Radio Frequency Identification (RFID)

White Paper

1 Radio Frequency Identification (RFID) Overview

RFID is a technology that enables the electronic labelling and wireless identification of objects using radio frequency communications [8]-[9]. RFID is also a subset of the broader area of Automatic Identification and Data Capture (AIDC) technologies, which include the more mature barcode, optical character recognition and infrared identification systems.

From a functional point of view, an RFID system consists of three components:

- **Tags** into which identification data can be embedded. These are devices that identify the item to which they are attached. RFID tags are also called transponders or more generally contactless data carriers.
- **Readers** that communicate wirelessly to the tags.
- **Software application** that reads/writes data to/from tags through the reader.

The application software (in a workstation or pc) initiates all communications between the reader and the tags. Both the reader and the tags are equipped with antennas that receive and emit electromagnetic waves.

1.1 RFID Readers

An RFID reader accomplishes two tasks:

- It receives commands from the application software
- It communicates with tags

Readers may be handheld or mounted on a particular object. In the case of handheld readers, the workstation (loaded with the application software), the reader and the antenna are all part of one device. Data exchanged with tags may be stored and transferred to a main processing unit at a later stage depending on the application.

An RFID reader is practically a bridge between the application software and the antenna that radiates radio waves towards the tags.

The radio waves emitted by the antenna propagate in the surrounding space. As a result, data travels wirelessly towards the tags that are in the vicinity of the antenna.

1.2 RFID Tags

RFID tags are de vices made up of an electronic circuit and an antenna integrated all into one. The electronic circuit of an RFID tag generally has a memory where data may be stored. The memory is physically – and logically – divided into cells. Some of these cells store data that may be read only, such as unique serial numbers written at the production stage. Other cells of an RFID tag may be both written to and read repeatedly.

RFID tags may be *active* or *passive* depending on whether they have an on-board power source or not.

- **Active tags reduce the power requirements of the reader and can transmit information over relatively far ranges**. They possess a battery that can last generally from two to seven years. The downsides of such tags are their cost and their size, which reflects their complexity. Generally speaking, the more functions an RFID tag can perform, the more complex and bigger it will be.
- **Passive tags are less complex than active tags, because the reader provides them with their operating power**. They are small, light, inexpensive and can last up to 20 years. Their range of transmission is relatively short and RFID systems with passive tags require a much higher-powered set of readers.

RFID tags are often considered as the next generation bar codes. Their reading does not require a line of sight or contact. Due to integrated circuit capabilities, RFID tags can carry a relatively greater amount of information than classical bar codes.

The following table illustrates the main differences between barcode and RFID technologies.

System	Barcode	RFID
Data Transmission	Optical	Electromagnetic
Typical Data Volume	1-100 Bytes	128-8K Bytes
Data Modification	Not possible	Possible
Position of Data Carrier for Read/Write	Visual contact	Non line of sight possible
Reading Distance	Several metres (line of sight)	From centimeters to meters (depending on the frequency and tags)
Access Security	Little	High
Environmental Susceptibility	Dirt	Very small
Anticollision	Not possible	Possible

- **Data Transmission**: The barcode is a binary code consisting of a field of bars and gaps arranged in a parallel configuration. The bars and gaps are arranged according to a given pattern that corresponds to some data. The configuration of such bars and gaps reflects a pattern when illuminated by a laser scanner. The optical power received by the scanner can then be processed and the data associated with the configuration extracted. Thus, in the case of barcode reading, transmission of data is performed optically. In RFID systems, the communication between the reader and the tags occurs through radio waves.

- **Typical Data Volume-Data Modification** In barcode systems, the amount of data that can be read from a pattern of bars and gaps is limited. A Byte is eight bits, i.e. a number of eight binary digits (possible values of each digit: 0 or 1). Barcodes may store up to 100 Bytes, that is, 100 sequences of eight binary digits. The amount of resulting data that corresponds to the sequences is therefore actually quite small.
  Generally speaking, a barcode will contain an identifier of the country of a product, or an identifier of the company with its name and address and a manufacturer's item number. In RFID systems, the capacity of an RFID tag is, at least, comparable to that of a barcode, allowing storage of exactly the same amount of information.
  In the best-case scenario, RFID tags can be equipped with a memory that is comparable to that of a personal computer commercialised a decade ago. Barcodes are symbols that may only be read when they have been printed, i.e. barcode content cannot be modified. This is not true of RFID tags that may be read and written repeatedly.
- **Position of Data Carrier for Read/Write**: Barcode systems need visual contact between the scanner and the barcode to read data. RFID systems allow electromagnetic waves to propagate through several materials; hence line of sight is generally not required for reading data from RFID tags.
- **Reading Distance**: Barcodes may be scanned from several meters, although this is only possible under particular conditions. In RFID systems, the reading distance does strongly depend on the frequency of operation and on the tags themselves (active or passive).
- **Access Security**: Security of data is certainly not guaranteed in barcodes as any scanner can read any barcode, regardless of who is operating it. RFID tags are better protected than barcodes as the radio communication between the reader and tags may be equipped with modern security techniques (authentication and encrypted data transfer methods) to provide the systems with a good level of security.
- **Environmental Susceptibility**: Barcodes cannot be read if they are dirty, if the pattern of bars and gaps is not clearly visible from the scanner, or if intense light interferes with the optical rays of the scanner itself. RFID tags can operate in much harsher conditions than barcodes: dirt, frost, humidity, grease and in the sunlight.
- **Anticollision**: A barcode scanner cannot read more than one barcode at a time. RFID readers, however, may be drivenby specific software applications that can handle the reading of multiple RFID tags. This feature is called anticollision as it permits a reader to avoid data collision from several tags that enter the reader's coverage.

1.3 Frequency

An important factor to be taken into account is the operating frequency of an RFID system. This is the frequency used to enable the reader to communicate wirelessly with the tags.

There are several available frequency bands for the deployment of an RFID system. Generally speaking, RFID systems may be classified as low- and high-frequency systems. The choice of operating frequency affects the reading distance, interference with other radio systems, communication data speed, and antenna size. Low frequency systems typically use passive tags whereas higher frequency systems operate with active tags.

As a rule of thumb, at lower frequencies, passive tags are not capable of transmitting their data further than a few feet, due to power limitations. However, wireless communications between the reader and the tags may occur through a non-line of sight path, i.e. travelling along a wide range of materials, with some exceptions. For example, passive tags may not be placed on metal objects because metal significantly reduces the flux of magnetic field. As a result of this reduction, RFID tags do not receive the minimum power to start functioning.

It is for this reason that some special construction techniques have been developed to install RFID tags into metal items such as tools or gas bottles. In these specific cases, the cost of a tag increases significantly due to the complexity of construction.

At higher frequencies the reading distance between the active tags equipped with internal batteries and the reader generally increases, although not dramatically because of power limitations imposed by international bodies that govern the frequency spectrum allocation. Electromagnetic signals at higher frequencies also suffer more signal attenuation when tags are covered with ice or water. In the worst-case scenario, a tagged object covered by a closed metal shield is invisible to any reader outside the shield. This is not surprising, as the higher the frequency, the more similar to light is the nature of the electromagnetic waves and it is a known fact that light cannot penetrate through a non-transparent shield.

However, reading distance is not the only factor which is influenced by the frequency, but also the electrical interference with existing systems (very high for frequencies lower than 300KHz decreasing for higher frequencies) and the data rate of communication between the tags and the reader (from Kbit/s to Mbit/s, respectively for frequencies lower than 300KHz and greater than 300MHz). Both these factors affect the performance of an RFID system.

If electrical interference is high then readers must be placed well apart one from each other and noise sources can degrade the communication of an RFID reader with tags.

If data rate is low the amount of data that can be transferred between the reader and tags over a fixed time interval may not be satisfactory for specific applications.

The size of antennas used to transmit data is always comparable with the wavelength of the electromagnetic waves, i.e. large for low frequencies and small for high frequencies. This physical fact implies that the size of an RFID antenna at lower frequencies can be of the order of square metres.

2 RFID Licensing Regulations and Standards

Not all frequency bands may be used for RFID systems. Any vacant space in the frequency spectrum for wireless systems is becoming scarcer as time goes on and the available license-free or Industrial-Scientific-Medical (ISM) frequency bands vary substantially from country to country in terms of regulations. This section gives a description of the frequency bands currently available for the deployment of RFID systems and introduces RFID standards.

Because they make use of electromagnetic fields, RFID systems can be considered as radio systems. As for any other radio system, to be deployed it must be guaranteed that other radio services already in place are by no means disrupted by its introduction. This is the reason why not all the frequencies may be used and only a few bands are available to RFID systems.

2.1 RFID Frequency Bands

The following bands are currently allocated to RFID.

- **125-134KHz** used for access control and animal identification applications. This band enjoys relative freedom from regulatory limitations because it has not been reserved as an ISM frequency range, although in this frequency interval other systems operate typically for aeronautical and marine navigational services. This frequency range is well suited for applications requiring the reading of small amounts of data at low speed within minimal distances. Radio waves at these frequencies penetrate through water, tissue, aluminium and wood but do not penetrate across metals and large antennas are required to receive and transmit.
- **13.553-13.567MHz** used for radio transcontinental connections and other ISM applications, such as remote control systems, demonstration radio equipment and pagers as well as integrated circuit (I.C.) card applications (which several working groups of the International Standard Organization (ISO) have been working on since 1998). This frequency range is well suited for applications requiring the reading of small amounts of data at low speed within minimal distances. At around 13.56MHz, electromagnetic fields can propagate through water and tissue but cannot penetrate metals. Antennas are made simply of turns of coils of small radius (10-20cms). It is important to note that the regulations regarding power levels allowed for RFID systems operating on this bandwidth differ from the U.S. to Europe.

- **400MHz-1GHz** used for several applications, also known as the Ultra High Frequency (UHF) range. Systems using this large band (from the lower to the higher end) are for example mobile commercial radio systems, TV broadcasting, telemetry systems, and amateur radio systems. Again, important differences exist between the U.S. and Europe, for example, for the frequency range across 915MHz, which is not available for ISM applications in Europe (GSM is present), whereas the bands 888-889MHz and 902-928MHz are available and used by some RFID systems commercialised in U.S. Electromagnetic waves do not penetrate closed metallic objects, but they may travel around open metallic items of finite size (e.g. a metal plate). Water and tissues do not allow propagation of radio waves.
- **2.4000-2.4835GHz** used partially by amateur radio systems. In this frequency range the electromagnetic waves act very much as optical rays, hence non-transparent obstacles attenuate the power of radio signals travelling through them.
- **5.725-5.875GHz** used by movement sensor systems such as those in shops or department stores.

2.2 RFID Standards

All frequency bands are subject to licensing regulations drawn up by standards institutes. Standards organisations may be international, regional and national.

International organisations include:

- International Organization for Standardization (ISO)
- International Electro-technical Commission (IEC)
- International Telecommunications Union (ITU)

Regional standards institutes include:

- Comité Européen Postal & Telegraph (CEPT)
- European Telecommunications Standards Institutes (ETSI)

National standards institutes include:

- British Standard Institute (BSI)
- American National Standard Institute (ANSI)

The fact that several institutions worldwide are continuously developing standards means that updates and changes are frequent. At present, the RFID industry shows lack of standards. The ANSI and the ISO are two of the bodies that play an important role in RFID standardisation.

2.2.1 ANSI

ANSI NCITS T6 256-1999 is an RFID standard that was released at the end of 1999 and deals with application programming interfaces (APIs) to RFID-based devices. This standard aims to promote interoperability and specifically consists of eleven C program function calls for RFID developers. The RFID interrogators compliant with this set of rules must operate within the 2.4GHz band. The ANSI standard is currently (at the time of writing this white paper) being revised and a new version of NCITS T6 256 is expected in the second quarter of 2001. This will also include standards for interrogators operating at 13,56MHz.

2.2.2 ISO

ISO and IEC have joined to form a committee, the ISO/IEC JTC1 that is divided into subcommittees (SCs). The thirty-first subcommittee, SC31, is dedicated to standardisation of AIDC technologies. SC31's fourth working group (SC31-WG4), is working on a standard defining functional commands and syntax for RFID systems. The finalisation of this standard is expected in 2001. As part of the results, RFID tags will be seen from a workstation as subdirectories of a directory associated with the reader that communicates with the tags. Reading and writing RFID tags will be equivalent to reading and writing data into files on the workstation, with the big difference that data is distributed over the physical assets.

In Europe, the standards given by ETSI provide the national authorities with a basis from which to create national regulations for the administration of radio and communications. Any RFID system that is to be deployed must comply with the rules imposed by its national authority. Typical regulatory documents set acceptable levels of physical quantities, such as:

- Maximum magnetic field emitted by an RFID transmitter at different frequencies
- Permissible levels of spurious, i.e. non-deliberate power emitted by RFID transmitters
- Modulation bandwidth of the carrier for data transmission

In addition to radio communication issues, there are also other factors to be considered for the standardisation of RFID systems.

- Data content is an important aspect to be considered when integrating RFID with existing applications, such as barcode technology applications. This is not a trivial task, as it must be guaranteed that the component features of barcode will be incorporated in RFID without constraining RFID by trying to accommodate bar code standards.
- Test specifications need to be set to guarantee a high quality of RFID components as well as expected compliance with several requirements.
- Product packaging must be standardised too, especially within open system applications, where, depending on the context, it may be needed to identify a tagged object that contains several tagged items but not the content itself (e.g. a container and boxes within it).

Standardisation is an important aspect of any technology from its incubation through to maturity [3]. Standardisation is advantageous for both vendors and customers.

For vendors, the benefits of standardisation include:

- Market broadening and global competition
- Products and applications interoperability
- Cost reduction
- Fast technology acceptance and technology advancement

For customers, standards help to achieve the following objectives:

- Increase confidence in a new technology
- Facilitate applications development and reduce customisation
- Reduce cost for equipment and software
- Increase decision flexibility
- Allow development of non-proprietary solutions that are not confined within one customer's organisation

In conclusion, RFID standards are now being defined, but are not yet available in a harmonised form that guarantees interoperability among different vendors' equipment. The lack of standards in this area, together with competition among manufacturers has meant a slow start for RFID technology advancement and disappointment for the RFID industry in general.

3 RFID Systems Accuracy and Scalability

This section examines the problems of RFID systems accuracy and scalability.

3.1 RFID Accuracy

RFID accuracy may be defined as the success rate at which a reader can identify a tag that falls into its covered area. Successful identification can be marred by the existence of certain physical constraints to which an RFID system must comply [4]. Such constraints include the position of antennas connected to the readers, the areas through which tags will pass, characteristics of environmental materials to contain the RFID system, power constraints and operating frequency.

To facilitate accuracy analysis, consider an RFID reader and a single tagged item. The main objective is to identify wirelessly the tagged object and communicate with it. The accuracy of this operation depends on several factors:

- Application requirements
- Noise levels
- Physical laws

In the following, it is assumed that issues such as tag memory size, security level and communication speed are selected according to the application requirements. Additionally, it is also assumed that the reader is sensitive enough to distinguish the data sent by the tag from the noise created by other systems operating in adjacent frequency bands.

Attention is therefore focused on the physical issues that hinder radio frequency communication.

3.1.1 Low Frequency RFID Systems

- **Distance Antenna-Tag** - At low frequency, for example at 13.56MHz, the RF communication between the tag and the reader very much relies on the power that the tag receives from the antenna connected to the reader. In free space, the intensity of the magnetic field emitted by the antenna decreases with distance, hence there is a threshold distance after which the tag is not activated and the RF communication is not established. Generally speaking, this threshold is of the order of tens of centimetres for a tag the size of a credit card. Decreasing the size of the tag decreases the threshold.
- **Environment** - Radio communication degrades if the magnetic field has to penetrate materials that attenuate electromagnetic power, as is the case with metallic objects. Additionally, RFID tags are not detected when embedded in metals, as the material itself drastically dampens the magnetic flux across the tag.

- **Tag Orientation** - The orientation of tags is important and can cause the magnetic flux to vary dramatically. In other words, if an RFID tag is parallel to the direction of propagation of the energy, the flux is null and no RF communication is established regardless of the distance between the tag and the antenna.

3.1.2 High Frequency RFID Systems

- **Environment** - At high frequencies, the performance of an RFID system strongly depends on the environment in which the communication between the reader and the tag occurs. As mentioned previously, metallic objects act as mirrors at higher frequencies, e.g. 2.4GHz, and radio waves propagation is highly attenuated through water and tissue. In a line-of-sight context, identification of a tagged object may be achieved at distances of the order of tens of metres whereas in the presence of an obstacle, the reading distance will dramatically decrease.
- **Power** – At high frequencies, RFID tags are generally active and accuracy may be degraded by lack of power, i.e. when batteries run low.

The accuracy of an RFID system mainly depends on the physical environment in which the system is embedded. Generally speaking, the most challenging task is to design the RFID infrastructure around the physical constraints mentioned above.

3.2 RFID Scalability

RFID scalability may be defined as the success rate at which a single reader can identify a large amount of tags simultaneously and communicate with them.

Consider the more general case in which many tags are to be read by several readers, possibly interconnected through a Local Area Network (LAN). Here, it is of interest to understand what is the maximum number of tags that can be read by a single reader is and the communication speed that may be achieved. Once the application software receives the data, scalability issues become those of computer network technologies.

An RFID reader identifies the serial number of the tags that enter into its interrogation zone, that is, the area covered by the magnetic field generated by the antenna. This serial number is put into the integrated circuit of the tag at production stage and consists of several bytes. The same reader could therefore theoretically detect thousands of tags wirelessly.

To give an example, a serial number of five bytes gives rise to possibly 550 billions of different tags. However, for many tags to be read simultaneously, the identification events must be serialised. In other words, a technique is required for the reader to handle multiple communications, in order to avoid what is technically known as data collision. The simplest way to serialise the reading of numerous tag identities is to force tagged objects to be read one after the other, even at a high frequency of detection (e.g. tens per seconds).

This may be achieved by forcing the tagged objects to flow in a sequence through a gate with an antenna mounted around it.

However, the ideal case is to be able to detect the tags simultaneously without constraining them to any position in space. More complex anticollision techniques are being developed today to achieve concurrent operation. At present, the order of magnitude of tags, which may be detected by a single reader simultaneously, is of hundreds. Future results are expected to increase this limit to thousands.

In terms of data rate, the levels achievable today are of kbits/s at all different frequencies greater than 1MHz for each communication reader-tag.

3.3 Conclusion

RFID system accuracy problems are usually due to physical causes. Their solution consists of applying sound design criteria to systems deployment. Position of antennas connected to the readers, areas where tags are going to be passing by, characteristics of the materials of the environment where the RFID system is going to be embedded into, power constraints and operating frequency are all factors that must be carefully selected. Experience and rules of thumb very often must be applied to finalise an RFID design [2].

RFID scalability problems arise most often when the application needs to detect/identify simultaneously a large number of tags that fall into the area covered by a single antenna. In this case, the solution relies on the development of suitable "anticollision" techniques. The RFID market of today is beginning to offer some suitable solutions for scalability problems.

4 RFID Technology Cost

The cost of RFID technology has been the largest inhibitor of RFID growth over the last years. Given a typical RFID system, the cost of the infrastructure is divided among the readers, the antennas and the tags. It is the latter that frequently represent the largest part of the investment.

The number of tags increases if the objects to be tracked are regularly leaving the space controlled by the reader, as is the case for tagged consumer goods. In comparison, the cost of the reader and antenna remain minimal.

It is important to have an idea of how tag costs will evolve in the next years. At present, the cost of a simple RFID tag with a read range of a few centimetres is generally around one U.S. dollar. More complex RFID tags may cost even tens of U.S. dollars.

Prediction of future tag cost remains vague with estimates given by the experts often contrasting [1]. For example, tag cost has been forecast to drop to a few cents by the end of 2001 in the most optimistic case. However, this prediction has not been confirmed by other experts in the RFID industry who claim that the cost of a tag can by no means be allowed to drop below the production cost, which in turn, depends on the following:

- Silicon die production (7-12 cents)
- Die placement on printed circuit board (PCB) (10 cents)
- Antenna / adhesive packaging (5 cents)
- Handling and shipping expenses

The more realistic approach would be to allow the tag cost to gradually decrease over the next few years. With this probable horizon in mind, it is still possible to envisage application of RFID systems. The most important point is that the cost versus benefit analysis of the implementation of RFID should be advantageous with respect to other AIDC technologies. For example, RFID may result cost effective when tracking high value items or reusable packaging and containers.

5 RFID Market Penetration and Uptake

The use of RFID technology and its growth has slowed down recently mainly because of the lack of standards and the high costs involved with implementation.

Frost and Sullivan, an international marketing, consulting and training company, has produced strategic research that predicts a steadily rising demand for RFID technology over the next four years at a constant rate of 33% [11]. Revenues of RFID industry are projected to reach nearly seven and a half billion U.S. dollars by 2006.

Small-medium sized companies that operate over regional scales have populated the RFID industry in the past. Regional companies have distinguished each other by implementing RFID closed systems for specific customers-organisations. Competition has been kept low, which has contributed to a stalling of cost and the slow progress of RFID technology.

The RFID industry is now changing, as large multi-national firms have entered the market across several regions. If these vendors would have preferred to develop proprietary standards in the past, they are now joining their efforts to define standards for RFID technology that will provide interoperability, increase competition, lower the costs and foster RFID growth at a faster pace [6].

However, it is not only the lack of standards and high cost that have prevented RFID technology from taking off. There are two other main factors that have contributed to this phenomenon.

The first is the search for a killer application that seems never to have showed up for RFID technology. This may be due to the fact that although the right technology at the right cost is out in the market, potential end users are still not educated as to what can be achieved by RFID deployment. They have been discouraged in the past by the chaotic situation concerning standards and generally prefer not to consider an investment in a closed system technology.

Hence it is understandable why predictions about RFID growth have often been issued by industry insiders and have sounded more like hype than realistic forecasts.

The second factor is that until now RFID research and development has kept a very low profile. Only recently have certain academic groups begun to invest in large-scale RFID initiatives. It is evident that such research efforts in RFID would lead to an advancement of the technology and an uptake on a global scale.

Scepticism still remains about RFID growth and RFID as an alternative to barcode technology. In RFID circles it is felt that probably right through to 2004 RFID will continue to be considered by many end users as a niche alternative to barcodes [10].

6 RFID Business Benefits

When examining the pros and cons of implementing RFID, two important facts must first be considered:

- Applications of RFID technology are still being incubated and not adopted on a large, global scale.
- As RFID costs are higher than barcode technology, a significant investment in this technology would have a payback period of at least several years, especially if RFID technology does not take off on a global scale.
  For example, it is hard to see the use of tagging containers and making them able to communicate with readers, if readers are not deployed within places that are not owned by the same organisation. This is a typical problem, which arises when developing open systems.

These two facts might discourage the use of RFID, as the costs versus benefits ratio might appear somewhat off-putting.

As things stand today, successful implementation of RFID would be confined within the boundaries of a particular organisation. Along with this assumption, the need for an advanced firm-wide IT infrastructure cannot be emphasised enough. This would facilitate the processing of useful data read out by RFID tags. It is vital that RFID data be communicated and used thoroughly by Information Management. Planning for profitable use of RFID data is certainly one of the first steps to be taken.

Although some limitations of RFID systems are evident, the use of RFID technology has already been proven as the winning solution in certain cases [7]. Common applications can be found in logistics, manufacturing, security, waste management, industrial laundries, automotive industry, food processing, postal tracking, airline luggage reconciliation, library management.

6.1 Public Transport

In Public Transport, RFID systems have been applied to implement automatic fare collection solutions. Conventional paper tickets are replaced by contactless smart cards with an RFID chip. Each bus is then provided with a reader inside the vehicles. Such a solution is beneficial for anyone involved in this transaction: the passengers, the driver, and the transport company.

For the passengers, cash is no longer necessary as RFID tags may be credited with sufficiently large amounts of money. Prepaid cards remain valid even when fares change and passengers do not need to know the precise fare when they start a journey.

For the driver, the implementation of an RFID system reduces distraction, means no cash in the vehicle thus reducing security risks and eliminates the need for calculating the daily income.

For the transport company, RFID-enabled automatic fare collection reduces maintenance costs of sales dispensers, increases dramatically protection against vandalism and fare dodgers, and provides flexibility in changing fares.

6.2 Industrial Production

RFID has also been applied to Industrial Production where RFID tags may be attached to an object on an assembly line. The objects may be identified and their current state tracked along with their future state.

The use of RFID systems in industrial applications brings about the following benefits:

- **Quality control of the production process**. This may be carried out automatically along the line.
- **System security**. This will be increased as possible software crashes of the central computer do not mean a loss of data, which may be written on the objects themselves.
- **Flexibility in the assembly process**. Data embedded into the objects may be read by programmable robots along the line as opposed to storing data on a central computer and complicating communication.
- **Increased resistance of RFID systems** Data reading may be performed in harsh conditions, thanks to the physical properties of RFID systems.

6.3 Warehouse Management

RFID Technology can also be applied to Warehouse Management. It is a well-known fact that misplacement of items can slow down the receipt and inventory of goods as well as lower productivity and efficiency. RFID technology represents the solution to this problem by enabling people to know where a product is when it is needed. In addition, RFID accelerates the reading process compared to barcode. Last but not least, RFID technology renders the spatial allocation of objects in the warehouse much more flexible as they can be found instantaneously.

6.4 Industry Examples

Below are some examples of successful real-life implementations of RFID technology (all examples found on publicly available web pages):

- San Francisco airport is using RFID tags to track and manage bags. Tagging bags on international flights, the airport makes sure that the bags have gone through all the right security steps.
  http://www.frontlinemagazine.com/rfidonline/c-s/1014.htm
- A large clothing retailer is piloting a system using RFDI tags to track products from the distribution centers to the stores and even on the store shelves.
  http://www.informationweek.com/story/IWK20010628S0008
- A branch of McDonald's is monitoring closely a marketing test that lets its patrons use a tiny, gray plastic wand to pay for meals, instead of cash.
  NewsEdge Corporation : McDonald's wants to make fast food even faster; 27/05/01.
- Mine Site Technologies offers an employee tagging and tracking system. RFID tags allow them to be tracked precisely and quickly in the mine, thereby supporting safety objectives.
  http://minesite.quinntech.com.au/product_service/tracker_tagging/overview.asp
- ExxonMobil is using RFID to track assets at a Torrance, CA refinery. Installed on pumps, motors, valves, and safety equipment, RFID tags are used to confirm operators properly perform procedures and verify that operators are at correct equipment. Operators make inspections with handheld computers and the data is uploaded into databases via wireless networks.
  http://construction-institute.org/cpi2000/cpi2000_proc.pdf
- Finnair is testing a RFID system eliminating boarding cards. Passengers carrying smart cards simply pass between detectors resulting in faster boarding.
  'Airline Finnair is doing away with passenger boarding cards this summer by adopting a technology previously used to track reindeer.' Business 2.0, UK Edition, May 2001
- London Heathrow Airport uses disposable RFID tags with customer baggage. Smart tags allow the airport to identify and track individual baggage as it moves through the airport. -
  http://www.rfid.co.uk/details12.htm
- OP Prostejov, a Czech clothing company, uses RFID tags to track clothing items from the point of manufacture to the point of sale, even to the extent of ensuring that trousers and jackets are correctly paired.
  Automatic ID News, July 1999
- A UK warehouse stores expensive whiskies, which were often stolen or misplaced by employees. Using RFID tags to identify and track inventory movement accurately, potential thefts or storage errors can be detected in real time.
  http://www.ti.com/tiris/docs/solutions/logsup_bond.html

- Swiss Federal Railway uses RFID tags to support the identification and tracking of rail vehicles. The tags also store maintenance information for later retrieval.
  http://aimglobal.org/technologies/rfid/casestudy/Swissrailway.htm

- Ford Motor Co., one of the early adopters of M2M technology, attaches wireless transmitters attached to its vehicles to help manage its massive inventory.
  http://www.idsystems.com/reader/1999_05/less0599.htm or
  e-com Magazine, March 2001, Title: (cover story) data-driven wireless - business unplugged [part 1]

- Black & Decker uses magnetic tags to help curb shoplifting.
  'Hey, security tag makers: You're it', USNews, May, 14th 2001,

- In order to track heavy commercial cargo, Singapore Airlines, one of the world's largest air cargo carriers, has rigged its distribution hub at Singapore Changi Airport with a wireless LAN. The hub routes tens of thousands of heavy cargo containers imported and exported each day. Scanners mounted along conveyor belts read passing RFID tags embedded into the containers, recording each shipment's location and contents, creating data that can then be accessed online.
  http://www.business2.com/articles/mag/0,1640,14548,FF.html

- In Vejle, Denmark, the main bus terminal has placed RFID tags on the front bumper of each bus. By enabling accurate tracking, the system provides passengers with real-time bus information and supports the allocation of buses to platforms.
  http://aimglobal.org/technologies/rfid/casestudy/busterminal.htm

- China's Ministry of Railways will extend TransCore's Railway Wireless Tracking System Nationwide.
  http://www.transcore.com/news/news010301.htm

- FedEx couriers use an automatic keyless entry and ignition system with RFID transponders embedded within a Velcro wristband.
  http://www.ti.com/tiris/docs/solutions/solutions.shtml

- Sweden's Botek Vagsystem AB uses RFID tags to identify individual rubbish bins. By combining this information with weight measurement of the material inside the bin, customers are charged for the exact amount of rubbish collected.
  http://www.ti.com/tiris/main.htm

- Malaysia is the first nation to launch the Government Multi-Purpose Card. A proposal under review would introduce smart identity cards carrying personal data and basic health information for children under twelve.
  Malaysian Government to consider extending smart cards to children under 12 years. Business Times (Malaysia), March 16th 2001.

- With a Nokia 5100 phone equipped with radiofrequency ID tags (RFID), a consumer in Raleigh can buy food and drinks at Taco Bell and Kentucky Fried Chicken by placing an ID-tagged phone containing credit or debit card information within a few inches of the merchant's card reader.
  http://press.nokia.com/PR/200101/803668_5.html

7 Some RFID Vendors

The following vendors are the main RFID vendors at the time of writing this white paper.

ADC Technologies

Established in 1986, ADC Technologies International manufactures access control equipment and provides total security management. The company also researches, designs and develops its own state-of-the-art systems based on innovative technologies to manage building access, alarm monitoring, closed circuit television (CCTV) and other vital functions in a company.

http://www.adc.com.sg/index1.html

Amatech

AmaTech is a world leader in the volume production of RFID systems and components such as contactless smart cards, smart labels, tags and readers as well as applications software and system solutions. With a global operation, the company has applied for 160 worldwide patents on products, machines and manufacturing processes in the identification technology sector; 72 have already been registered, 88 are still pending.

http://www.amatech.de

Amtech International

Intermec Technologies, Amtech division, provides automatic vehicle identification systems as well as equipment monitoring systems for the intermodal, rail, fleet, parking, access control, airport and transit as well as electronic traffic management markets. Products comply with AAR, ISO, CEN, IATA, and UIC standards in automatic identification.

http://www.amtech.com

Axcess

Axcess Inc. manufacturers products for use in the tracking and monitoring of vehicles, assets and personnel. Employing active Radio Frequency Identification technology, Axcess Inc. products easily interface with both new and existing security systems with unique features such as "hands-free" control, long-read range, and multi-tag read. Applications: Fleet Management, Time and Attendance, Vehicle Access Control, Personnel Access Control, and Asset and Personnel Tracking.

http://www.axsi.com

Elpas

EIRIS™, Elpas Infra-Red Identification and Search Systems, is a market technology leading solution. EIRIS™ provides cost-effective wireless facility systems for the comfort, life safety, security, energy efficiency and operation of corporate and healthcare environments. EIRIS™ solutions, developed for commercial markets, are based on patent pending Infra-Red (IR) and Radio Frequency (RF) technology that originally evolved in the Israel Defence Forces.

http://www.elpas.com

Gemplus Tag

Gemplus Tag, a division of Gemplus, is today the recognized supplier of field proven RFID products from smart labels to readers and application specific reading stations.
Gemplus Tag products are today widely used in many applications including industrial gas, laundry, automotive, libraries.

http://www.gemplus.com/app/smart_tracking/index.htm

Id Systems

Id Systems design and manufacture a wide range of innovative RFID products, both for low (125/134kHz) and high (13.56MHz) frequency tags and smart labels available from leading vendors. Their wide product range provides transparent support for tags from different manufacturers, and includes OEM boards, hand-held readers, interfaces for popular hand-held computers, and fixed position readers.

http://www.idsys.co.uk

Identec Solutions

Identec is dedicated to providing innovative data-gathering solutions to reduce losses and increase profitability for customers. ILR is the newest, on RFID based, data gathering solution available today. Applications: Item tracking, Inventory Control, Manufacturing Process Control, Warehousing – Distribution.

http://www.identec.at

Idesco

Idesco is a Finnish hi-tech company that develops, manufactures and markets readers, reader modules, tags and cards based on RFID.

http://www.idesco.fi

Motorola

Motorola's new RFID innovation, BiStatix, is bringing RFID price points to very low levels. This breakthrough technology allows antennas to be printed on materials including paper.

http://www.motorola.com/GSS/SSTG/smartcard/2_0_rfid_home.htm

Inforay Technologies

InfoRay Technologies develops and manufactures wireless positioning and identification systems using RFID technology. The Company's product lines include the EXACT passive tag system and LongReach™ active transponder system. The EXACT passive tag system has a read range of up to 130 feet with 2 feet positioning accuracy and the LongReach™ active transponder system has a read range of up to 6 miles with 15-100 feet positioning accuracy.
The Company is also active in the cellular industry. InfoRay has developed innovative technology, which provides handset 3D position at an accuracy level of 15 to 100 ft.

http://www.i-ray.com

Inside Technologies

Created in 1995 by engineers coming from leading companies in the smart card industry, Inside Technologies is a French corporation situated near Aix-en-Provence in the South of France. The company was set up to develop contactless chips for the smart card and electronic identification (RFID) markets.

http://www.insidefr.com/default.htm

Isis

Isis is a systems integration company based in London, United Kingdom. They have developed the Aspects Asset Management Software to locate, protect and manage IT assets on a real-time basis and help companies cut the total cost of ownership.

http://www.isis.co.uk

Marconi Infochain

Marconi InfoChain delivers wireless data application and capture and web-based information management services that track products and assets in real-time as they move through the supply chain. Marconi's innovative, patented RFID tag designs enable businesses to tag, trace and monitor the location of their assets.

http://www.marconi.com

Omron

OMRON helps its business partners develop solutions for their customers by supplying automatic identification technology-based system components.

http://www.omron.com

Philips Semiconductors

Philips Semiconductors offers a total capability in IC-based identification technology, providing integrators with the technologies they need to develop innovative identification solutions. Applications: item tracking, personal identification, inventory control, manufacturing process control, security, time and attendance, warehousing – distribution.

http://www.semiconductors.philips.com/identification

Pinpoint

PinPoint's 3D-iD Local Positioning System uses long-range radio frequency tags to automatically locate, track and secure a facility's assets or personnel. PinPoint's LPS is unique as it differs from usual RFID systems.

http://www.pinpointco.com

Samsys

Samsys Inc. is a developer/manufacturer of a unique Radio Frequency Identification Technology that markets under the name of Fastrak. This technology is most suitable for applications within the logistics management/materials handling environment, with particular emphasis on pallets and returnable containers.

http://www.samsys.com

Savi

Savi Technology provides RFID-based systems that enable customers to locate, monitor, track and optimise the utilisation of their assets. The company's solutions encompass a broad range of RFID and other AIDC products, supported by the Savi Asset Manager client/server software platform.

http://www.savi.com

Siemens

Siemens is one of the leading companies for radio frequency identification systems (MOBY) in Europe with branch offices worldwide. Main applications are in industrial automation, such as assembly lines, commissioning and logistics, box identification in warehouses, container and cargo identification, subtrains identification, etc.

http://www.ad.siemens.de/moby

Texas Instruments

TIRIS (Texas Instruments Registration and Identification System) - Radio Frequency Identification. Aimed at applications in logistics; automotive; vehicle identification; animal identification and access control.

http://www.ti.com/tiris/default.htm

Thax

In Findentity, Thax Software has developed a system for finding and organizing files, books and other things in rooms and identifying them via PC. At the click of a mouse, the storage location is indicated on a 3D plan, described by voice-over or shown by a laser beam, without having been previously manually registered in the computer. Information such as addresses, invoices, etc. can also be read out of files without the need to hold them physically.

http://www.thax.de

Trolley Scan

TrolleyPonder technology is an implementation of RFID technology. It is a protocol that allows many simple low cost transponders to be attached to items that are to be identified, and for a reader that is up to 6 metres away to quickly read all those identities accurately and provide either a local display or a computer compatible data stream with the identity information.

The transponders comprise of a simple electronic circuit connected to a simple antenna in a form suitable for the packaging requirements of the application. Although RFID systems are well known and widely used, the TrolleyPonder protocol allows the handling of multiple objects at a time, medium range reading ranges, and uses a much simpler and therefore cheaper transponder circuit than was previously available.

http://trolleyscan.co.za

Tss

TSS is revolutionising Intelligent Transport Systems (ITS), radically improving the efficiency of companies and organisations tasked with transporting goods and people by road, rail and sea, by using their patented technology for automatic identification, positioning, detection and data capture.

http://www.tss-tag.com

Wavenet

WaveNet International, Inc. is a high technology company that provides portable, mobile and fixed products that integrate AIDC, Barcode and Wireless Data Networking technologies. WaveNet solutions are designed for applications in industrial manufacturing, transportation, distribution and other industries.

http://www.wavenet-rf.com

Wherenet

WHERENET develops unique web-enabled wireless asset management systems that use RFID technology and Resource Management software to provide constant real-time asset location and portable data file capabilities. Real-time location is accurate within ten feet with a long-range read of 200 to 400 feet. Applications include automated warehouse management, job-order-tracking and high-value asset management.

http://www.wherenet.com

8 Conclusion

As with any innovative technology, and the uncertainties that accompany it, Radio Frequency Identification is experiencing a slow uptake. Although RFID systems have been successfully applied to implement solutions in areas such as public transport, industrial production and warehouse management, it is true to say that success has been specific to certain areas of implementation. In these particular cases, RFID technology has proved viable because the business benefits enjoyed justify the implementation costs incurred.

Growth and uptake have been hindered by the high costs involved with implementation, certain physical constraints and a lack of standards for this technology. Implementation is complex and involves accounting for the physical constraints at the design stage of any project. Designing around the physical constraints requires sound expertise and it is becoming increasingly evident that the best policy of dealing with the physical challenges involved in deploying an RFID system is on a case-by-case basis.

RFID technology continues to evolve, for example, work is being conducted to render data "anticollision" procedures more stable and powerful. At present, although potentially RFID systems can be made to detect billions of objects, current systems are sold with limited capabilities in terms of multiple identifications.

Standards groups are finally moving forwards on RFID, though it is impossible to estimate the speed with which global standards for this technology might be defined [5]. RFID market penetration is also reported to be steadily growing, causing the RFID market to become more global, which should increase competition and gradually lower the cost of this technology.

Appendix

This appendix aims to expand on some of the RFID concepts that were introduced in the main body of this white paper. In particular, a brief description of the relevant features of RFID readers is given as well as a short definition of RFID data transmission methods and tag classification alternatives to the typical passive/active one.

The final part of the Appendix offers some and relevant links to RFID Internet sites and a list of useful articles and publications.

RFID Readers

To exchange data with the application software the reader has two distinct modules:

- An interface
- A control unit

In particular, the control unit is basically a small computer (a microprocessor, a memory and additional integrated circuits) that performs several operations, such as the communications with the application software and the execution of commands, the control of communications with tags and electromagnetic signal coding and decoding. In more complex RFID systems, the control unit of a reader is able to perform three further crucial tasks listed below.

- **Anticollision algorithms**, necessary to detect separately different tags covered by a single reader. In a *non*-organised scheme, the tags simultaneously attempt to send a reply back to the reader accessing the communication channel at the same time and causing a collision of data. Regulating replies so that a reader may detect exactly the tags within its range is defined as anticollision.
  Three different anticollision techniques may be implemented: *spatial*, *frequency* and *time* domain procedures. In the spatial domain technique, the reader basically restricts its interrogation zone in order to reduce the possibility that two different transponders fall into the area covered by the reader itself. By doing this, the number of readers covering a large area must be increased. Frequency domain procedures are based on frequency domain multiplex techniques or spread spectrum technologies. In these systems, the reader broadcasts a status of frequencies allocated to the communication with the transponders, with the ones currently occupied by a transponder suitably flagged. A new transponder accessing the reader's coverage can then send its ID number on an unoccupied frequency.

Time domain anticollision techniques are divided into two categories: interrogator (reader) and transponder driven procedures. Interrogator driven time domain anticollision procedures may then be divided into two further groups: *polling* and *binary search* procedures. Polling techniques consist of requesting all the transponder serial numbers that could be used until a transponder with an identical serial number responds. This procedure may be very slow unless the number of transponders is quite small. Binary search is faster and is based on search algorithms over binary trees whose leaves are the transponders' IDs. The reader does not control transponder driven techniques. They are based on the cyclic transmission of ID numbers by the transponders in such a way that it is highly unlikely that any two transponders will send their own ID at the same time.

- **Authentication**, necessary feature in high-security systems (such as ticketing or payment systems) in which the unauthorised reading of data carriers and the placing of foreign data carriers into the system to accomplish frauds are to be avoided. There are essentially two types of authentication: *mutual symmetrical* and *using derived keys* techniques.
  According to the standard ISO 9798-2 in a mutual symmetrical procedure, both the reader and the transponder check each other's knowledge of a secret key. This approach is not applicable to RFID systems with millions of transponders as the probability of discovering the unique key must be always taken into account and this event would mean total manipulation by foreign components. Authentication may also be carried out using derived keys. In this scenario, the reader requests the serial number of the transponder that is incorporated in a special section during the production. In the Security Authentication Module (SAM) of the reader the transponder's specific key is calculated by using the serial ID and a master key and then it can be used to initiate the authentication procedure.
- **Data Encryption/Decryption**, necessary to protect the transmission of data from external attacks. Non-protected data might be intercepted (passive attack) or even modified (active attack) before reception. Altering the transmitted data by using a secret key K and a secret algorithm usually perform encryption. The data so modified are defined cipher data. The receiver then processes the cipher data by using a secret key K' and a secret algorithm. If the keys K and K' are identical or related to each other, then the encryption procedure is defined symmetrical, otherwise the procedure is an asymmetrical key procedure. If each character of the data transmitted is individually encrypted the technique is defined stream ciphering, otherwise if several characters are incorporated into a block and the block is encrypted the procedure is called block ciphering.

To communicate with tags the reader must be provided with a module called High Frequency (HF) interface that is the set of a transmitter and a receiver.

The HF interface is ended with an antenna which emanates/receives electromagnetic power towards/from the tags.

RFID Data Transmission

As far as data transmission is concerned there are essentially two main ways in which the reader and the tags can communicate with each other: inductive (or magnetic) and electromagnetic backscatter coupling.

- **Inductive coupling**: in this type of system, the antenna of the reader emits a magnetic field that varies periodically in time. As a tag falls into this magnetic field, a time-varying magnetic flux passes through the coils of the tag. This gives rise to a current that flows along the coils and hence activates the tag. The physical principle according to which this occurs is the well-known Lenz's Law.
- **Electromagnetic backscatter coupling**: in this type of system, the antenna of the reader emits electromagnetic waves. A tag consists basically of an antenna that reflects part of the electromagnetic power back to the antenna of the reader. Reflection of electromagnetic waves back to the reader's antenna is also known as backscattering.

RFID Tags Classification

- According to the amount of information carried by the tags, there are two types of tags: 1-bit tags and electronic data carriers.
- 1-bit Tags can store only 1 bit of information, i.e. only two states may be represented: transponder in the interrogation zone or transponder not in the interrogation zone. 1-bit tags are applied in Electronic Article Surveillance (EAS) to defend against theft.
- Electronic Data Carriers are based on integrated circuits (microchips) and physical effects. The latter are tags with sensor functions, employed, for example, in wireless temperature measurements in animal keeping. RFID data carriers are equipped with integrated circuits and are divided into two groups: transponder with state machine memory and with microprocessors (programmable).
  Tags may vary over a broad spectrum in terms of complexity, from read-only tags to data carriers with cryptological functions, passing by writeable tags. Read-only tags begin transmitting their ID number to the reader as soon as they enter in its interrogation zone. They are used mainly in animal keeping and location and in industrial automation with central data management. Writeable tags may be written and commonly have a memory size of up to 64KB. Tags with cryptological functions are the most advanced data carriers, as they are writeable and protected against unauthorised access. The memory area is equipped with an additional storage section for the storage of secret keys and a configuration register for selectively write protecting selected address areas.

Useful Links

Academic Groups

Automatic Identification and Data Collection at University of Pittsburgh

MIT Auto-ID Center

RFID page at Virgina Tech

The Center for AutoID at Ohio University

Organisations

AIM Global Network

Autoid.org

Frontline Europe Show Overview

Frontline Expo Show Overview

Frontline Solutions Website

IDSystems.com RFID Edge

Intermec Industrial Solutions Search

RFID Standards Organisations

RFID books

Frontline Solutions - Online RFID Source Book

RFID Handbook

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http://www.idsystems.com/reader/2000_11/comm1100/comm1100.htm

[2] Good Design Makes RFID Work,
http://www.idsystems.com/reader/1999_11/good1199/good1199.htm

[3] New Standards, Lower Prices Foster RFID Growth,
http://www.idsystems.com/reader/2000_10/new1000/new1000.htm

[4] Physical Reality: A Second Look,
http://www.idsystems.com/reader/1999_03/phys0399_pt2/phys0399_pt2.htm

[5] Planning for RFID Ubiquity,
http://www.idsystems.com/reader/2000_07/plan0700/plan0700.htm

[6] Steady Growth Predicted for RFID,
http://www.idsystems.com/reader/1999_05/quic0599.htm

[7] The Cutting Edge of RFID Technology and Applications for Manufacturing and Distribution, by Susy d'Hont, Texas Instrument

[8] Ubiquitous Electronic Tagging, http://www.computer.org/dsonline/articles/ds2wan.htm

[9] What is RFID? Research Note by Gartner Group, 1 September 2000

[10] Will RFID Challenge Bar Codes in the Warehouse? Research Note by Gartner Group, 24 October 2000

[11] World RFID-Based Application Markets, Frost and Sullivan Consulting Report, September 2000

