the FIFA World Cup 2006. Talks showed how the first real world mass application of RFID technology at the 2006 FIFA Soccer World Cup worked. Group monochrom staged a special 'Hack RFID' song.\[120]

Zeitgeist The Movie theorised that RFID chips will one day be used to track the world population and keep them under control. Due to the nature of this film, they are presented as a negative technology.

**Human implantation**

The Food and Drug Administration in the US has approved the use of RFID chips in humans.\[121\] Some business establishments give customers the option of using an RFID-based tab to pay for service, such as the Baja Beach nightclub in Barcelona.\[122\] This has provoked concerns into privacy of individuals as they can potentially be tracked wherever they go by an identifier unique to them. There are concerns this could lead to abuse by an authoritarian government or lead to removal of freedoms.\[123\]

On July 22, 2006, Reuters reported that two hackers, Newitz and Westhues, at a conference in New York City showed that they could clone the RFID signal from a human implanted RFID chip, showing that the chip is not hack-proof as was previously claimed.\[124\]

Surgery, even on a small scale, comes with its risks. The RFID chip implantation is no exception. According to David B. Smith, the author of "Using Radio Frequency Identification (RFID) Technology in Humans in the United States for Total Control," Smith gives the examples of health risks such as “…adverse tissues reaction migration of implanted transponder, compromised information security, failure of implanted transponder, failure of insertion, failure of electronic scanner, electromagnetic interference electrical hazards, magnetic resonance imaging incompatibility, and needle stick” (38). Such risks can happen to anyone undergoing an implantation procedure.

**Government control**

With the rise of technology, some individuals have grown to fear the loss of rights due to RFID human implantation.

By early 2007 Chris Paget (hacker) of San Francisco, California, showed that RFID information can be pulled from individuals by using only $250 worth of equipment. This supports the claim that with the information captured, it would be relatively simple to make counterfeit passports.\[126\]

According to ZDNet, critics believe that this technology will lead to tracking individuals every movements and will be an invasion of privacy. Some conceptualize a future where every movement is tracked by the government.\[127\] In Katherine Albrecht's SpyChips: How Major Corporations and Government Plan to Track Your Every Move with RFID, one is encouraged to "imagine a world of no privacy. Where your every purchase is monitored and recorded in a database and every belonging is numbered. Where someone many states away or perhaps in another country has a record of everything you have ever bought. What's more, they can be tracked and monitored remotely".\[128\]
Deliberate destruction of RFIDs in clothing and other items

According to an RSA laboratories FAQ, RFID tags can be destroyed by a standard microwave oven; however some types of RFID tags, particularly those constructed to radiate using large metallic antennas (in particular RF tags and EPC tags), may catch fire if subjected to this process for too long (as would any metallic item inside a microwave oven). This simple method cannot safely be used to deactivate RFID features in electronic devices, or those implanted in living tissue, because of the risk of damage to the "host". However the time required is extremely short (a second or two of radiation) and the method works in many other non-electronic and inanimate items, long before thermal buildup (fire) problems become of concern.

See also

- AS5678
- Biometrics
- Barcode
- Bin bug
- Contactless payment
- DASH7
- Electronic Product Code
- E-ZPass
- Identification friend or foe
- Local Positioning Systems
- High Capacity Color Barcode
- List of emerging technologies
- Mass surveillance
- Microchip implant (animal)
- Microchip implant (human)
- Mobile RFID
- Near Field Communication
- ODIN technologies
- Omni-ID
- Pharmacy informatics
- Polymer electrolyte
- Proximity card
- Real-time locating
- Resonant energy transfer
- RFID race timing
- RFID Zapper
- RuBee
- Smart cards
- Supranet
- Tracking system
- U-Key
Radio-frequency identification

References


[21] https://www.prestocard.ca/StaticContent/Gtafs


[36] * USDA Bets the Farm on Animal ID Program (http://www.thenation.com/doc/20071231/pentland_gumpert)

Radio-frequency identification

[38] RFID's reduction of Out-of-Stock study at Wal-Mart (http://www.rfidradio.com/?p=11), RFID Radio
[39] RFID's Second Wave (http://www.businessweek.com/technology/content/aug2005/tc/2005089_4131_bc_215.htm), BusinessWeek
[40] Gambon, Jill (16 April 2007), "Recall Corp. Uses RFID to Recall Cartons" (http://www.rfidjournal.com/article/purchase/3187), RFID Journal...
[41] ClearCount Medical Solutions - SmartSponge System® (http://www.clearcount.com/smart-sponge-system.html)
[47] DFARS 252.211-7006 clause (a) (2).
[59] Datatisnet misfornøyd med nye pass – digi.no (http://www.digi.no/php/art.php?id=275753) also in Biometric passport#Norway
[63] Schoolchildren to be RFID-chipped (http://networks.silicon.com/lans/0.39024663.39122042.00.htm)
[64] Schoolkid cloning trial a 'success' (http://www.theregister.co.uk/2007/10/22/kid_clipping_doncaster/g/)
[74] High-tech cloning (http://blogs.reuters.com/blog/2006/07/22/high-tech-cloning)
[77] "VeriChips Implanted at CityWatcher.com" (http://www.complianceandprivacy.com/News-VeriChip-concern.asp). Compliance and Privacy. . Retrieved 2007-02-03. "No one I spoke with at Six Sigma Security or at CityWatcher knew that the VeriChip had been hacked. They were also surprised to hear of VeriChip's downsides as a medical device. It was clear they weren't aware of some of the controversy surrounding the implant. (Liz McIntyre)"
Radio-frequency identification

[120] monochrom. "R F I D" (http://www.monochrom.at/rfid/).
[129] RFID faq (http://www.rsa.com/rsalabs/node.asp?id=2120#13)

External links

- What is RFID? (http://rfid.net/basics/190-what-is-rfid) at The RFID Network video series (http://rfid.net)
- RFID Radio – Educational RFID podcasts (http://www.RFIDRadio.com/)
- How RFID Works (http://www.howstuffworks.com/RFID.htm) at HowStuffWorks
- Detailed explanation of RFID (http://www.engineersgarage.com/RFID) at EngineersGarage (http://www.engineersgarage.com/)
- RFID (http://www.dmoz.org/Society/Issues/Science_and_Technology/RFID/) at the Open Directory Project
- How RFID Works (http://www.rfidinregion.com/how-rfid-works) at RFID IN REGION (http://www.rfidinregion.com/)