# en_RFID

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Data de publicació: 26-02-2024

Various RFID transpondersUniversal RFID handheld reader for 125 kHz, 134 kHz and 13.56 MHz; optional barcodeDevice for UHF tags, 630 mW powerRFID Bluetooth handheld reader for 13.56 MHz, with ferrite antenna for reading very small metal transponderAndroid 5.1 mobile device with LF and HF RFID in one device

RFID (radio-frequency identification [??e?d??? ?f?i?kw?nsi a??d?nt?f??ke??n?] "identification using electromagnetic waves") is a technology for transmitter-receiver systems for the automatic and contactless identification and localization of objects and living beings using radio waves.

An RFID system consists of a transponder (colloquially also known as a radio tag), which is located on or in the object or living being and contains an identifying code, as well as a reader for reading this identifier.

RFID transponders can be as small as a grain of rice and can be implanted, for example in pets. In addition, it is possible to produce RFID transponders from polymers using a special printing process of stable circuits. [1] The advantages of this technology result from the combination of the small size, the unobtrusive readout option (e.g. in the case of the new ID card introduced in Germany on 1 November 2010) and the low price of the transponders (sometimes in the cent range).

The coupling takes place by alternating magnetic fields generated by the reader at a short range or by high-frequency radio waves. This not only transmits data, but also supplies the transponder with energy. To achieve longer ranges, active transponders with their own power supply are used, but these are associated with higher costs.

The reader contains software (a microprogram) that controls the actual reading process and RFID middleware with interfaces to other computer systems.

Contents

History of development

The first RFID applications were used in the air war between Great Britain and Germany at the end of World War II. There, a secondary radar was used for friend-foe detection. [2] Transponders and reading units were installed in the planes and tanks to detect whether or not the position or aircraft to be shot at were to be attacked. To this day, successor systems are used in the armies. Harry Stockman is considered to be the one who laid the foundations of RFID with his publication "Communication by Means of Reflected Power" in October 1948. [3]

At the end of the 1960s, "Siemens Car Identification", or SICARID for short, was developed as one of many proprietary solutions. This made it possible to clearly identify first railway wagons and later car parts in the paint shop. It was used until the 1980s. The identification carriers were cavity resonators, which could cover a data space of 12 bits by screwing in screws. They were queried by a linear frequency ramp. These cavity resonators can be regarded as the first purely passive transponders that can be interrogated by electromagnets. The first passive backscatter transponder of the type still used today with its own digital logic circuit was not presented until 1975 in an IEEE paper.

In the 1970s, the first primitive commercial precursors of RFID technology were introduced to the market. These were Electronic Article Surveillance (EAS) systems. By checking for the presence of the marking, an alarm can be triggered in the event of theft. The systems were based on high-frequency technology or low- or medium-frequency induction transmission.

The year 1979 brought numerous new developments and applications for RFID technology. One focus was on applications for agriculture, such as animal identification, e.g. for racing pigeons, livestock and other domestic animals.

Since the 1980s, the application of RFID technology has been promoted in particular by the decision of several American states and Norway to use RFID transponders in road traffic for toll systems. In the 1990s, RFID technology, such as RFID technology, was introduced. the E-ZPass, widely used in the USA for toll systems.

This was followed by new systems for electronic locks, access controls, cashless payments, ski passes, fuel cards, electronic immobilizers and so on. [4][5]

In 1999, the establishment of the Auto-ID Center at MIT heralded the development of a global standard for goods identification. With the completion of the work on the Electronic Product Code (EPC), the Auto-ID Center[6] was closed in 2003. At the same time, the results were handed over to EPCglobal Inc., which was newly founded by the Uniform Code Council (UCC) and EAN International (now GS1 US and GS1).

In 2006, researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) in Bremen succeeded for the first time in casting temperature-insensitive RFID transponders into metallic components made of light metal. This process development makes it possible to replace the conventional methods for product identification of cast components with RFID technology and to integrate the RFID transponders directly into the component during component production in the die-casting process. In 2011, IFAM announced that it had also succeeded in integrating an RFID chip with the additive manufacturing process of laser melting into surgical instruments with complex inner workings. [7]

## Technology

The RFID transponders differ from each other depending on the transmission frequency, manufacturer and intended use. An RFID transponder consists of an antenna, an electrical circuit for receiving and transmitting (transceiver) and a digital circuit with memory. All electronics are often integrated into a single microchip.

RFID transponders have a memory that can be written at least once, which contains their immutable identity. If multiple writable memories are used, further information can be stored during the service life.

Depending on the area of application, key figures such as clock frequency, transmission rate, service life, cost per unit, storage space, read range and range of functions differ.

## Functionality

In systems that are standardised in accordance with ISO 18000-1 et seq., the transmission of identification information is carried out as follows: The reader, which, depending on the type, may also be able to write data, generates a high-frequency alternating electromagnetic field to which the RFID transponder (RFID tag) is exposed. The high-frequency energy it receives through the antenna serves as a power supply for its chip during the communication process. In the case of active tags, the power supply can also be provided by a built-in battery. In the case of semi-active tags, the battery only takes over the power supply of the microchip.

The microchip in the RFID tag, thus activated, decodes the commands sent by the reader. The response encodes and modulates the RFID tag into the irradiated electromagnetic field by attenuating the field in the non-contact short circuit or counter-phase reflection of the field emitted by the reader. In this way, the tag transmits its serial number (UID), other data of the marked object or other information requested by the reader. The tag itself does not generate a field, but influences the electromagnetic transmission field of the reader.

Depending on the type, the RFID tags operate in the range of longwave at 125 kHz, 134 kHz, 250 kHz, medium wave at 375 kHz, 500 kHz, 625 kHz, 750 kHz, 875 kHz, shortwave (HF) at 13.56 MHz, UHF at 865-869 MHz (European frequencies) or 950 MHz (US and Asian frequency bands) or SHF at 2.45 GHz and 5.8 GHz. The approved frequencies for LF and UHF tags differ regionally for Asia, Europe and the Americas and are coordinated by the ITU.

RF tags use load modulation, which means that they consume part of the energy of the alternating magnetic field by short-circuiting. This can be detected by the reader, but theoretically also by a more distant receiver. The antennas of an RF tag form an induction coil with several turns.

UHF tags, on the other hand, work in the far electromagnetic field to transmit the response; the process is called modulated backscattering. The antennas are usually linear, folded dipoles or spiral, the chip sits in the middle between the antenna of the RFID tag.

In order for a tag to be read both horizontally and vertically, circular polarization is often used. Although this reduces the signal-to-noise ratio, it is irrelevant in which orientation the tag is glued to the goods. Since water absorbs the UHF energy very strongly and metal reflects these electromagnetic waves very strongly, these materials influence the propagation of the antenna fields. Furthermore, dielectric substrate materials 'detune' the resonant frequency of the antennas, so it is necessary to precisely match UHF tags to the materials of the marked objects.

UHF or SHF technology is designed to be much more complex than LF or HF technology. Due to their speed, UHF and SHF tags can transmit significantly longer data sets in one passage.

For example, a passive UHF tag according to ISO/IEC 18000–6C requires an operating current of about 0.35 microamps for the chip. This is provided by the radiation field of the reader. Since the intensity decreases quadratically with distance, the reader has to transmit correspondingly strongly. Between 0.5 and 2 watts of EIRP transmit power are required. Semi-active tags require much less transmitting power from the reader.

For more complex applications, cryptography modules or external sensors such as GPS can also be integrated into the RFID transponder. The RFID transceiver units differ in range, range of functions and design. They are installed, for example, in shelves or personnel locks (access control, gate entrances).

The large number of different devices and labels is fully compatible within the framework of the various standards (ISO/IEC standards ISO/IEC 18000-x). However, new proprietary solutions are constantly being introduced that deviate from these standards and in some cases cannot be used in a neighborhood at the same time.

Problems can arise if the RFID transponder sits directly on a product that is electromagnetically incompatible with the selected tag. In order to circumvent electromagnetic adaptation problems, so-called flap or flag tags are used in logistics, among other things, which protrude at a right angle from the marked article and thus have a greater distance from it.

The read success (read rate) of an RFID solution can be affected by a variety of errors (tag defective, electromagnetic interference, movement in the wrong direction, too fast or too close to each other, etc.).

Designs and sizes
125 kHz transponder with coil on ferrite core13.56 MHz transponder with printed coilISO 15693 13.56 MHz transponder, miniatureClose-up of a screw head with a 13.56 MHz transponder pressed into the center

Transponders consist of:

Microchip, with a diameter of about one millimeter.
Antenna, usually a coil. In miniature transponders, the diameter of the antennas is often only a few millimeters, while in applications with longer ranges, antenna diameters of up to half a meter are common.
Carrier or housing that protects the transponder electronics from environmental influences.
In the case of active and semi-active transponders, an energy source, usually a battery. In the case of passive transponders, the power supply is provided by the antenna from the outside.

The size is determined by the size of the antenna and the housing. The microchip can be manufactured in a comparatively small size. With the exception of the antenna, all the necessary electronic components are integrated into the microchip.

The shape and size of the antenna depends on the frequency or wavelength and application. Depending on the required application, transponders are offered in different designs, sizes and protection classes. In addition to the frequency, the range of passive transponders depends largely on the antenna or coil size (inlay size). The range decreases rapidly for both UHF and HF with smaller antennas.

Depending on the area of application, active RFID transponders can be the size of a book (e.g. in container logistics). On the other hand, it is now also possible to manufacture passive RFID transponders that are flat enough to be embedded in banknotes or paper. For example, small versions for 2.4 GHz are 50 × 50 ?m in size[8].

At the beginning of development around 1980, transponders were initially produced and used primarily as "LF 125 kHz passive". ISOCARD and CLAMSHELL card designs from the LF-125 kHz range are the world's most widely used designs in the field of access control and time recording. In the same way, there are also designs that are built into the car key (immobilizer) or serve as implants, rumen boli or ear tags for the identification of animals. In addition, there is the possibility of integration into nails or PU disk TAGs for pallet identification, into chipcoins (billing systems, e.g. in public baths) or into chip cards (access control).

In the field of electronic tickets, electronic wallets or electronic IDs, the 13.56 MHz Mifare or ICODE technology is used in accordance with standards such as ISO 15693. The transponder chips are manufactured by NXP Semiconductors, among others. In this area, there are also special transponders that can be used directly in metallic objects such as metallic tools. The structure is based on a winding body for the antenna coil and carrier for the transponder chip. In order to protect the transponder from external mechanical influences and chemical media and to make it sufficiently durable for press-fit into a 4 mm hole hole, appropriate housing shapes are available. These transponders, which also operate in the 13.56 MHz band, can only be read at close range due to the shielding effect of the metallic environment. It is therefore necessary to hold the readout device and the antenna coil directly on the transponder in the form of a pin about 4 mm thick. [9]

Energy supply

The clearest distinguishing feature is the type of power supply of the RFID transponders.

Passive RFID transponders are supplied by the radio signals of the interrogation device. A coil or rectenna is used to power the integrated circuit, which provides the response signal, for example by modulating the coil attenuation. This limits the possible range. Due to the low cost per transponder, typical applications are those where many transponders are needed, for example to label products or identify documents. Ranges of a few centimeters are typical.

RFID transponders with their own power supply enable longer ranges, lower latencies, but a larger range of functions, such as temperature monitoring of refrigerated transports, are more expensive. Therefore, they are used where the objects to be identified or tracked are themselves more expensive, such as reusable bins (containers) or trucks for toll collection.

Battery Transponders are usually in sleep mode and do not emit any information until they are activated (triggered) by a special activation signal. This increases the service life of the energy source to months to years. There are two types of battery-powered RFID transponders:

Active RFID transponders use their energy source both to power the microchip and to generate the modulated return signal. Depending on the permissible transmission power, the range can be kilometres.
Semi-active RFID transponders or semi-passive RFID transponders are more economical, because they do not have their own transmitter, but only modulate their backscatter coefficient, see Modulated backscattering.  For this purpose, the range is reduced to a maximum of 100 m, depending on the power and antenna gain of the transmitter. The other advantages over passive transponders are retained.

Frequency bands

So far, various ISM frequency bands have been proposed for use and some of them have been released throughout Europe or internationally:

Long waves (LF, 30–500 kHz). They have a short to medium range (? 1 meter) at a low data rate. Detection rates of 35 transponders per second for up to 800 transponders in the antenna field are possible. LF transponders are a bit more expensive to buy, but the read/write devices are comparatively cheap. This gives LF systems cost advantages, as long as relatively few transponders are required but many read/write devices. The LF systems can cope with high (air) humidity and metal and are offered in a wide range of designs. These properties favor use in harsh industrial environments, but they are also used, for example, for access control, immobilizers and warehouse management (often 125 kHz). Some LF versions are also suitable for use in potentially explosive atmospheres and are ATEX certified.
Shortwaves (HF, 3–30 MHz). Short to medium range, medium to high transmission speed. Medium to high price range for readers with ranges greater than 10 cm, inexpensive readers for short ranges. The so-called smart tags (usually 13.56 MHz) operate in this frequency range.
Very high frequencies (UHF, 433 MHz (US, DoD), 850-950 MHz (EPC and others)). Long range (2-6 meters for passive transponders ISO/IEC 18000-6C; around 6 meters and up to 100 meters for semi-active transponders) and high reading

speed. Used, for example, in the field of manual, semi-automatic, automated distribution of goods with pallets and container identification (door seals, license plates) and for the control of individual shipping and trading units (EPC tags) as well as for vehicle license plates (so far only in Great Britain). Typical frequencies are 433 MHz, 868 MHz (Europe), 915 MHz (USA), 950 MHz (Japan). Due to their low price, they are now also permanently used on consumer products such as clothing, but their range of several meters sometimes causes incorrect readings by readers, for example through reflections. [10]
Microwave frequencies (SHF, 2.4–2.5 GHz, 5.8 GHz and above). Short range for only semi-active transponders from 0.5 m to 6 m at higher reading speed due to high passage speed for vehicle applications (cars in multi-storey car parks, wagons in railway stations, trucks in driveways, all types of vehicles at toll stations).

Encryption
The older types of RFID transponders send their information in plain text, as provided for in the ISO/IEC 18000 standard. Newer models also have the option of transmitting their data in encrypted form or not opening parts of the data storage to everyone who can access it. In the case of special RFID transponders, which are used, for example, to control access to external mobile security media, the RFID information is already transmitted encrypted in accordance with the AES standard with 128-bit.

Modulation and coding methods
Keying/modulation is a method of conducting digital signals over analog transmission channels. The term keying comes from the early days of the telegraph. Modulation methods include:

Amplitude Shift Keying (ASK): used in proximity and vicinity coupling
Frequency Shift Keying (FSK, 2 FSK): used in vicinity coupling
Phase Shift Keying (PSK, 2 PSK): used in close coupling
Phase jitter modulation (PJM): statistical modulation method and standardized in ISO/IEC 18000-3 for use in RFIDs.

Higher modulation methods such as phase jitter modulation are used in RFID systems when a large number of RFIDs in close proximity are to be read almost simultaneously.

Encoding determines between the sender and receiver how the digital data is recoded in such a way that it is optimally adapted to the characteristics of the transmission channel, in this case the radio link. The most commonly used channel coding methods in the RFID sector are:

Biphase Mark Code and the Inverted Biphase Space Code
Pulse phase modulations in combination with the data center code
Manchester Code
Miller Code

A special case are SAW tags that use SAW effects. The identifier is encoded in the transit time of the reflected signals.

Bulk Detection
The term bulk detection refers to the use of known protocols in which individual RFID tags are read immediately after each other, whereby this process organizes itself. This means that

not all tags report to the same reader at the same time, and
read only once a day, if possible, and
a day read once after the first successful reading is silent until it leaves the reading field or the reading field is switched off,
or that the individual tag already known there is directly reactivated by the reader.

Many applications of this radio-technical separation, also known as "singulation", are intended to enable the receiver to recognize the different identities of the existing tags one after the other. The concept is provided for in the standard in various forms, but has not yet been widely used. Other proprietary versions can be found from the various manufacturers. Technical problems with passive tags are not changed by the fact that active tags can arbitrarily contact a recipient.

RFID tags alone do not solve the following problem:

how many objects,
how many tags and
how many license plates have been read

a good reading success.

Since the first reports until today, there are no known bulk detection facilities that ensure complete coverage (2011) and would therefore be suitable for an inventory or a check of completeness.

If there is no anti-collision and mute mode in the read process, geometric isolation outside the reading area and the limitation to one day in each reading area is the procedure with a generally better detection rate.

Anti-collision or multi-access procedure
Anti-collision describes a set of procedures that enable the tags to communicate simultaneously, i.e. to exclude the overlapping of several different signals. The anti-collision procedure regulates compliance with the order or spacing of the responses, for example by sending these responses randomly so that the recipient can read each tag individually. The performance of the anti-collision procedures is measured in the unit "tags/s". There are four basic types of anti-collision or multi-access procedures:

Space Division Multiple Access (SDMA): Distances, range, antenna type and positioning are set
Time Division Multiple Access (TDMA): the access time is shared between the participants
Frequency Division Multiple Access (FDMA): different frequencies are used
Code Division Multiple Access (CDMA)

Typical anti-collision methods in the RFID sector are:

Slotted ALOHA: a variant of the ALOHA process from the 1970s (Aloha Networks, Hawaii). Aloha was the inspiration for the Ethernet protocol and is a TDMA process.
Adaptive Binary Tree: This method uses a binary search to find a specific day in a mass.
Slotted Terminal Adaptive Collection (STAC): has similarities to the ALOHA process, but is considerably more complex.
EPC UHF Class I Gen 2: is a singulation method.

Identity
All RFID tags must be clearly labeled so that the recipient can recognize responses/requests of all tags:[11] RFID tags in which this marking can be changed are of no practical value for secure process control in an open system (example: EPC Generation 1).

Distinguishing features of RFID systems
Minimum features of an RFID system are:

a numbering system for RFID tags and for the items to be tagged[12]
a description of the procedure for marking and for describing and reading the markings[13]
an RFID tag attached to objects or living beings that provides information that can be read electronically and contactlessly
a matching RFID reader

Auxiliary functions
Many tags also support one or more of the following operations:

The tags can be permanently deactivated via a so-called "kill code" or, for example, by a magnetic field (kill, disable).
The tags allow you to write once.
The tags can be written multiple times with data.
Anti-collision: The tags know when to wait or respond to requests.
Security: The tags may require a secret password (even encrypted) before communicating.

Data Stream Operating Modes

RFID can exchange data with the reader in duplex mode or sequentially. A distinction is made:

full duplex system (FDX)
half duplex system (HDX)
sequential system (SEQ)

Storage capacity
The capacity of the writable memory of an RFID chip ranges from a few bits to several KBytes. The 1-bit transponders, for example, are in article surveillance labels and only allow the distinction "there" or "not there".

The data record of the transponder is stored firmly in it as a running unique number (inherent identity) when it is manufactured, or as non-unique data (e.g. batch number) when it is used. Modern tags can also be changed later or described with additional data.

Descriptiveness
Writable transponders currently mostly use the following storage technologies:

Non-volatile memory (data is preserved without power supply, therefore suitable for inductively powered RFID):

EEPROM
FRAM

volatile memory (need an uninterrupted power supply to retain the data):

SRAM

Energy supply
Passive transponders take their operating voltage from the electromagnetic field of the reader. The reader "illuminates" the chip and it reflects a small part of the energy. Therefore, passive transponders need a powerful reading field.

Semi-passive (also called semi-active) transponders have a (backup) battery for volatile storage and for operating connected sensors, but not for data transmission. The energy ratio between "illumination" and reflection is the same as that of passive tags.

Active transponders use batteries for the processor and also for data transfer, are equipped with their own transmitter and thus achieve a longer range. The query signal from the reader is about as low as the transponder's transmission signal, so the reading process for active transponders is particularly low-interference compared to passive transponders.

Beacon transmitters, which transmit continuously intermittently and do not respond to an excitation, always work with batteries (primary batteries or accumulators). The energy ratio between the query and the response signal is the same as that of active tags. The transmitting process for beacon transponders is particularly low-interference compared to passive transponders, despite the constant transmitting function.

In Germany, active transponders are also classified as telemetry devices (see below). Telemetry SRDs (radio links over short distances, e.g. from sensors) are also sometimes referred to as RFID, they use an active transmitter that is supplied with energy, for example, by solar cells or the movement of the object (e.g. tire pressure sensor). In warm-blooded organisms, the supply from a temperature difference is also in development. [14]

Operating frequency

FrequencyRangeAllowed frequencies (ISM band)

Long Wave Frequencies (LF)
30... 300 kHz
9... 135 kHz

Shortwave Frequencies (HF)
3... 30 MHz
6.78 MHz, 13.56 MHz, 27.125 MHz, 40.680 MHz

Decimeter waves (UHF)
0,3... 3 GHz
433.920 MHz, 868 MHz, 915 MHz, 2.45 GHz

Microwaves (SHF)
> 3 GHz
5.8 GHz, 24.125 GHz

Ranges and typical applications
Flag tag label with integrated RFID chip

According to English usage, the following distinctions have been established:[15]

Close coupling: 0... 1 cm (ISO 10536)
Remote coupling (also proximity coupling): 0... 0.1 m (ISO 14443, ISO 18000-3)
Remote coupling (also vicinity coupling): 0... 1 m (ISO 15693, ISO 18000-3)
Long range coupling: more than 1 m (ISO 18000-4, ISO 18000-5, ISO 18000-7)

FrequencyTypical Max Reach for TagsTypical Applications

Long Wave Frequencies (LF)
0.5 m (passive)
Animal identification and reading of objects with a high water content

Shortwave Frequencies (HF)
0.5 m (passive)
Physical access control

Decimeter waves (UHF)
3–6 m (passive)
Warehouse and logistics area (pallets)

Microwaves
?10 m (active)
Vehicle Identification

Technically, longer distances can be achieved, but only the specified ranges at permitted transmission field strengths are typical. The illumination field strength for passive tags (query by readers) is about 1,000 times higher than the transmission field strength of active tags (reception by readers).

Frequency Manipulation

Reflection / directional or non-directional scatter (backscatter): The frequency of the reflected wave is the transmitting frequency of the reader
Attenuation modulation: the transponder influences the field of the reader (frequency ratio 1:1)
subharmonic wave (frequency ratio 1:n)
Generation of harmonics (n-fold) in the transponder

Coupling Methods

electrostatic fields in capacitive coupling (for RFID rather the exception, not a standard)
Magnetic fields for inductive coupling or near-field coupling (NFC): Data transmission and usually also power supply take place via the magnetic near field of the coils in the reader and in the tag (frame antennas or ferrite antennas are common). This coupling is common at frequencies of 135 kHz (ISO 18000-2) and 13.56 MHz (ISO 18000-3) as well as for 13.56 MHz NFC (ISO 22536).
Electromagnetic dipole fields for far-field coupling: Data transmission and often also power supply are carried out with antennas (dipole antennas or spiral antennas are common). This coupling is common at frequencies of 433 MHz (ISO 18000-7), 868 MHz (ISO 18000-6) and 2.45 GHz (ISO 18000-4).

Use
Logistics is the main area of application. The breakthrough to general expansion sometimes fails because the business case is budgeted across company boundaries (see also Reporting Point (Logistics)). Examples from 2013 are:

Vehicle Identification
Electronic Road Pricing System in Singapore

The e-Plate license plates are automatically identified on readers. As a result, access controls, inner-city toll systems and also section control speed measurements are possible. If the sensor network is correspondingly dense, path profiles can also be created. In a large-scale test in April/May 2006, the British Department of Transport had about 50,000 license plates equipped with RFID radio chips. The aim is to collect information on the counterfeiting rate as well as the validity of registration and insurance coverage. Detection requires a distance of less than ten meters.

As of 2006, wagons and locomotives in the USA and Canada are marked with an RFID tag on both sides, which is read at about 500 stations during the journey. [16]

Electronic documentation of the state of construction
The automotive industry uses RFID for the automated documentation of test vehicles and prototype parts (Transparent Prototype project).

Banknotes
As early as 2003, the European Central Bank negotiated with the Japanese electronics company Hitachi about the integration of RFID transponders into euro banknotes. [17] The so-called ? chip (0.16 $mm^2$ × 0.064 mm thick) has a 38-digit number (128 bits). [18] Banknotes marked with such an RFID chip are said to be better protected against counterfeiting. Due to the costs associated with the implementation and data protection issues, the introduction is not yet planned.

Payment cards
Debit and credit cards with a wireless payment system[19] also allow identification. The security risk that could arise from possibly unnoticed reading and debiting is countered by limiting the payment amounts to a maximum amount or to a certain credit balance. Examples include Mastercard's PayPass system.

Identification of persons
RFID chips are included in all German passports issued since 1 November 2005 and in all identity cards from 1 November 2010. Since 1 March 2010, the Swiss passport has been delivered with an RFID chip. [20] In November 2004, the U.S. Food and Drug Administration (FDA) approved the use of the "VeriChip" in humans. [21] The transponder is applied under the skin. It advertises the easy availability of vital information in the event of an emergency.

Patient wristbands link their data to the patient information system in the hospital via the medical staff's PDA. [22]

Identification of animals
Glass transponder for animal identification (right) with associated application device (left)

RFID transponders have been used on large farm animals since the 1970s. Implants for pets (EU pet passport, ISO/IEC 11784 and ISO/IEC 11785) are also used. The animals in the zoo also receive such implants.

125 kHz – international for zoo animal husbandry, livestock identification, sea turtle registration, research.
ISO 134.2 kHz – (originally European) international standard in livestock identification, implants in pets. [23]

Authenticity for medication
The U.S. Food and Drug Administration (FDA) recommends the use of RFID in the fight against counterfeit drugs. For the transport of temperature-sensitive medical devices, RFID tags with sensor functions are used on the transport containers. The record documents a violation of transport conditions and supports the protection of patients by qualified discarding of incorrectly transported goods.

Hose stations and filling plants
For reliable control and electronic monitoring of refilling and filling processes, the RFID antenna is located in the coupling half on the system side, the RFID transponder in the movable coupling half, e.g. on the hose side of a tank car. When coupled, information is then transmitted contactlessly. The system control system can then automatically start subsequent process steps.

Printed Circuit Boards and Components
RFID tags are used to make printed circuit boards or other components traceable. [24]

Textiles and clothing
RFID tag of a garmentRFID tag sewn into a garment from the French sports outfitter Decathlon. Front and back as well as transmitted light scan.

In the textile and apparel industry, an increasing use of RFID is likely due to a higher margin compared to other industries. Lemmi Fashion (children's fashion) was the first company to convert its supply chain to RFID and implement an integration with the merchandise management system. In 2006, the company Levi Strauss & Co. began equipping its jeans with RFID tags. [25] The company Gerry Weber has been working on the technology since 2004 and since 2010 has integrated an RFID tag into all garments, which also acts as article surveillance. [26][27][28] RFID has been used by the fashion company C&A since 2012[29], and since 2013/2014 by Adler Fashion Markets[30][31]. Since 2013, the sporting goods chain Decathlon has been sewing RFID labels into textiles of its own brands and attaching them to third-party products.[32]

Container Seal
For sea containers, mechanical seals with additional RFID tags have been designed. They are either used repeatedly (semi-active RFID tags according to ISO/IEC 17363, from 2007) or used once (passive RFID tags according to ISO/IEC 18185, from 2007). So far, there is no obligation to use such electronic seals.

Immobilizer
As part of the ignition key, transponders form the core of the electronic immobilizer. The transponder is read by a reading coil at the ignition lock and, with its stored code, represents the supplementary key element of the vehicle key. Crypto transponders are usually used for this purpose, the content of which cannot be manipulated without destroying them.

This anti-theft device requires a lot of effort in the event of a lost key.

Contactless smart cards
In Asia and larger cities, contactless, rechargeable tickets are common. The global market leader for so-called ticketing is NXP (emerged from Philips) with its Mifare system. In the U.S. and Europe, access control and time recording are often implemented with RFID technology. Some credit card providers use RFID chips as successors to magnetic stripes or contact chips.

In 2006, RFID technology was used in Germany for tickets for the Football World Cup. The aim was to reduce the black market by tying the card to the buyer. Bayer 04 Leverkusen, VfL Wolfsburg and Alemannia Aachen use this technology in Bundesliga matches.

Almost all major ski resorts in the Alps use contactless ski passes.

Merchandise & Inventory Management

In libraries of all sizes and types, RFID is used for media booking and backup. Prominent installations include the Munich City Library, the Hamburg Public Libraries, the Vienna Main Library, the Stuttgart City Library and the main libraries of the Graz University of Technology and the Karlsruhe Institute of Technology. In 2013, the network of Berlin's public libraries also completed the conversion of media management to RFID. The library of the University of Konstanz is also equipping its media with RFID technology as part of the renovation.

RFID tag hidden under the label of a liquor bottle

The RFID readers of the libraries are able to read the RFID transponders in batches (bulk capture). This simplifies the borrowing and return process. Return machines allow returns outside of opening hours. At the doors and stairways there are readers similar to the security barriers in department stores. They check that the loan is correct. The inventory of the collection and the finding of missing media becomes easier and faster.

Retail chains such as Metro, Rewe, Tesco, and Walmart are interested in using RFID to control the flow of goods on the sales floor. This makes it possible to automate the payment process and control the inventory. The Chinese retail chain BingoBox operates small markets without staff and uses RFID tags on every piece of merchandise. [33]

Position

In industrial applications in enclosed areas, driverless transport systems are used, in which the position is determined with the help of transponders embedded in the ground at a short distance from each other on the basis of their known position via the read identity and via interpolation. Such systems are dependent on the fact that only previously determined routes and routes are used. For rail vehicles, the magnetically coupled Eurobalise is used.

Waste disposal

RFID chip on garbage can

In the Austrian districts of Kufstein and Kitzbühel, an RFID-based garbage can detection system was in use from 1993 to 2015. [34]

RFID chip in garbage can (plastic button on the edge)

In the district of Celle, garbage cans have been marked with chips since about 1993[35]. Residual waste, organic and paper bins are equipped with it. The yellow bins do not have electronic identification.

In the German cities of Bremen and Dresden, garbage cans are equipped with RFID transponders for fee-based collection.

In the UK, several hundred thousand garbage cans have been fitted with RFID transponders without the knowledge of citizens. [36] The background is said to be the intention of the British municipalities to record the recycling behaviour of citizens. [37]

Access control
Transponders on or in the key are used to check if workstations are equipped with appropriate readers, as well as for user authentication for special external mobile security hard drives if they are equipped with appropriate readers in the housing.

Access
? Main article: Access control

Transponders on or in the key are used for access control if the doors are equipped with appropriate readers or with corresponding locking cylinders with a reading option.

Time tracking
? Main article: Time tracking

Transponders serve as a digital identification feature in sports competitions on the shoe (strap) or in the bib number of a runner or on or in the context of a racing bike (product examples: ChampionChip, Bibchip, DigiChip)

At terminals, the times of coming and going, possibly also the break times, are recorded when the user brings his RFID medium (usually chip card or key fob) within reading range.

Rescue and emergency services
In the fire and rescue service, RFID transponders can be used to recognize people based on the transponders and thus organize the distribution of clothing, protective equipment and accessories in the clothing store, among other things.

Transponders are available on certain clothing, which simplify the inventory and management of garments.

RFID in loading aids
Some manufacturers of loading aids offer solutions with integrated RFID transponders in accordance with ISO/IEC 18000-6C. Examples are transport pallets made of plastic or wood as well as small load carriers. [38][39][40] The integrated transponders can be e.g. can be used for load carrier or container management or, after the temporary marriage of the aid to the goods to be transported, as an identification feature of the loading unit in the context of supply chain event management. [41]

RFID at airports
By 2020, airports should be equipped with readers for RFID chips[42] integrated into the baggage tag[42] with personal data such as the name and gender of the owner. This is intended to reduce the loss of luggage and to better record the luggage. At airports such as Las Vegas since 2016[43] and Hong Kong, Milan-Malpensa, Lisbon, Aalborg, RFID technology had already been introduced in 2017 in addition to barcodes. [44] By the end of 2023, almost all flight baggage is to be equipped with it. Without RFID, 1.8% of baggage would have been misdirected. [45]

Distribution and costs

IndustryKum. Number (in millions)

Transportation/Automotive
1000

Finance/Security
670

Retail/Consumer Goods
230

Leisure
100

Laundries
75

Libraries
70

Manufacturing
50

Animals/Agriculture
45

Health service
40

Air traffic
25

Logistics/Post
10

Military
2

Other
80

Total
2397

Cumulatively, a total of 2.397 billion RFID chips were sold between 1944 and 2005. [46] The exact distribution by application is as follows:

In 2005, 565 million high-frequency RFID tags (according to ISO/IEC 14443) were sold, which is mainly due to the increased demand in the logistics sector. [47] In 2006, global sales were expected to reach 1.3 billion RFID tags. [48] Partly due to the increasing standardization of RFID solutions and the increased exchange among interested parties, market researchers had to lower their forecast for market growth in 2007 by 15%. In 2007, for example, it was expected to generate less revenue of around $3.7 billion for RFID services and solutions. [49]

In industrial applications, the cost of the chips and their expected degression are not the decisive factor. Much more significant are the installation costs for seemingly banal items such as cabling, sockets, transformers and antennas and so on, which are installed in conventional craftsmanship and for which therefore hardly any cost degression is to be expected. In comparisons of the profitability of RFID to barcodes, for example, it was and remained these infrastructure costs that could not be offset by the expected rationalization returns of an RFID system. [50][51]

The costs for the transponders (i.e. the RFID chips) range from 35 euros per piece for active transponders in small quantities to 5 to 10 cents per piece for simple passive transponders with purchases of several billions. [52][53]

Study Opportunities
A number of universities offer courses in the field of RFID within existing training courses. Since the summer semester of 2009, for example, it has been possible to complete a master's degree at Magdeburg-Stendal University of Applied Sciences.

Standards

German Association of the Automotive Industry (VDA)

VDA 5500: Fundamentals for RFID use in the automotive industry
VDA 5501: RFID Use in Container Management
VDA 5509: AutoID/RFID Use and Data Transfer for Tracking Parts and Components in Vehicle Development
VDA 5510: RFID for Tracking Parts and Assemblies
VDA 5520: RFID Use in Vehicle Distribution

Waste disposal

Trovan
BDE VKI (variation ISO 11784 / 11785)[54]

Animal Identification

ISO 11784
ISO 11785: FDX, HDX, SEQ
ISO 14223: advanced transponders

Contactless Smart Cards

ISO/IEC 10536: close coupling smart cards (range up to 1 cm)
ISO/IEC 14443: proximity coupling smart cards (range up to 10 cm)
ISO/IEC 15693: vicinity smart cards (range up to 1 m)
ISO/IEC 10373: Test Methods for Smart Cards

DIN 69873/ ISO 69873: Data carriers for tools and grips; Dimensions for data carriers and their installation space
Container Identification (Logistics Area)

ISO 10374: Container Identification (Logistics)
ISO 10374.2: "Freight Container – Automatic Identification" the so-called licence plate
ISO 17363: "Supply Chain application of RFID – Freight Containers" the so-called shipment tag
ISO 18185: "Freight Container – Electronic Seals" the so-called eSeal

VDI 4470: Anti-theft device for goods (EAS)
VDI 4472: Requirements for transponder systems for use in the supply chain

Sheet 1: Use of transponder technology (General part)
Sheet 2: Use of transponder technology in the textile chain (HF systems)
Sheet 4: Cost-Benefit Assessment of RFID Systems in Logistics
Sheet 5: Use of transponder technology in reusable logistics
Sheet 8: Guide to RFID Project Management
Sheet 10: Acceptance Procedure for Testing the Performance of RFID Systems Area
Sheet 12: Use of transponder technology to support traceability using the example of the automotive supply chain

Item Management (Verwaltung von Gegenständen)

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
Part 4: Parameters for air interface communications at 2,45 GHz
Part 6: Parameters for air interface communications at 860 MHz to 960 MHz
Part 7: Parameters for active air interface communications at 433 MHz

Data Structures and Reader Communication Protocols

EPCglobal (Electronic Product Code)
ISO/IEC 15961 AIDC RFID Data Protocol – Application interface
ISO/IEC 15962 AIDC RFID Data Protocol – Encoding Rules

Concerns and criticism
An RFID license plate is first and foremost an open – i.e. readable for all those equipped with the necessary technology – individual license plate. In connection with concerns about RFID chips, there is therefore talk of "spy chips". [55]

Technical limitations
The limitation of RFID technology can be recognized by the technically usable range and the selected fixed information. RFID chips do not provide information about the exact location (position), orientation (direction) and movement (speed), but the identity of the license plate without further information about the wearer of the license plate.

Motion Profile
However, location information is always obtained indirectly through the knowledge of the location of the reader. RFIDs attached to portable objects and thus carried by persons are a danger to informational self-determination, since the data read out can be personally related if the connection is known (see below). In this respect, RFID is similar to a switched on mobile phone, the location of which can be roughly determined from the nearest radio cell. However, due to the comparatively short range of a few meters with passive RFID chips, the location determination at the moment of reading is much more accurate, even more precise than with civilian use of GPS. By strategically placing several readers at various traffic junctions, bottlenecks, doors and the like, it would also be possible to create a movement profile that is relatively accurate in terms of time and space. The danger for informational self-determination lies in particular from the fact that many RFIDs are hidden in place, so the wearer does not know that he is carrying them, in combination with a completely unnoticed reading process.

During the protests in Hong Kong in 2019/2020, RFID shielding measures of the demonstrators were cited as an example of the mechanization of the protests. [56]

Dangers of Loss of Informational Self-Determination
StopRFID campaign logo

The danger of RFID technology, for example, lies in the loss of informational self-determination, i.e. the individual no longer has any influence on what information is disclosed due to the "hidden" transmitters. Therefore, the imminent mass use of RFID transponders is problematic from a data protection point of view. To avoid this, some critics suggest the destruction of RFID transponders after purchase. This could be done (similar to disabling the anti-theft device) at the checkout. As a rule, it is not possible for the consumer to prove that a transponder has really been destroyed or that its memory has really been deleted. [57] For this reason, the technique is often pejoratively referred to as a sniffer chip or sniffer chip. [58][59]

Furthermore, the integration of additional, undocumented memory cells or transponders is conceivable. For the consumer, an RFID transponder thus becomes a black box, which is why some demand seamless monitoring of the entire production process.

In 2003, the Metro Group equipped some of its customer cards with RFID transponders without informing its customers of this. As a result, the company was awarded the negative Big Brother Award. Metro is continuing its RFID trials in its Future Store, but has exchanged the loyalty cards in question. This is what privacy activists see as a result of their protests. In general, a customer can successfully defend themselves against such practices if they are not done secretly. In 2007, Deutsche Bahn AG received the aforementioned Big Brother Award because it continued to equip the BahnCard 100 with RFID chips without informing customers.

Attack and protection scenarios

You can try to prevent the RFID transponders from receiving their energy. To do this, you can, for example, remove the battery or put the RFID transponders in a Faraday cage. When RFID transponders dock inductively at low frequencies around 100 kHz, shielding made of magnetizable materials such as iron or mu-metal can be used. At high frequencies above 1 MHz, wrapping with thin aluminum foil is sufficient.
In the case of larger RFID transponders, the spirals of the antenna can be clearly seen in the X-ray image. If it is severed at one point, the RFID transponder will no longer work.
The inductance of a coil antenna is usually matched to the operating frequency with an integrated capacitor (oscillating circuit). By covering it with aluminum foil, the resonant frequency is increased very significantly and the range is reduced accordingly.
An electromagnetic pulse on the transponder and antenna also destroys them and renders them unusable. As an example of this, the RFID zapper was presented at the Chaos Communication Congress 2005. This is a device that deactivates RFID transponders by means of an electromagnetic pulse. The high field strength of a microwave oven also destroys the electronics, but with the risk of damaging the carrier material (e.g. a customer card).
Complex: By transmitting an interference signal – preferably on the frequency on which the RFID transponder transmits – the rather weak signals of the RFID transponder can no longer be received. However, this jammer can in turn be located.
The transmission can also be disrupted by placing a large number (several hundred to thousand) of RFID transponders on a common carrier (housing). If the resulting jamming device is brought into the reading range of a reader, the tags all respond at the same time. Even if the reader works with anti-collision methods, it is still overwhelmed by such a large number of transponders and is no longer able to recognize "real" RFID tags (e.g. on goods). Such jamming devices can be disguised as MP3 players, mobile phones, etc.
Hardly effective: As with the telephone (by wire or wireless), RFID signals can also be spied on. In this way, at best, you can read what the RFID is currently sending back.
Extremely time-consuming: RFID signals can be manipulated. In the case of a memory chip for authentication, encryption methods are therefore also used.
At the IEEE Conference of Pervasive computing 2006 (Percom) in Pisa, scientists led by Andrew S. Tanenbaum presented a method for using manipulated RFID chips to compromise the back-end databases of RFID systems. They describe their work as the world's first RFID virus of its kind. [60] However, this representation is now considered by various sources to be too theoretically constructed. [61]

Environment and Recycling
According to the current state of knowledge, RFID tags applied to outer packaging cannot be recycled as well as outer packaging without RFID tags. Homogeneous packaging material such as waste glass, waste paper or plastic can be contaminated by the RFID chips made of copper and other metals, which are difficult to separate. Possible risks of contamination of the recycled material by RFID chips can mean more complex recycling or inferior quality of the resulting raw materials. [62][63]

Currently, there are no rules for the disposal of transponders as electronic waste for mass use, such as supermarket items. Among other things, research is being carried out on new materials (e.g. polymer-based), which should serve to further reduce manufacturing costs and open up new areas of application (e.g. transponders incorporated into ID cards and clothing)[64].

Another point is the resource consumption of RFID transponders. Precious metals are lost with them in a diffuse manner in landfills and waste incineration plants. Although a single transponder contains only a small amount of precious metal, a large number of chips (e.g. in food packaging) would significantly increase resource consumption.

Disruption of medical technology by RFID
In June 2008, a study[65] was published in the Journal of the American Medical Association showing that numerous diagnostic measurements are falsified by the electromagnetic waves required for reading RFID. [66] Medical devices, which are present in every well-equipped intensive care unit, reacted with varying degrees of sensitivity with measured value distortions. "At a distance of one centimeter to six meters, 34 out of 123 tests showed a malfunction of the medical

equipment. In 22 cases, these disorders were judged to be dangerous because ventilators failed or automatically changed the respiratory rate, because infusion pumps stopped or external pacemakers failed to work, because a dialysis machine failed or the ECG monitor showed a non-existent arrhythmia." [67]

See also

- Auto-ID
- Smart card
- Data mining
- Organic Electronics
- Near Field Communication
- Ubiquitous computing
- Internet of Things
- Secondary Radar

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