

TAG IT

Innovation using Tracking and Sensing Solutions

An Information Booklet for Managers



1 Commercial Opportunities for Exploiting Non-contact Data Transfer Technologies

1.1 Introduction - “Chips with Everything”.

The widespread exploitation of RFID (radio frequency identification) technology in commercial applications, such as electronic article surveillance, animal tagging and high volume logistics supply, has resulted in the availability of very low cost device technology that can be exploited by companies seeking to add value to their products or operations. The latest generation of chipless RFID tags promise such low costs that the tags can be applied to permanently identify food stuffs and clothing articles.

The reducing cost trends of the devices indicates that in the future the potential to incorporate such technologies in products will offer significant commercial opportunities for companies to innovate. Indeed, in the future the reduction in costs combined with the added values delivered by the technology could result in the widespread adoption of this device technology in products, leading to a move towards a situation where “chips with everything” is a reality.

1.2 Current Applications of Non-contact Data Transfer Technologies

The most common form of non-contact data transfer technology in current application is that of RFID device technology. RFID technology delivers passive devices (devices that do not require a permanent power supply) for the storage of data, including a permanent unique identity code, to allow tracking, identification and control functions to be performed on the item ‘marked’ by the device. Typical application areas for the use of RFID technology includes:

- Animal tracking, especially in applications such as the labelling of pets so that they can be identified or to ensure vaccination, dairy cow feed and yield recording, and for livestock tracking from breeding to the supermarket. The importance of tracking has been highlighted in recent years with the outbreaks of 'mad cow' disease.
- Logistics supply. To allow the processing of high volumes of items in application ranging from parcel services to supermarket retail supply chain management. These systems provide real time information on the status of every single item essential to fulfill customer's requirements and precise automatic stock control.
- Security applications such as electronic article surveillance (EAS). The market size already exceeds 6,000 million units per year for this application.
- Vehicle access and security applications. Around the world, more than 100 million transponder-based keys are protecting vehicles against car theft using RFID technology. In addition future transponders will hold additional information such as the drivers preferred seat and steering position, in-car temperature and entertainment requirements.
- Personal identification, security and access control. This application includes building security systems and for leisure applications such as ski passes.
- Road tolling, where window mounted transponders can be used for traffic management.

- Electronic article surveillance (EAS) where it is already reportedly reached a market size of over 6,000 million units per year, with strong continued growth.

The penetration of RFID technology into such high volume areas has reduced the unit cost significantly, making the use of this technology a viable commercial possibility in innovative application areas.

RFID implementations will add extra costs in comparison to bar-coding but significant benefits can often arise from the automation facilities it enables, for example in advanced object tracking, quality maintenance and production control.

Another under-utilised non-contact sensing and data transfer technology is that of capacitive sensing technology. One potential advantage of the application of capacitive data transfer is the low cost of the aerial, which in the ultimate design could consist of low cost foil plated packaging. One notable, example is the demonstration of data transfer from a tag device located on a cereal packet using this technology.

Capacitive sensing applications offer a wide variety of applications. These applications include:

- Flow or pressure measurement where the movement of a diaphragm with stable deflection properties can be measured
- Liquid level measurement, where the liquid level in a reservoir by measuring changes in capacitance between conducting plates which are immersed in the liquid or fixed to the outside of a non-conducting tank.
- Spacing or thickness measurement. For example, if a metal object is near a capacitor electrode the mutual capacitance is a very sensitive measure of spacing. Electrostatic measurement techniques such as this can also be applied in reversing aids for vehicles, where the distance between the vehicles bumper and an object can be sensed.
- Limit switches. The proximity of a metal machine object can be detected as an increase in capacitance, and the proximity of a plastic component by virtue of its increased dielectric constant over air.

An innovative application of capacitive sensing is in the detection of ice on aeroplane wings where ice formation can be detected using insulated metal strips in wing leading edges.

However, capacitive or electrostatic sensing solutions can also be applied in non-sensing applications. For example, many lamp dimmer switches uses 50 Hz excitation to respond to a human body.

These applications indicate that innovative control, sensing and data transfer solutions can be developed using capacitive non-contact sensing solutions.

In order to make the introduction of systems using this technology profitable, the challenge is to develop technical solutions that achieve high-performance at a low cost. Low-cost solutions usually imply the system has to be passive (that is, having no internal power supply). In addition the technology has to operate and perform well in different kinds of environments to achieve the required robustness and reliability.

These technologies will make further progress in the next five years. These developments provide an opportunity for companies to exploit high volume, low cost technologies in product ranges that otherwise could not deliver the volumes required to achieve this cost competitiveness.

The challenge facing entrepreneurs is therefore how to apply this technology to deliver innovative, new products that can deliver sales growth and improve customer satisfaction levels.

The experience of the companies partaking in the EC SIDCOM project provides some insights and exemplars of the adoption of this innovative application of technology.

1.3 Market Growth Projections

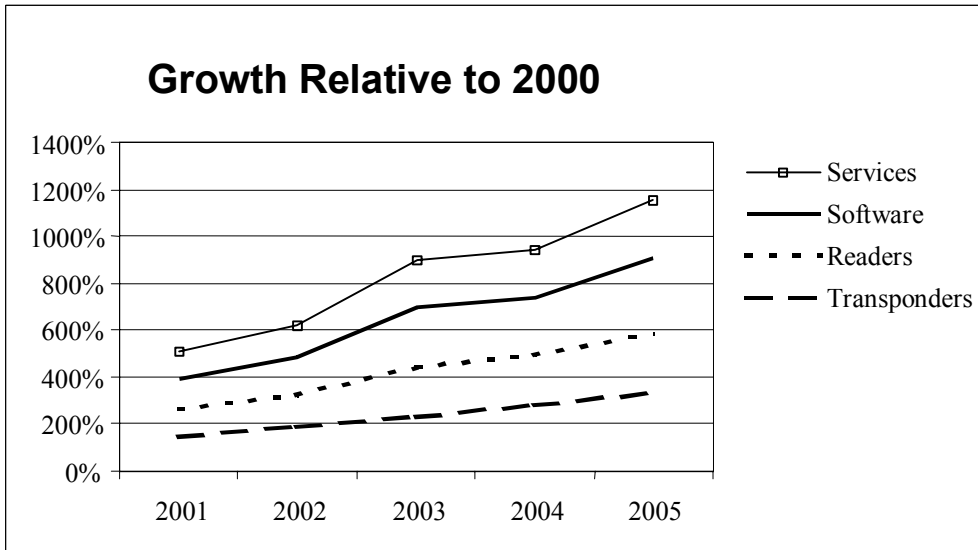
The economic advantages of utilising RFID technology has resulted in a significant growth in the market for products and related services. It is this economic growth that will provide cost reductions and maturing technologies that can be applied in other innovative applications.

The global market revenue for RFID systems was \$965 million in 2002¹, and is still growing. As issues of compatibility and acceptance of ISO specifications to consolidate industry and application standards are increasingly adopted then new product lines and new application developments will further occur.

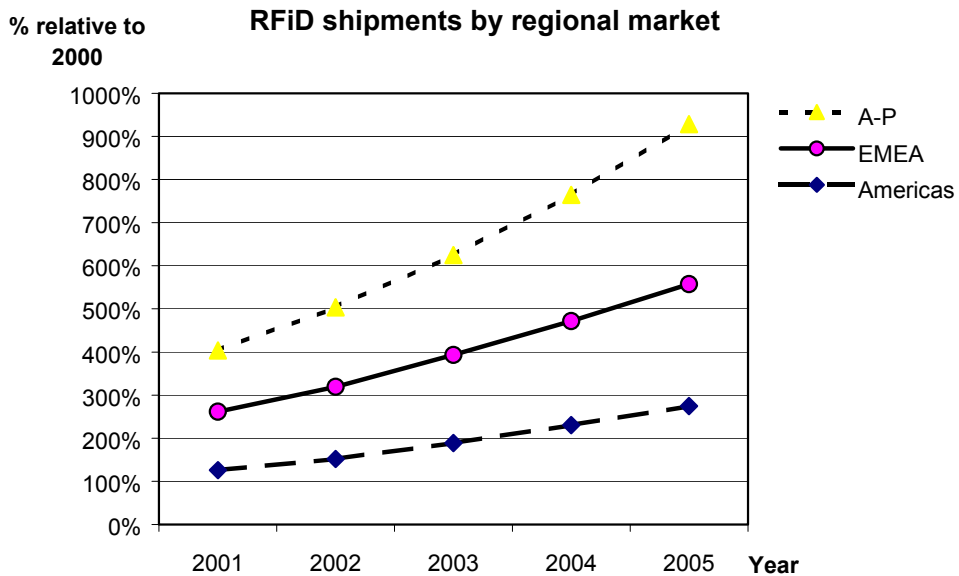
There has been an increased take-up in the use of the technology in recent years, with application areas varying from use in libraries, laboratories, manufacturing to laundries. The primary use of the technology in these application areas was that of item or material management. In addition, the co-operation of logistics and materials handling system designers with RFID technology solution suppliers has also resulted in the increased use of the technology in the areas of logistics, warehouse and asset management and industrial automation.

The growth in sales achieved and projected in RFID technology is indicated in the following chart. Currently there is an annual market growth of 24%, which is the highest of any automated identification technology.

¹ Source: Venture Development Corporation, 2003



This market growth is not uniform. It is anticipated that there will be a higher increase in the level of adoption and user acceptance in Europe than any other region. This will lead to an increase in European sales of over 100% in the next 5 years, and this growth provides a major opportunity for companies to innovate using this technology.



Key:

EMEA – European and Middle East

A-P - Asia / Pacific

APPLICATION	Number of units estimated in 2003
Supply Chain Management	440 million
Parcel Services	240 million
Rental applications	176 million
Re-usable media applications	120 million
Airline	83 million
Emerging and other applications	190 million

Projected Use of Smart Labels with Embedded RFID Devices

The low cost and flexibility of smart labels are gaining increased attention for applications such as baggage labeling, and is now being seen as a significant growth area for item management of various kinds.

However, the area of "emerging and other applications" is indicated to be 19% of the total projected number of smart labels sold. This is a very high available market opportunity for exploitation.

Chipless technologies are emerging that may well influence the growth in the future. As chipless technologies gain visibility and are further developed the prospects for significant low cost, near-contact, label-based applications in, for example, the areas of small item security and document handling are clear.

The fusion of technological development and standards, and the commercial acceptability of the technology (as indicated by market growth projections) indicate new application areas for this device technology will emerge in the next few years. Innovative companies made aware of this technology can fully exploit this opportunity.

1.4 Innovative Application Opportunities for Non-contact Sensing and Data Transfer Technologies

Analysis of data communications and data handling processes is a significant key to identifying appropriate applications for the use of RFID technology, and to establishing the requirements that have to be fulfilled to realise the technical solution.

One of the main challenges is to define the value of data to the system, the data structure required to deliver this value, the system and associated technology requirements and finally the economic and people-based needs that have to be satisfied. Value can be added in several areas, including:

- Introduction of mobile data bases located in the product, removing the need for complex, integrated database systems
- Reductions in manual handling through improved automation possibilities.
- Reduction in error count and quality costs as a result of improved quality control system implementations.

- Reduction in costs by removing active data transmission requirements and the introduction of passive, non-contact data transfer mechanisms.
- The development of new services based on contactless cashless card systems.

Details of examples of such innovative commercial applications can be located on the SIDCOM web site (www.euro-sidcom.com).

Other illustrative examples of the use of these technologies include:

- i. The integration of a capacitive sensor solution in an aid for the disabled to prevent the accidental trapping of fingers in the moving mechanisms.
- ii. The application of an active tag with integral memory, microcontroller, sensors and RFID communications interfaces that allow the tag to monitor at regular intervals the environmental conditions experienced by the tag and its associated cargo whilst in transit. This product allows the verification that shipping requirements of critical items (for example, vaccines or frozen food) were adhered to.
- iii. Innovative vending machine applications for controlling the dispensing and return of rental items such as videos or DVDs.
- iv. Pumping controllers with integrated RFID technology that check a tank is only filled from the correct nozzle in order to prevent contamination of the product. For example, a recent patent applies this principle in petrol stations where a small transponder fitted alongside the filler cap of motor vehicle's fuel tank enables the pump to sense the vehicle's fuel requirements automatically so as to dispense the correct grade of fuel.
- v. Document protection. By using RFID technologies to indicate specific data, documents can be given a signature that can be used for verification of the documents. Systems can then be developed to prevent the photocopying of certain documents depending on their signature.
- vi. Safety and personnel tracking systems, which use RFID solutions to detect the presence of individuals in a critical area and to take appropriate safety actions following this detection.
- vii. Power tool use control using RFID technology to limit the application of equipment to only authorised users issued with an appropriate transponder device.
- viii. Condition monitoring systems, where data can be stored in a tag mounted for example on a moving shaft during normal operation for later evaluation. A variation on this them is the logging of operational hours of a product.
- ix. The prevention of forgery of critical components, for example as used in the aerospace industry, by attachment of an RFID tag with encoded data to enabling receiver verification. One application involves the integration of tags within fire doors to validate the product and to verify the production methods employed.
- x. Non-invasive sensing for medical applications, including the development of systems for sensing the fluid levels in plastic bags, or for detecting bubbles or droplets in drug and other dispensing products.

- xi. Home automation systems that apply capacitive sensing solutions to enable controls to be embedded into furniture.
- xii. Innovative proximity sensing solutions based on capacitive sensing solutions for door annunciation system or lighting controls.
- xiii. Plumbing controls using capacitive sensing technology for level sensing in spas or pools, or leak sensing.
- xiv. Electronic controls in disability aids using capacitive sensors to sense small body movements or to reduce the need for pressure or pull strength.
- xv. Automotive product solutions, such as rear bumper parking aids or windscreen rain detection systems.
- xvi. Location systems for recovering items. For example, a recently granted patent proposes a RFID technology solution to finding lost golf balls on a golf course.
- xvii. Laundry control systems. A recent patent details the concept of embedding transponders into clothing so that laundry appliances can then interrogate the garment and set up the correct washing cycle, water temperature and spin cycles for the garments.
- xviii. Tyre pressure sensors using capacitive non-contact data transfer have been proposed.

A brief consideration of the potential for the application of non contact sensing and data transfer technologies indicated by these innovative proposals clearly indicates the innovation opportunities available to companies.

1.5 The Cost Benefit Equation

The incremental increase in product cost resulting from the inclusion of the RDID transponder is usually less than 2 Euro if volumes of 10,000 units per annum are achieved. Whilst detailed cost estimates for the additional part costs can be obtained, the major economic decision to be made is the product development cost and the analysis of the expected payback benefits that this can produce.

The economic payback is most easily calculated where the technology is to be applied in a product to be marketed through existing channels. Here, traditional market demand estimation methods can be used to project annual sales volumes, sales revenues and margins.

However, the economic benefits are often less clear when the benefits of applying RFID technology is considered by the end user. Here the benefits can be described in terms of such factors as:

- Improved security of items with the RFID tag fitted
- Improved capacity to track and locate items
- Reductions in transportation costs through improved distribution control
- Reduced sorting times, using automation techniques

- Increased reliability of item data.

A cost –benefit analysis for the customer

Consider as an example the case of a company considering the installation of a warehouse system which would reduce the need for manual work sheets to be produced.

A typical analysis is in the area of error reduction cost saving analysis through the introduction of RFID technology. Consider the cost of retesting a sample that has been misplaced or incorrectly processed in chemical laboratory. The cost of this error could include the following terms:

Management time to re-arrange second sample correction - cost 20 Euro

Collection costs for the sample:- cost 30 Euro

Additional administrative costs (maintenance of records etc.) – cost 10 Euro

Customer complaint management –cost 30 euro

Therefore an error may lead to a cost of 110 Euro. If one such error was to occur every day then the annual cost would be of the order of 23,000 Euro.

Similar exercises can be done to calculate the cost of errors in other areas of a company's activities. For example, errors in data entry mistakes or in issuing incompatible work tools to operators can be estimated. In many cases the true cost of correcting mistakes or the price of non-conformance is much higher than most end users realise. In the worst cases, it may involve a total recall of product from the market; a very expensive proposition.

The realisation of this potential saving to clients has resulted in one company integrating RFID technology in its laboratory processing machinery to prevent incorrect processing. The introduction of the technology also allowed additional improvements in record traceability and improved database systems. The use of RFID technology therefore reduced user costs whilst delivering improved performance – a notable success for the company!

1.6 Applying the Technology to Deliver Innovative and Profitable Products and Services

The identification of new business opportunities suitable for the application of RFID and non-contact sensing technologies requires an identification first of the commercial needs faced by the customer of the products. This might include an assessment of the following factors:

- i. Could the product or process be improved by the adoption of the technology. For example, can any of the following improvements be delivered:
 - Reduced product / process cost by the removal of unnecessary contact based connectors.
 - Improve technical performance through the sharing of data between moving units at appropriate stages in the process cycle.

- Improved process control through the application of control systems that react to data stored in the tagged item.
 - Lower cost, non-invasive sensing solutions.
- ii. Can the use of the technology deliver improved customer satisfaction by, for example, the delivery of:
- Stored information which can be applied to improve the process or to predict maintenance needs.
 - Reduced errors in the distribution process thereby reducing product return or recall costs.
- iii. Can the technology allow the company or its customer to become more effective in its operations by, for example:
- More effectively managing its processes by the provision of more accurate information.
 - Managing its stores levels better, through the use of improved information supplied via the use of RFID technology.

These, and similar, opportunity identification processes can lead the company towards new business opportunities and improved growth prospects.

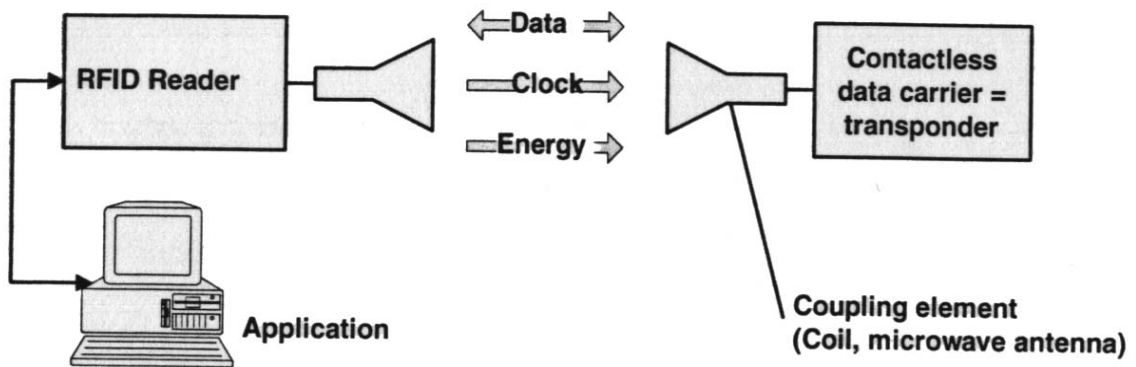
It is clear that RFID technology markets are maturing, rapidly growing and increasingly being accepted in general use. This background provides a major opportunity for companies aware of the technologies' capabilities to develop innovative products.

2 An Introduction to RFID Technology

A RFID systems comprises of the following components:

- A transponder (or tag), which is the object to be identified.
- A reader (or interrogator), which may be read only (RO), or Read Write (RW) depending upon the technology.
- An antenna for reception and transmission.

The function of each component may vary between systems, but basically perform in a similar manner. Since data is gathered for use in computer-based systems, usually the reader/interrogator interfaces to a PC or a network of server-clients, eventually connected to the Internet.



Basic RFIID system

2.1 Reader

The reader/interrogators can differ quite considerably in complexity, depending upon the type of tags being supported and the functions to be fulfilled. However, the overall function is to provide the means of communicating with the tags and facilitating data transfer. Functions performed by the reader may include quite sophisticated signal conditioning, parity error checking and correction. Once the signal from a transponder has been correctly received and decoded, algorithms may be applied to decide whether the signal is a repeat transmission, and may then instruct the transponder to cease transmitting. This is known as the “Command Response Protocol” and is used to circumvent the problem of reading multiple tags in a short space of time. Using interrogators in this way is sometimes referred to as “Hands Down Polling”. An alternative, more secure, but slower tag polling technique is called “Hands Up Polling” which involves the interrogator looking for tags with specific identities, and interrogating them in turn. This is contention management, and a variety of techniques have been developed to improve the process of batch reading. A further approach may use multiple readers, multiplexed into one interrogator, but with attendant increases in costs.

A reader typically contains a radio frequency module (transmitter and receiver), a control unit and a coupling element to the transponder (antenna). In addition many

readers are fitted with an additional interface (RS232 or RS 485) to enable it to forward the data received to another system (PC, embedded system, etc).

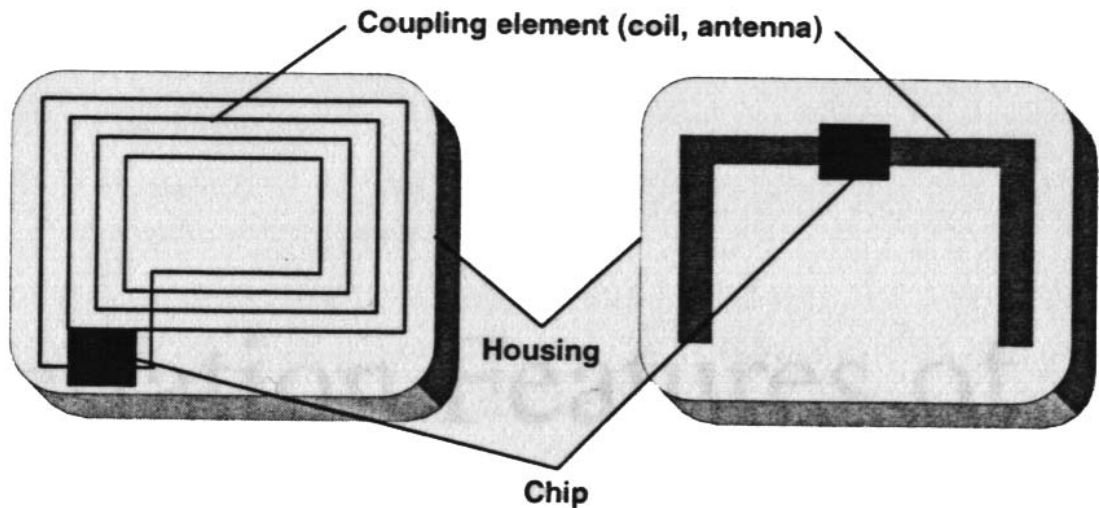
2.2 Antenna

The antenna emits radio signals to activate the tag and read and write data to it. Antennas are the conduits between the tag and the transceiver, which controls the system data acquisition and communication. Antennas are available in a variety of shapes and sizes; they can be built into a door frame to receive tag data from persons or things passing through the door, or mounted on an interstate toll booth to monitor traffic passing by on a freeway. The electromagnetic field produced by an antenna can be constantly present when multiple tags are expected continually. If constant interrogation is not required, the field can be activated by a sensor device.

Often the antenna is packaged with the transceiver and decoder to become a reader/interrogator, which can be configured either as a handheld or a fixed-mount device. The reader emits radio waves in ranges of anywhere from one inch to 100 feet or more, depending upon its power output and the radio frequency used. When an RFID tag passes through the electromagnetic zone, it detects the reader activation signal. The reader decodes the data encoded in the tag integrated circuit (silicon chip) and the data is passed to the host computer for processing.

2.3 Transponder

The transponder, term derived from TRANSmitter/resPONDER, represents the actual data carrying device of an RFID system, and normally consists of a *coupling element* and an electronic *microchip*. When the transponder, which does not usually possess its own voltage supply (battery), is not within the interrogation zone of a reader it is totally shut off. The transponder is only activated when it is within the interrogation zone of a reader. The power required to activate the transponder is supplied to the transponder through the coupling unit (contactless) as is the timing pulse and data.

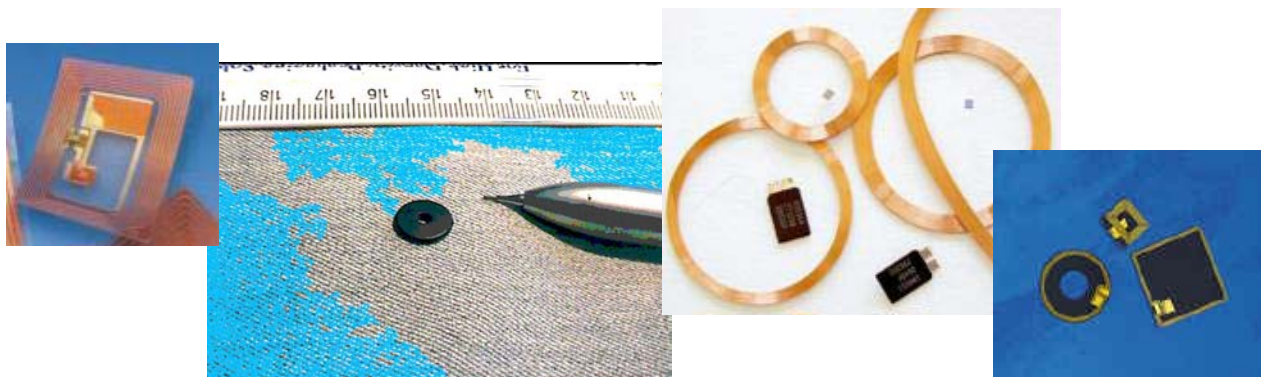


Basic layout of the RFID data carrying device, the transponder. Left: Inductively coupled transponder with antenna coil, right: Microwave transponder with bipolar antenna.

RFID transponders exist in countless variants, produced by an almost equally high number of manufacturers.

They can be grouped into three basic packaging types

- Tags – ampoules, coins, pills, “stick”, key fob
- Cards - credit card size (the already addressed contactless smart card)
- Smart Labels – printed label with an RFID tag embedded. They are thin, flexible, disposable.



Some samples of commercial transponders

If we are to maintain an overview of RFID systems we must seek out features that can be used to differentiate one RFID system from another. These features can mainly identified in the following:

2.4 Data capacities of RFID transponders –

The data capacities of RFID transponders normally range from a few bytes to several kBytes. So-called 1-bit transponders represent the exception to this rule: a data quantity of exactly one bit is just enough to signal two states to the reader: “transponder in the field” or “no transponder in the field”. However this is perfectly adequate to fulfil simple monitoring or signalling functions. Because a 1-bit transponders does not need an electronic chip, these transponders can be manufactured for a fraction of a cent of Euro. For this reason vast number of 1-bit transponders are used in *Electronic Article Surveillance* (EAS) to protect goods in shops and businesses. If someone attempts to leave the shop with goods that have not been paid for the reader installed in the exit recognises the state “transponder in the field” and initiates the appropriate reaction. The 1-bit transponder is removed or deactivated at the till when the goods are paid for. Transponders with data capacity up to 128 bits are used for storing identification or serial number, together with one bit for parity check. These devices can be programmed both by the manufacturers and by the users. Tags with data capacity up to 512 bits are always user-programmable and suitable to store identification data as well as other specific information as serial number, process instructions, and results of most recent transactions. Tags with data capacity of about 64kBits can be regarded as carrier for portable data files. Higher data capacity also allows to organise data in records or pages that can be selectively accessed during the reading process. Depending on the tag memory characteristics it is also possible to identify *read-only* tags, *WORM* (write once read many) tags, and *read/write* tags.

2.5 Possibility of writing data –

In very simple systems the transponder data record, usually a simple (serial) number, is incorporated when the chip is manufactured and cannot be altered thereafter.

In writeable transponders, on the other hand, the reader can write data to the transponder. Three main procedures are used to store the data: in inductively coupled RFID systems EEPROMs (electrically erasable programmable read only memory, non volatile memory) are dominant, however these have the disadvantage of a high power consumption during the writing operation and a limited number of write cycles (typically of the order of 100,000 to 1,000,000). FRAMs (ferromagnetic random access memory) have recently been used in isolated cases. The read power consumption of FRAMs is lower than that of EEPROMs by a factor of 100 and the writing time is 1000 times lower. Manufacturing problems have hindered its widespread introduction onto the market as yet.

2.6 Power supply to the transponder

RFID tags are categorised as either active or passive. Active RFID tags are powered by an internal battery and are typically read/write, i.e., tag data can be rewritten and/or modified. An active tag memory size varies according to application requirements; some systems operate with up to 1MB of memory. In a typical read/write RFID work-in-process system, a tag might give a machine a set of instructions, and the machine would then report its performance to the tag. This encoded data would then become part of the tagged part history. The battery-supplied power of an active tag generally gives it a longer read range.

The trade off is greater size, greater cost, and a limited operational life (which may yield a maximum of 10 years, depending upon operating temperatures and battery type).

Passive RFID tags operate without a separate external power source and obtain operating power generated from the reader. Passive tags are consequently much lighter than active tags, less expensive, and offer a virtually unlimited operational lifetime. The trade off is that they have shorter read ranges than active tags and require a higher-powered reader. Read-only tags are typically passive and are programmed with a unique set of data (usually 32 to 128 bits) that cannot be modified. Read-only tags most often operate as a license plate into a database, in the same way as linear barcodes reference a database containing modifiable product-specific information.

2.7 Frequency of operation

Choice of field or carrier wave frequency is of primary importance in determining data transfer rates. In practical terms the rate of data transfer is influenced primarily by the frequency of the carrier wave or varying field used to carry the data between the tag and its reader. Generally speaking the higher the frequency the higher the data transfer or throughput rates that can be achieved. This is intimately linked to bandwidth or range available within the frequency spectrum for the communication process. The channel bandwidth needs to be at least twice the bit rate required for the application in mind. Where narrow band allocations are involved the limitation on data rate can be an important consideration. It is clearly less of an issue where wide bandwidths are involved. Using the 2.4 - 2.5 GHz spread spectrum band, for example, 1 megabits per second data rates may be achieved, with added noise immunity provided by the spread spectrum modulation approach. Spread spectrum apart, increasing the bandwidth allows an increase noise level and a reduction in signal-to-noise ratio. Since it is generally necessary to ensure a signal is above the noise floor for a given application, bandwidth is an important consideration in this respect. The previous considerations, along with the fact that transponder working in high frequency, so communicating by means of transmitted waves rather than by inductive link, are often active devices, make every frequency range suitable for particular applications.

There are basically four main frequencies of operation for a RFID system:

- Low Frequency (<135KHz)
- High Frequency (13.56MHz)
- Ultra High Frequency (433 MHz, 860MHz, 928MHz)
- Microwave (2.45 and 5.8 GHz)

And these systems have the following features:

2.8 Data Capacity.

This is the measure of data that the tag can carry, and is given in bits. E.g. a 1kbit tag is able to carry 128 characters.

2.9 Read-write or read only (RW/RO)

Read only tags have to be programmed at the factory and carry the identification number. Read/write tags can have their contents updated in the field, however there may be a limit to the number of RW operations possible for a particular tag memory technology.

2.10 Transfer rate.

The rate at which the tag data is transferred to the reader unit, this is usually expressed in bits per second.

2.11 Read (and write) time.

This is linked to the transfer rate, but with the time overhead of any communications management protocols. In a multiple tag environment, the read time must be multiplied by the number of tags to be read. There is an issue when the tags are not able to communicate with the reader, or that the read zones are restricted, then the read time becomes crucial and the faster the better. Another factor that has to be included is the amount of data to be transferred, and if all the tags data has to be transmitted at any one time. With RW tags, the write time can be significant for the successful transfer of data.

2.12 Range.

This is defined as the distance that the tag can be reliably read/written to by the reader/programmer. The main factors affecting range is the transmission power and frequency, and these are both regulated by national and international regulations.

2.13 Read accuracy and repeatability.

Below are the main factors that affect accuracy and the success of reading a tag.

- Orientation – is the tag more sensitive to a particular orientation when in the field of the reader.
- Anti-collision and multi-tag environments – can many tags be read when they are all in the field of the reader, using an anti-collision algorithm to ensure that only one tag responds to the reader field at one time.
- Obstacles – the field may block the field, especially if the obstacle is ferrite based. The field will not be linear and ‘blind spots’ can reduce the effectiveness of the reader.
- Sources of interference – other electrical equipment maybe produce interference that will affect the reader field and reduce the read range and accuracy/repeatability.

2.14 Tag shape and robustness.

Tags can be formed in many different shapes and their robustness is dependant upon their ‘carrier’ or encapsulation.

2.15 Cost

Part cost for the tag, reader or read/writer.

	RFID technology (by carrier frequency)			
	Low frequency	High frequency	Ultra high frequency	Microwave
Data Capacity (tag type)	Typically. 64 bits to 2kbits. (Passive or active)	Typically 512bits to 8kbits. (Passive or active)	Typically 32bits to 4kbits. (Passive or active)	Typically 128bits to 32kbits. (Passive or active)
RW /RO	Both available	Both available	Both available	Both available
Transfer rate	Typically 200bits/s to 1kbit/s	Typically 25kbits/s to 100kbit/s	Typically 28kbits/s	Typically 100kbits/s to 1Mbit/s
Read (and write) time	Typically 0.5s ²	Typically 2ms ³	Typically 2ms ⁴	Typically 0.05s ⁵
Range	Near contact, or up to 0.5m, for an active tag	1.2m for RW , 1.5m for RO passive tags	1.2m for RW , 1.5m for RO passive tags	1 to 2m for passive tags, active tags > 10m
Accuracy and repeatability	Single tag and multi tag anti-collision systems	Single tag and multi tag anti-collision systems. Better noise immunity than low frequency systems	Single tag and multi tag anti-collision systems.	Single tag and multi tag anti-collision systems.
Tag shape and robustness	Wide variety available, but susceptible to low frequency interference	Wide variety available, including smart cards and smart labels. Rigid and flexible substrates available	Wide variety available	Wide variety available, including smart cards and smart labels. Rigid and flexible substrates available

² 96bits transferred at 200bits/s

³ 512bits transferred at 26kbits/s

⁴ 512bits transferred at 28kbits/s

⁵ 32kbits transferred at 100kbits/s

	RFiD technology (by carrier frequency)			
	Low frequency	High frequency	Ultra high frequency	Microwave
Costs	Dependant upon tag shape and application, typically used in systems where tag: reader is < 30:1	Dependant upon tag shape and application, e.g. Smart labels cost = 30 cents.	Dependant upon tag shape and application, e.g. Tag cost = 40 cents	Dependant upon tag shape and active or passive operation
Application areas	Access control, animal identification, vehicle and container identification and manufacturing support	Airline baggage management, library systems, parcel tracking and supply chain logistics	Asset tracking and supply chain logistics	Factory automation, access control, road tolling and supply chain logistics

3 Contactless sensing technologies

The commonly used contactless sensors are of four types: inductive, capacitive, ultrasonic and photoelectric.

3.1 Inductive sensors

They create a radio frequency field using an oscillator and a coil. The presence of a metal object changes the frequency of the oscillator and the sensor is able to detect this.

The applications of this kind of sensors are:

- Conveyor on/off switches
- Begin machine cycle
- Quality control (sense lids, proper alignment)
- Count, determine direction of motion and rotation positioning and anytime you want to sense metal

The advantages are that they can detect metal target even through non-metallic barriers, eliminate need for contact, operate in harsh condition, rapid response time and long life. For these reasons they are widely adopted in industrial control process applications.

The limitations are: they can only detect conductive metal, short range (less than 1” sensing distance) and may be affected by metal chips collecting on sensor face

3.2 Ultrasonic sensors

They send out sound waves above audible frequencies and listen for the return. Uses the time delay and the speed of sound in air to determine presence and distance to object. There are different types of ultrasonic sensors:

1. *Ultrasonic proximity sensor with analogue output stage:* Both current and voltage outputs from the sensor are proportional to the distance of the sensor from the target. This allows simple non-contact measurement.
2. *Ultrasonic retroreflective sensor:* A fixed machine is used here as a reflector. The time between the emission and the reception of an ultrasonic signal (propagation time) is fixed and known. When an object comes within this sensing distance the output is activated.
3. *Ultrasonic through beam sensor:* These sensors are ideal for applications in which objects follow each other in succession. They are also recommended when high switching frequencies are required up to 200 Hz

The advantages of this kind of sensors are that they can detect more types of objects than other type of sensors, they are very good for telling distance, have a longer operative range than inductive and capacitive sensors.

Their limitations are that they have a “dead zone” close to the face of the sensors so they cannot detect very close objects, they can't detect very small objects (depending on

the wavelength) and smooth surfaced objects must be aligned correctly or echo won't return to sensor. Also the very high cost is a major limitation for this sensor.

3.3 Photoelectric sensors

A photoelectric sensor is one in which the light source and light sensor are housed in the same unit. The sensor picks-up the pulse of the emitting Led which is usually in either the infrared or visible light range, as it reflects off the object being sensed

The various kinds are:

1. *Thru-Beam*: Source unit in one location sends a light beam to a detector unit in other location . An object is detected when it passes between the source unit and the detector unit interrupting light beam
2. *Reflex*: The source and detector are housed in one package and placed on the same side of the target object's path. When the object passes by, the source signal is reflected back to the detector by a retro-reflection
3. *Diffuse Reflective*: It Is analogue to the Reflex but the source signal is reflected back to the detector off the target objects itself.
4. *Background Rejection*: This is a special type of diffuse reflective sensor that includes two detectors. This arrangement allows the sensor to detect target reliably within a defined range., and to ignore objects just outside of this range. Unlike a standard diffuse reflective sensor, color or reflectivity has minimal effect on the sensing range.

The advantages are a very great sensing range, and very accurate response but its limitation is being too expensive and doesn't function in contaminated environment.

3.4 Capacitive sensors

The whole next section focuses on these kind of sensors, whose application has been specifically challenged by the user experiments carried out under the SIDCOM Action.

This technology works using two plates to form a linear capacitor. The amount of energy that can be stored between the plates depends on the material between them. When a material other than air is present the sensor can detect this variation.

The first reference to capacitive sensors is found in Nature, 1907, but the penetration today is only a few percent of all sensor types. This is surprising, with the technology low cost and stability and its simple conditioning circuits often, the offset and gain adjustments needed for most sensor types are not required, as the raw output span of the signal on the capacitive sense electrodes can be nearly to the supply rails.

An often-heard objection to capacitive sensor technology is that it is sensitive to humidity and needs unstable, high impedance circuits. In fact, as the dielectric constant of humid air is only a few ppm higher than dry air, humidity itself isn't a problem. Very high impedance circuits are needed, but with proper circuit design and proper printed circuit board layout, capacitive sensors are as rugged as any other sensor type.

In addition today, some techniques are available based on capacitive sensing, that permits a digital control of the sensing, enabling to manipulate system gain, response time, filtering, and amazing variety of options to increment stability and immunity of the sensors.

Capacitive sensors can sense a variety of things motion, chemical composition, electric field and, many other variables which can be converted into motion or dielectric constant, such as pressure, acceleration, fluid level, and fluid composition.

Capacitive sensors are contactless, the sensing element can be placed anywhere, close the sensing zone, and any object can become as sense element itself, because the interesting measure depend only on the capacitive coupling between the electrodes. All the substances have dielectric properties so we can sense through any material.

3.5 Capacitive sensing system

Capacitive sensing system requires, in addition to sense plates, a means of interpreting the information acquired form the sense and an information management system. A system will also include the driving capabilities of the sense plates itself.

A basic capacitive system consist of two components:

- the *sensing electrodes*, which is located close the measuring zone.
- the EU or *elaboration unit*, which, depending upon design and the technology used, may be a simple microcontroller or a specific devices.

The function of each component may vary between systems, but basically perform in a similar manner.

Sensing electrodes are a critical part of any capacitive sensing solution. Most conducting objects can become an intrinsic electrode and even a non conductive objects can act as electrodes simply adhering a wire or a metal foil to the object. However to obtain good results is suggested usually follows these steps:

- Design electrode plates to measure the desired variable. Maximize capacitance with large-area, close-spaced plates
- Surround this sensor with appropriate guard or shield electrodes to handle stray capacitance and crosstalk from other circuits
- Calculate sensor capacitance, stray capacitance and output signal swing
- Choose an excitation frequency high enough for low noise. As excitation frequency increases, external and circuit-generated noise decreases
- Design circuit to meet accuracy specifications and provide immunity to environmental challenges

The *interpretation unit* can differ quite considerably in complexity, depending upon the functions to be fulfilled. However, the overall function is to provide the acquisition of the data from the sensing element its elaboration and optionally conversion in the output desirable format (i.e. digital serial communication, 4-20 mA line, voltage output).

3.6 Key attributes and limitations

Main beneficial key attributes of non-contact capacitive sensors are in their features of being:

- Versatile: it can detect just about anything because all materials have a distinct dielectric constant. In addition can detect differences of objects not only presence
- Robust: it can operate in harsh condition, and has a long operation life

SIDCOM Booklet

- Low cost: Its cost is lower than photoelectric and ultrasonic sensor

As limitations are that it can be affected by varying of temperature and humidity conditions.

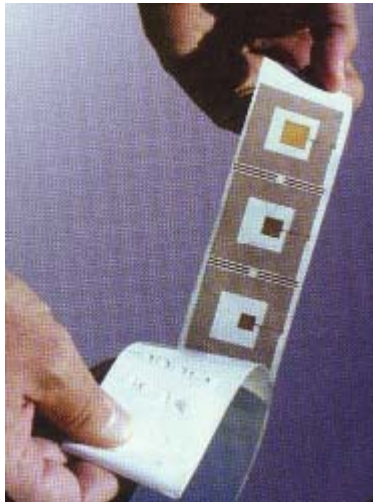
4 CHIPLESS Technology

An important emerging area of RFID technology is that of chipless data carriers. These are usually passive devices generally formed from low cost inductive components, magnetic materials and electromagnetic reflective or absorptive materials. These devices are generally low capacity data devices, although marginally higher capacity, two-dimensional data structures are proposed in the future.

Chipless technology devices generally have the characteristics:

- Thin form factor. The devices are realised using thin foil or film materials
- Low data capacity
- Ranges of less than 1 metre
- Wider temperature ranges (-40 to + 200 °C) than chip-based RFID devices
- Lower cost relative than chip-based devices. Prices are eventually projected to be less than 20 cents in volume.

These advantages have to be offset against the limited data capacity and higher reader costs relative projected for chip-based readers.



Chipless tags samples used for airline baggage tracking

Pictures courtesy of C.W.

4.1 Chipless Technologies

4.1.1 Wiegand/Buakhausen Magnetic Technologies.

The Wiegand card technology is comprised of data carrier elements formed from small, specially processed ferromagnetic wire. Sharp reversal of the wire's magnetic field causes a short duration voltage pulse to be generated; the Buakhausen effect. Bit representation is achieved by the manner in which the data determining wire elements are arranged relative to a defined read line. These devices are low capacity (tens of bits), short range (up to 2.5 cm) storage devices. (reference <http://www.hidcorp.com/>)

4.2 LC Array, Card-Based Technologies.

LC array technology exploits the resonance of inductor-capacitor circuits as a basis for data encoding. Devices using this approach, otherwise known as Multiple Tuned Circuit Identification (MTCID) tags, are characterised by arrays providing a range of resonant frequencies. The presence or absence of frequencies in a scan across the frequency range defines the code held by the tag. The greater the number of resonant points defined the greater the number of code combinations (or data capacity) can be accommodated. These devices are low capacity (typically 12 digits), short range (up to 1 metre) devices (reference: <http://www.cwosrfid.com/>)

4.3 Magnetically-Based Chipless Data Carriers

These are non-contact magnetic encoded devices. The three principal technologies are Programmable Magnetic Resonance (PMR), Flying-Null (FN) and Holotag low frequency magnetic (LFM) tag technologies.

4.3.1 Programmable Magnetic Resonance Devices

PMR devices exploit resonance features of magnetically soft magnetostrictive materials in association with data carrying hard magnetic material, to provide tags that can be interrogated using an appropriate low frequency alternating magnetic field. The data is written to the tag using a contact method similar to that used conventionally for magnetic stripe. In response to the reader interrogation field resonances from the PMR tag are detectable that relate to data stored in the hard magnetic material. The particular harmonics can be enabled or disabled to distinguish a bit-string along a magnetically hard coding strip forming an integral part of the tag. 20-bit and 64-bit tags (capable of supporting data encoding schemes with error protection) are available costing in the region of 25 cents and 50 cents respectively.

4.3.2 Flying-Null Data Carriers

Flying-Null technology exploits the properties of very high permeability magnetic materials. The data is defined by a series of simple, passive magnetic structures, analogous in many respects with the bars for conventional linear bar codes. The data is actually stored by reducing or removing the magnetic permeability of selected regions of the high permeability material. FN tags are capable of tolerating a reasonable amount of non-ferrous metal within the interrogation zone.

Read/write tags are simple to implement for FN technology. The writing process requires contact with the write head. However, the tag is read by means of a high-resolution magnetic inductive reader providing read ranges of typically 50 cm and up to 1 m with loop antennas and of the order of few cm for side-scan devices. The interrogation process involves the use of an alternating magnetic field (typically 2 KHz) of intensity sufficient to saturate the high permeability material except in a null or zero region defined by two opposing fields. A scan field is applied to oscillate the null at a frequency that is typically $1/110^{\text{th}}$ that of the interrogator field. Within the null of the scanning field the data elements can be effectively revealed, the process being somewhat analogous to a scan of a linear bar code. (reference: <http://www.flying-null.com/>)

4.3.3 Holotag Low Frequency Magnetic Data Carriers

Holotag low frequency magnetic device technology is based upon thin film smart magnetic materials. Tags are made of many layers of metal alloy, each rotationally oriented at a small angle (about 3-4 degrees) and capable of being magnetised in a highly directional manner. The presence or absence of the directional magnetisation in the individual layer determines the data stored. Reading is achieved by a rotating magnetic interrogation field and detection of the magnetic interactions.

The data capacity for presently available tags is limited to less than 50 bits; although higher capacity devices are in prospect. Prices for Holotag devices are in the region of 10 cents for 10,000 off quantities and 8 cents for 1,000,000 off quantities (referenc holotag.co.uk).

4.3.4 Microwave Chipless Technologies

Although still under development, amorphous alloys in the form of small diameter (100-125 microns) glass coated wires are being used to structure tags that can be interrogated by microwave (2.45 GHz) sources to reveal a signature code or data sequence.

5 Design Considerations

The problem facing a prospective user of RFID technology is which of these technical solutions to select, and further which of the numerous supplier solutions to select amongst. The following discussion will assist in this selection process, but cannot provide an all encompassing selection solution.

5.1 Selection Methodology – Economic Evaluation

Fundamentally all technology selection processes will eventually revolve around the economic viability to the technology selected. The impact of the tag solution must be evaluated in relation to the cost savings or increased sales potential achieved by the adoption of the technology on a per unit basis. This involves estimation of project costs and unit price costs for the development / implementation project, and arriving at a cost per RFID tag.

This cost estimate should incorporate an allowance for the reusability of the RFID tag itself. For example, if a read – write system can be used many times then the effective cost per application will be significantly reduced.

Sharp (reference “Look before you make the [RFID] leap”, www.idsystems.com) argues that the acceptable cost estimate on a per tag basis need not be precise. As indicated in Table 1 indicates Sharp suggests approximate cost bands can be applied to result in the evaluation of the feasibility of the technology choice.

APPLICATION VALUE PER TAG	ECONOMIC IF THE FOLLOWING CONDITIONS ARE TRUE:
More than 10 Euro	Application probably makes sense unless the tag must survive extremely demanding environmental conditions or provide very large data capacity
5 to 10 Euro	Annual tag volume greater than 1000
2 to 5 Euro	Moderate environmental challenges. Annual tag volume greater than 10,000
0.75 to 2 Euro	Moderate environmental challenges. Annual tag volume greater than 100,000
0.50 to 0.75 Euro	Moderate environmental challenges. Annual tag volume greater than 1,000,000
Less than 0.50 Euro	Application probably not economically feasible at this time

Table 1: Cost Estimate / Value Trade-off For RFID Applications

The information contained in the Table 1 can be applied to be determine roughly whether the application is economically viable. However, this approximate evaluation should be followed up with an analysis conducted with potential suppliers.

5.2 Selection Methodology – System Requirement Specification

The technology selection process will require the definition of the system requirements that the RFID tag system have to meet. This system specification process will define the general requirements of the system and not the specific

implementation technology, and therefore the system requirement document will consider the following:

5.2.1 RFID Data Memory Requirements

The memory requirement will include an assessment of:

- The amount of storage required for a particular application.
- The need to process information (or not) in the RFID device.
- The range of unique identification numbers required, and whether the device is to be uniquely identified (for example, with a dedicated company code).

The information requirements of an RFID tag will require careful consideration, and specification in the system specification before RFID device selection.

The application will define the required amount of memory. For example, the anticipated production volume for a product, with the addition of an adequate estimation margin, will define the maximum number of unique identity codes required for the RFID device.

Finally memory size should not be over specified if not absolutely required. This is because the rate of transfer of the information from a tag to a reader device will be defined for a specific tag frequency, and the larger the RFID memory then the longer the read time for any interrogation transaction. This could limit the rate, at which units pass a reader and may therefore, prejudice the application of RFID technology.

5.2.1.1 Memory Types

The RFID transponder device may have one of the following form of memory:

1. ROM (Read Only Memory). These devices have a unique identification code programmed into the device at the time of manufacture, and this identification number cannot be altered thereafter. The relationship between an unit or item fitted with this tag requires therefore, a conversion from unique identification code to unit / item serial number using a lookup table. Because the code cannot be changed, the ROM memory option provides a highly secure, if inflexible, tagging solution.
2. WORM (Write Once Read Many) devices are programmed by the user, enabling the user to introduce their own identity numbers on a once off basis. No further changes can then be made to the tag information. This provides some flexibility, and a reasonable level of security.
3. RW (Read /Write) devices contain memory that can be altered several times in use, and therefore offer low security but a high degree of flexibility.

Some RFID device technologies may offer a combination of the above memory options. For example, a device may be pre-programmed at manufacture with a unique identity code but offer a limited RW (read write) memory facility as well.

The specification will define which of these memory types is required. For example, a system required to track an item may only require unique identification of the item, and therefore a ROM device programmed by the supplier would suffice. However, a reusable system used to identify and record process stages in a production environment might require a RW memory RFID device solution.

Finally, whilst a read only RFID tag may be sufficient for identifying an item there may be the requirement for several transactions to an information database to identify

process information. If the transaction costs to an information database are high enough then it could justify the use of a more expensive RFID tag capable of storing the process or status information without incurring these transaction costs. A careful analysis of the use of the data is therefore required.

5.2.2 Interrogation Space Definition.

The specification must define the maximum space envelope that the tag will be present in when energisation and data transfer must occur reliably. The specification should therefore specify the set of maximum interrogation distance from the reader unit and the position relative to the reader unit, as a 'capture / reading volume'. If the tag can always be guaranteed to be in one plane relative to the reader unit this will obviously reduce to a maximum reading distance. In defining this parameter, a key factor is whether the reader can be moved relative to the tag. This will minimise the reading distance required, but will obviously increase reading transaction times.

The 'capture /reading volume' is the most basic requirement for the selection of an RFID technology.

The actual reading distance that will be realised by the selected RFID technology will depend on several factors including the RFID device type, transponder size, and antenna design, relative orientation, and electrical noise levels.

5.2.3 RFID Device Size

The maximum size of the RFID device that can be used is an important design consideration. For a given RFID device, the larger the associated tag antenna (and hence the tag itself) then the greater its reading distance. In general, therefore the specification should state the maximum RFID tag size consistent with the product application.

5.2.3.1 RFID Shape

An associated factor would be the allowable shape of the encapsulated RFID tag unit. The directionality of the coupling between the RFID tag and the reader unit will depend in part upon the shape of the tag antenna, and a product shape definition might allow the tag antenna to be designed so as to minimise the directionality response.

5.2.4 Reader Antenna Specification

A related size requirement is the maximum size of the reader unit's antenna. Again, in general, for a specific tag type the larger the size of the antenna then the better the reading range. The directivity of the electro-magnetic field emanating from the RFID device will also influence the size and shape of the readout antenna required.

5.2.4.1 Potential for Orientating the Transponder

The freedom to orientate the transponder with respect to the antenna also impacts on the reading range performance of the system. To achieve maximum reading range the orientation of the antenna with respect to the transponder can be optimised to achieve maximum coupling, and the freedom to achieve this will improve performance.

The field generated by a reader unit at the RFID tag location has a direction. As the orientation of the tag in this field changes the power transferred to the tag can vary from a maximum when the tag antenna is perpendicular to the reader antenna, to zero when the edge of the tag is perpendicular to the reader antenna.

If the tag orientation cannot be controlled this will require a more sophisticated reader unit / antenna design to compensate for this physical reality. For example, this may introduce the need for gate reader antennas with rotating fields. The reader unit design will be simplified if tag orientation can be controlled.

5.2.5 Tag Speed

The speed at which the RFID tag will move through the tags can move through the interrogation space volume will determine the amount of time available for a complete interrogation transaction for the device. This transit time must exceed the minimum time for a data transaction to occur.

The available reading time will be severely reduced if more than one RFID transponder device enters the reading volume or if the system is used in extremely electrically noisy environments where an allowance may be required for further interrogation to be made. This would however depend upon the reliability of the data transfer mechanism discussed later in this document.

As noted previously, the speed at which the RFID tag moves through the read volume is one factor that determines the selection of the data contents and signal transmission protocols used.

At low frequencies (120 –130 KHz) a standard reader unit will complete one read transaction in approximately 120ms, enabling RFID tags to be read at a speed of 3m/s with 'standard' antenna designs. Much higher speeds can be accommodated by using larger antennas. For example, read speeds of 65m/s or about 240km/hour have been recorded. 2.4 GHz systems can accept and transfer large packets of data quickly: 1,000 to 2,000 kilobaud, versus 100 to 400 kilobaud in 902 MHz systems.

5.2.5.1 The Reliability of Data Transaction

So as to obtain an error-free data exchange between the RFID tag and the reader unit additional, redundant data can be added to the RFID memory contents to enable error correction to be conducted. For example, the Texas TIRIS system uses a 16-bit Cyclic Redundancy Check algorithm which ensures that only 'valid' data is transferred to the reader. The use of well known error correcting algorithms therefore, results in a high reliability data transfer system.

However, whilst increasing the data length to add a number of error checking / correcting bits increases the reliability of the system it will result in a more complex and costly RFID tag design solution and an increase in the data transaction time.

5.2.6 Multiple Device Scanning

If a reader unit to tag reading range is a few centimetres it is improbable that in most operating conditions that several RFID devices will reside in the read volume. However, with longer range RFID devices, often having operating read ranges measured in metres, it is probable that there will be more than the one transponder in the reading volume at any one time. This multiple RFID transponder situation will cause significant system complications through the occurrence of data contention.

Data contention occurs where there is only one communications channel to transfer information over, and several units attempting to transfer data at any one time. This will result in signal level corruption causing a major problem in attempting to extract meaning from the confused messages. For RFID devices, there is a single frequency available to transfer data from the transponders to the reader.

The system must have an anti-contention communications protocol to be able to operate in a multiple RFID tag environment, otherwise it can only communicate with one transponder at a time.

5.2.6.1 Protocols for multiple transponder situations.

For application systems in which multiple occurrences of tags within the reading volume can occur and all of these must be recognised and read, an "anti-collision" protocol system must be used.

The most common anti-collision methods use algorithms designed to ensure that the multiple tags active in the reader's energisation field transmit their information such that only one tag at a time is active at any one time, and hence is interacting with the reader.

In a multiple transponder situation, the minimum transaction time for the group of tags in the reading volume will exceed the transaction time of a single tag multiplied by the number of tags in the reading volume.

For example, multiple transponder situations can occur where the 13.56MHz frequency range magnetic transponders are applied. The manufacturers of RFID devices operating in this frequency range have realised the necessity of implementing anti-collision protocols, and many have proprietary anti-collision protocols incorporated into their products. The majority of these systems operate by providing a continuous energising field during the scanning period to power the tag devices and to separate the replies from the separate tags using response times to separate replies. Generally, this is achieved by ensuring the transponder transmits its data at random times over the relatively long read time thereby increasing the probability that each RFID tag transmission will be received without error. This is normally acceptable where the number of transponders in the reading volume is relatively few in number.

An alternative design solution which however incurs additional cost for the onboard receivers is to implement a communications protocol whereby each transponder can be individually addressed using unique identities, and the transponders individually polled.

With an appropriate choice of operational frequency and data contention algorithm it is possible to read 1000 transponders in a reading volume zone accurately and quickly.

5.2.7 Future Proofing of the System Designs

In specifying the reader unit requirements it is worthwhile considering that the rapid growth of RFID applications will invariably lead to further tag designs and applications arising in the future. Therefore, it would be an advantage if the reader unit is compliant with existing reader standards such that it provides the maximum possibility for commonality with these emerging devices and solutions.

5.2.8 Environmental conditions

The environmental conditions under which the tag must (i) operate and (ii) survive will be a critical factor in the selection of the appropriate RFID technology.

In general, the need for the RFID tag to operate in demanding environments will result in higher per unit costs for the devices, due to the significant increase incurred by adding suitable protective packaging.

The main environmental conditions to be specified for the RFID tag include:

- Temperature.
- Humidity
- Vibration & shock.
- Dirt, dust and chemical conditions.

Operational and survivable levels for each of these parameters must be specified.

5.2.8.1 Metallic and Other Surfaces & Obstructions

A significant aspect to consider in specifying the operational environment will be the presence of metallic surfaces in the vicinity of the tag unit. The presence of such surfaces could cause shielding or reflections to occur that could influence operational factors such as reading range, and therefore must be defined. Therefore, ensuring that the signal is reliably transferred from a reader to the RFID tag is a challenge.

The presence of metals can also affect RFID tag performance in more ways than just reflecting signals. An antenna in a near-field tag acts an inductor in a circuit tuned to the reader unit's transmission frequency, and a conducting metal close to the tag can change this inductance, introducing a frequency shift in the system resulting in a reduction in overall system performance. In some instances RFID tags optimised for maximum read range with a highly tuned circuit will experience a significant frequency shift preventing these tags from gathering enough power to be energised.

The signal coming from the reader can also be absorbed. For example water, and therefore ice and bodies, absorb high-frequency far fields better than lower-frequency near fields. RFID systems operating at 2.4 GHz are susceptible to absorption by water, and therefore this communications link could be affected by animal tissue making it unsuitable for animal tagging. However, RFID tags operating at 135 KHz and 13.56 MHz would not be affected.

5.2.8.2 Noise Sources

The presence of electromagnetic interference noise sources in the vicinity of the reader unit will result in the potential for errors to occur in reading process. The EMC Directive and related specifications define field levels and modulation indices under which systems should operate correctly. In many instances the close proximity of the reader unit to machinery etc. may result in higher levels of interference noise occurring. The device specification should therefore attempt to quantify the interference noise sources present in the local reader's environment, using appropriate EMC standards as the minimum requirement.

5.2.9 Regulations and Standards

International standards are a major issue when looking at applications.

This document cannot provide a comprehensive review of all applicable International standards for RFID systems, because of the dynamic rate of the market growth for the technology and the increasing rate of product introduction in the field.

5.2.9.1 Standards

The standards defined worldwide for the application of RFID products are being developed by ISO (International Standards Organisation). Other regional standards (for example, ANSI standards in the USA) further complicate the position regarding relevant standards.

These standards are generally defined for low frequency applications (135 KHz and 13.65 MHz applications). However, other potential frequencies of operation are possible; for example a solution for UHF operation is the 868 MHz band in Europe and the 915 MHz band in America, or the 2.45 GHz band (worldwide). Each of these bands has relevant specification limitations which address the allowed bandwidths and the power limitations at this frequency. In Europe the power limit is the most important limitation. For example, using the 868 MHz band only 0.5 W is allowed. Therefore if higher frequencies are being used it is advisable to check the local radio standards for that country as world-wide commonality cannot be assumed.

Note: It is important to realise that there exists a possibility that some of the elements of an International Standard may be the subject of patent rights. Therefore, it is important that if independent design of an RFID tag is undertaken that a full evaluation of all patents in the field is undertaken. Finally, standardisation is an evolving process; readers are recommended to review current status before proceeding with an implementation.

5.2.9.2 Communications Standards for Readers

The ANSI 256 standard specifies an application-programming interface (API) for RFID readers. The adoption of this API specification will provide companies with the possibility of producing a single software program interface for identification devices which is compatible with any selected RFID technical solution for a specific application.

5.2.10 Conclusion

Knowing what your business wants and how the tags must perform in the application situation and environment places the customer in a strong position when discussing a specific technology with vendors. For example, when the vendor proposes a frequency of operation this can be related to the definition of read range for the required system.

The first process of technology selection is therefore to carefully define your requirements as outlined above.

6 Technology Selection

The final system design stage will require that a selection of operational frequency, memory configurations, and air interface protocols will be required for the RFID tag. The decision criteria for the selection of an appropriate RFID device technology will be influenced by factors such as: the fact that higher frequency tags can support higher read/write rates or that lower frequency tags are more available and are generally less costly.

6.1 Frequency of operation

Operating frequency determines a number of system design characteristics such as data transfer rates, required energy and operating distances. The choice of frequency is therefore one of the most fundamental decisions facing designers, users, and systems integrators implementing RFID projects

6.1.1 Typical Frequencies

The typical RFID frequencies of operation are:

1. 135 kHz.
2. 13.56 MHz.
3. 850 - 950 MHz band
4. 2.45 GHz.
5. 5.8 GHz.

The lower frequencies (in the order of 125kHz –135KHz) are generally classified as induction systems with few radio or emission regulation requirements. However at 13.56MHz normal radio and spectrum allocation regulations also apply. Below 100 Mhz the mode of propagation is magnetic coupling and range becomes an issue as it is difficult to project the energising field several metres from the reader unit.

In contrast at higher frequencies the RFID tag systems use E-field communication. This is based on the emission of radio energy by the reader, which in turn is collected and reflected by the transponder. These systems generally operate between 433 MHz and 2.45 GHz, with the largest number of applications appearing in the 850 –950 MHz band.

It is postulated that in future the frequency of operation of the transponders where operating range and manufacturing costs are the issue will lie in UHF frequency band, somewhere between 800 to 950MHz.

The selection of the operational frequency significantly influences signal type and antenna design.

Far-field signals typically require antenna loops of at least one-eighth the wavelength of the signal, which is practical only at frequencies above about 500 MHz.

In contrast the energy captured by a near-field coil is proportional to the product of the inductance of the antenna coil and the frequency employed. This means at lower frequencies the antenna may require many turns to achieve a high enough inductance to work effectively. Medium-frequency systems can be implemented as printed antenna designs using only a few turns.

The operating distance is determined by the amount of energy that is required to activate the RFID transponder, and the amount of energy that can be transmitted under various radio spectrum and emission regulations. However typical operating distances may however be in the order of 1500 –6000 mm for a 13.5 MHz system and in the order of 20 – 300 mm for lower frequency inductive coupling systems.

The lower frequency systems depend critically upon transponder size and reader antenna size. For example, for the Texas TIRIS system a standard 32mm glass capsule can be read with a stationary reader and a gate antenna from a distance of up to 1 metre, whilst larger transponders can achieve ranges up to 2 metres.

6.1.2 Range / Power/ Frequency Interactions

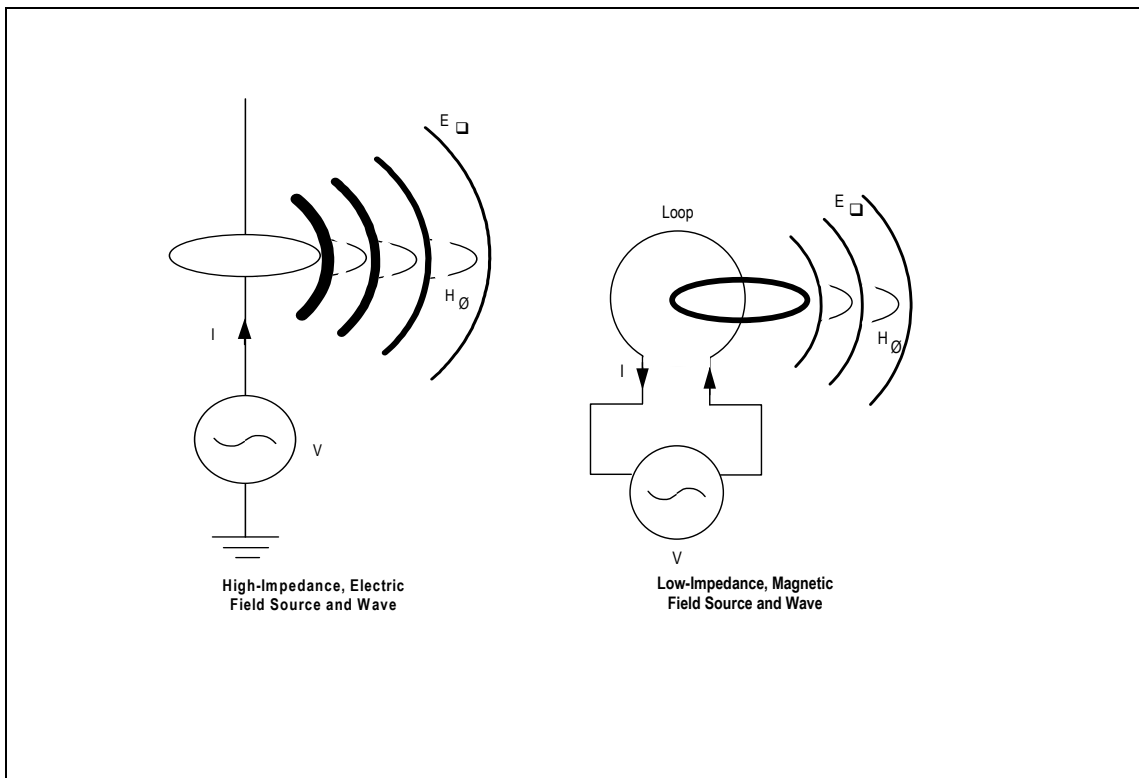
The interaction between the range, power and frequency of operation for RFID systems is complex, but the following sections indicate their importance in the selection of an appropriate RFID device technology.

6.1.2.1 Near Field / Far Field Operation

RFID systems use signals transmitted through space, but not all of these RFID systems use what is technically called a radio signal. Some devices might be more correctly called magnetically coupled RFID systems. An understanding of the difference performance implications as a result of this distinction is fundamental to understand the system solutions offered by vendors.

A passive RFID system needs a power transfer link and a data communications link. The power transfer link is required so that the transponder can extract its power directly by the carrier. The mechanism by which this power is transferred depends on whether the device is operated in the near or far field.

An alternating current passing through a conductor generates two fields that travel through space. Both field types are capable of transferring power and information from one conductor, through space, to another conductor. The illustration below indicates that close to the conductor, which is in the near field, the electrical field is either magnetic or electrostatic in composition. At distances further from the source, which is in the far field, the coupling is achieved through the mechanism of electromagnetic plane waves.



The electromagnetic field vector equations that apply to describe the field structure are complex. However, in the near field the electric field dipole and magnetic field dipoles have the following characteristics:

- Electric Field Dipole : Predominant E vector rate of fall off at $1/r^3$
- Secondary H vector rate of fall off at $1/r^2$

Magnetic Field Dipole : Predominant H vector rate of fall off at $1/r^3$
 Secondary E vector rate of fall off at $1/r^2$

6.1.2.1.1 Near Field

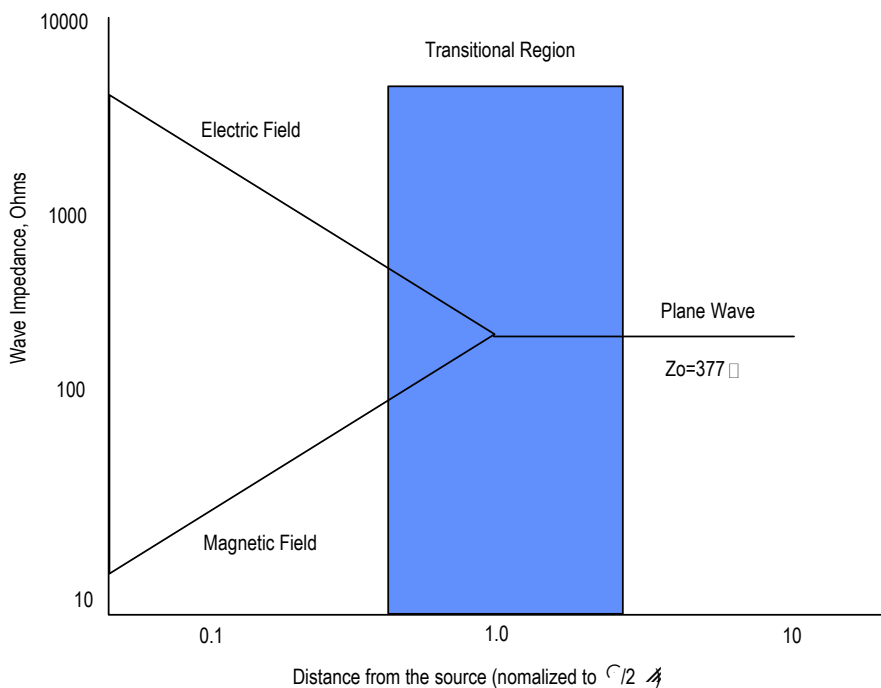
The near/far field boundary is defined as the point where the $1/r^2$ and $1/r^3$ terms in the field equations become comparable with the $1/r$ far field term, and is given by the formula:

Near/far field boundary = $\frac{\lambda}{2\pi}$, where λ is the wavelength of the excitation signal.

This is often approximated to one sixth of the wavelength ($\lambda/6$). (Note that this distance for the near/far field boundary holds for simple dipole sources only).

The significant aspect of the near field is that the magnetic field power level drops off as the cube of the distance from the antenna. Therefore a magnetic field is only one-eighth as powerful at 50 millimetres as it would be at a position 25 millimetres from the radiating coil. The sharp decrease in power level with distance is a benefit where there is a need to limit the possibility of accidentally reading of another RFID tag within the reading distance of the reading unit..

When the transmitting and receiving antennae are close together, it is possible to transfer power efficiently between the two systems, as if the system were operating as a power transformer. This enables the RFID tag to extract power, so that it can communicate. In general, near-field RFID solutions are applicable when the user needs to know where a tag is when it is read.



6.1.2.1.2 Far Field

Outside the transition zone, the electromagnetic signal can be considered a radio signal. This signal field generated by the drops off only as the square of the distance from the antenna. For example a far field is one-quarter as powerful at 200 centimetres as it would be at 100 centimetres from the antenna. Therefore, the relatively slow roll-off in the far field (commonly called an electric field in many RFID articles) transponders generally provide vastly increased ranges over the magnetic coupled tags, and makes it a good choice for long distance RFID applications.

Electric field tags need to operate in an ordered spectrum management system as their radiated energy can be detected by other sensitive receivers far away and cause possible interference. The systems must therefore comply with local electromagnetic spectrum limitations.

As noted above the energy density of the radiated signal decreases as the inverse of the distance squared between the source and the transponder. Whereas sensitive receivers can compensate for this loss of energy over long distances in the data communications field a passive transponders must use the reader's energising field as a source of power. This means that far field RFID tags are practically limited to about ten metres at 400 MHz, or approximately 1 metre at 2.5GHz. Beyond that distance it is necessary for the tags to use an external battery as a source of power (refer to Section 5 below).

6.1.3 Antenna Design Implications

The selection of frequency of operation has a direct impact on the antenna design solution, and can be mapped on to the near (magnetic) and far field coupling solutions.

6.1.3.1 Magnetic Coupled Systems

Magnetic coupled RFID tags find application in tagging animals, labelling gas bottles, and factory automation.

The magnetic mode of RFID power transfer is generally preferred at operating frequencies below 500 MHz. The frequencies lending themselves to near-field signals can be further divided into two groups:

1. Low-frequency systems with frequencies below about 1 MHz.
2. Medium-frequency systems operating from about 1 MHz to 500 MHz.

The read range in these systems is related to how the reader antenna can spread lines of flux to the tag by the flux passing through the coil of the transponder. To spread the lines of flux, the read antenna sizes generally need to be large, and for example can be the size of a doorway for access control applications. To collect sufficient energy from the reader unit's magnetic field the RFID tags operating at frequencies typically in the order of 125 – 135 KHz are characterised by the use of antennas that comprise of many turns of a fine wire around a coil former. Therefore, low-frequency coils (below about 1 MHz) typically require many turns. This increases manufacturing complexity and cost.

As the read distance depends on the size of the respective transponder and reader magnetic fields that interact with one another the transponder field can be increased by making the transponder bigger, increasing the number of coils in the antenna, or by

inserting a ferrite core into the coil. Most of these improvements in performance are achieved with an increase in the cost of the transponder.

Typical antenna sizes and achieved ranges are indicated in the following table.

Antenna Size	Transponder Size						
		12 Round	18 - 20 Round	28 - 32 Round	80 x 50 Card	75 x 50 x 20	230 x 140
150 Rod	95	130	155	220	365	455	
100 Circle	125	155	195	240	390	485	
100 x 125	125	175	215	280	425	535	
300 x 300	130	200	280	395	545	745	
300 x 375	140	245	345	450	740	940	
375 x 550	110	225	330	445	810	1015	

Typical Induction Transponder Operating Distances (mm)

(reference “An overview of RFID technologies”, www.bistar.com)

Medium-frequency coils (operating from about 1 MHz to 500 MHz) can usually be produced with a few turns of conductor, often as screen-printed or etched antennas. The tags comprise of a small coil of a few turns, often etched on a flexible printed circuit substrate, and to which the RFID device is mounted. The printed or etched antenna is a coil; the two ends of the coil being separated by intermediate turns. This multi-layer configuration allows high volume production. These transponders might be as small as 1.5cm by 1.5cm in area. Energy coupling is again achieved using magnetic coupling. The reading and writing distance of such tags is limited by the magnetic coupling mechanism to typically 20 cms, but some manufacturers claim much longer read ranges.

6.1.3.2 Electric Field Coupled RFID Systems

The electric field mode is preferred for frequencies above 100 MHz as the antenna designs for electric field coupling start to become practical for tagging applications above this frequency.

For example for an electric field coupled mode, a typical half wave dipole antenna's length would be:

$$\text{Length (centimetres)} = 15000 / \text{Operating frequency (MHz)}$$

Therefore, the electric field transmission mode requires antenna systems that are 150cm at 100MHz, 15 cm at 1GHz, 5 cm at 2.5Ghz and 2.5cm at 5.8Ghz. This causes practical limits to how low a frequency to start using electric field transmission systems due to the size of the antenna.

For electric mode coupled RFID systems the transmitter in the reader radiates via the transmit antenna energy. The energy per square unit at a given range from the transmit antenna is given in mathematical terms by the formula:

$$\text{Energy density (W/sq m)} = \frac{P_t * G_t}{4 * \pi * \text{range(m)}^2}$$

Where:

P_t is the transmitted energy

G_t is the antenna gain

π is 3.14159

Range is distance from antenna

The energy available at the RFID transponder is the energy that can be collected in the effective aperture of the transponder, and is determined by the relationship:

$$\text{Energy received(W)} = \text{Energy density at range(W/sqm)} * \text{Effective aperture (sqm)}$$

Recent developments in passive RFID tag technology has reduced the power received requirement for the tag less than 1 milliwatt in some cases. This development not only has reduced the power needed by the reader but has significantly increased the range over which passive transponders can operate effectively.

The effective aperture of the transponder is a function of the gain of the tag antenna and the square of the operating wavelength. Assuming that the gain of the antennae, and minimum operating voltage for the transponder and its matching are constant in all situations, then the operating range of the system is a function of the transmitted power and the operating wavelength.

These constraints meaning that a 2.45GHz system would need 7 times more transmitter power than a 900MHz system for the same range, while still having an antenna system that is 36% of the size of the 900Mhz version. The size of the antenna aperture area for a 915MHz dipole is 134cm².

Far-field transmission and reception in RFID systems typically use a single loop of conductor for the antenna. These tags employ antennas of a full, half, quarter, or eighth wavelength. The length of conductor required therefore significantly decreases as the frequency increases, so you typically apply this technical solution at frequencies above about 500 MHz.

The simplicity of the antenna design results in RFID tags that are very cheap to produce. This is ideal for the situations where there is one reader and many tags.

The impact of near / far field operation and frequency selection on antenna design is summarised in the following table.

FREQUENCY RANGE	ANTENNA CONSIDERATIONS
LOW (less than 1 MHz) near field, inductive coupling	Many turns required, sometimes several hundred, typically wound around an air or ferrite core
MEDIUM (1 to 500 MHz) near field, inductive coupling	Fewer wire turns required, typically printed or etched on a flat surface
HIGH (more than 500 MHz) far field radio signal	Single loop

Antenna – Frequency Interactions

(reference2. “Physical Reality: A Second Look”. Idsystems.com)

6.1.4 Operating power vs frequency

Electric field coupling RFID tags need to operate in an regulated spectrum management system as their radiated energy can be detected by other sensitive receivers cause possible interference. The amount of power that can be used or such an application is also governed by health and safety requirements.

The allowable transmit power, bandwidth of operation and limitations on use of the RF spectrum warrants a separate document in itself. Therefore, for more and up to date information in this area the reader is referred to the following web sites:

- www.etsi.org (European Telecommunications Standards).
- www.radio.gov.uk (Radio Communications Agency in UK)
- www.fcc.gov (USA)

The latter of these web sited provides links to other countries communications approval agencies and allows in depth review of world wide regulations to be performed.

6.1.5 Combination of Frequencies in a Tag Application

The selection of frequency is critical, but many applications will require a combination of frequencies and indeed a combination of RFID and other data collection technologies.

As an illustration, a system might require the use of a low-frequency signal from the reader unit to "wake up" the tag located in the very restricted read volume associated with the use of this frequency, and use a higher frequency (e.g. 902 MHz signal) to return the data to its receiving antenna. This could be used to provide high data transfer rates, for example in road toll tagging transactions.

System design solutions that seem insurmountable using one frequency of tag transmission can therefore be overcome by the use of such composite designs.

6.2 Active RFID Devices

RFID systems are often described as passive or active.

Passive transponders are transponders that have no onboard battery but receive their operating energy from the reader unit's energising field. The use of passive

transponders is undertaken because they are cheaper than the active transponder solution, and their life is not limited by battery capacity constraints.

Whilst the SDICOM project promotes the application of passive transponder systems, in some cases the use of active systems may be required.

In an attempt to overcome the limitations of passive transponders, such as limited range, *active transponders* drive their onboard circuitry from energy derived from a battery or another wired supply. The transponder then functions like a transceiver radio unit, and system coupling is based on the propagation of communications signals only. The operating distance is then determined by the efficiency of the transponder antenna, and the amount of interference occurring at the frequency of communication. In essence the system is a two-way radio system, and its operating range could extend up a 1000 metres. However, in practice operating distances for read distances may be in the order of 4 - 6 metres.

Active transponder products can be used as dynamic database carriers in production environments, and as unique identifiers in some specialised applications. An application for active electric field tags relate to the development of transponder / smart card systems for toll road applications. Here the tags are active but only consume battery power after the tag is "activated" by passing through a high-energy activation field. Thereafter the tag can send / receive data and can adjust the data representing the balance remaining in the smart card after the toll fees are deducted.

Disadvantages associated with active transponder systems include additional cost, limited life, possible safety considerations in certain applications, increased unreliability, and the need to consider possible environmental hazards at disposal.

6.3 Semi-Active RFID Tags

A separate category also exists of "active" tags, in which RFID tags wake themselves up from a low power "sleep mode" periodically upon receipt of a signal from the reader unit and transmit their data before returning to the "sleep mode".

An example of such a system solution is the use of the AT88RF001, Atmel's latest 13.56 MHz RFID asset identification product. The AT88RF001 is a stand-alone 13.56 MHz RFID front end that includes a serial port suitable for connection to an external high-density serial memory or system microprocessor.

These large tags can be used to store information, such as biometric data for security badges, in connected memory devices. In addition when connected to microcontroller the AT88RF001 device will allow the product to be used as a remote sensor / logger with RFID interface. Such systems could provide much longer battery life than where the RF transmission is also powered from the battery.

Appendix 1: Relevant Standards

Some relevant standards the reader should be aware of are listed below. This is not a comprehensive listing, and the reader is advised to perform his / her own search for a given application.

ISO 18000

The ISO 18000 (, Radio-frequency Identification Standard for Item Management -- Air Interface) specification series addresses the following:

Part 1, Generic Parameters for Air Interface Communication for Globally Accepted Frequencies

Part 2, Parameters for Air Interface Communication below 135 kHz.

Part 3, Parameters for Air Interface Communication at 13.56 MHz.

Part 4, Parameters for Air Interface Communication at 2.45 GHz.

Part 5, Parameters for Air Interface Communication at 5.8 GHz.

Part 6, Parameters for Air Interface Communication - UHF Frequency Band

ISO/IEC 15961

ISO/IEC 15961 (Information Technology -AIDC Techniques - RFID for Item Management - Host-Interrogator-Tag Functional Commands and Other Syntax Features) addresses the common functional commands and syntax features (for example, . RFID data storage formats, etc.), independent of transmission media and air interface protocols.

The 15961 Standard is intended to be a companion standard to **15962**, which defines the overall protocol for data handling. The 15961 standard will comprise a super set of all functional commands and other syntax features appropriate to RFID for Item Management.

The 15961 functional commands are at a higher abstract level than those of 18000, to enable common data handling rules to be applied for all RFID technologies. The interrogator-tag commands of 18000 are at a detailed lower level and are specific to the particular technologies that are part of 18000.

ISO/IEC 15962

ISO/IEC 15962 (Information Technology AIDC Techniques - RFID for Item Management - Data Syntax) specifies the interface procedures used to exchange information in an RFID system for item management. As there can be no direct communication between the host system and the RFID tag, the protocols established in this standard ensure the correct formatting of data, the structure of commands and the processing of errors in the RFID system.

This standard is used to ensure the interoperability of systems.

ISO/IEC 15963

ISO/IEC 15963 (Information Technology- AIDC Techniques - RFID for Item Management- Unique Identification of RF Tag and Registration Authority to Manage the Uniqueness) addresses the following:

- Part 1: Numbering system
- Part 2: Registration procedure and management guidance and rules
- The standard defines unique identification of RFID Tags so as to ensure interoperability between different RFID tags. This standard addresses the the traceability of the RFID device itself during the manufacturing process, its traceability throughout their use in the applications where they are used, and finally anti-collision of multiple tags in the reader's field of view.

ISO 11784

SO 11784:1996 (Radio-frequency identification of animals - Code structure) is a published international standard that specifies the structure of the radio-frequency (RF) identification code for animal tagging applications.

ISO 11785:1996

ISO 11785:1996 (Radio-frequency identification of animals - Technical concept) is a published standard defining the principle of the radio-frequency identification (RFID) system for animal identification, and specifies how a transponder is activated and how the stored information is transferred to a transceiver. ISO 11785 is applicable in connection with ISO 11784 (see above).

ISO 14223

ISO 14223 (Radio frequency identification of Animals, advanced transponders – Air interface) consists of the following 3 parts:

Part 1: Radio Frequency Identification of Animals, Advanced transponders - air interface

Part 2: Radio Frequency Identification of Animals, Advanced transponders - code and command structure

Part 3: Radio Frequency Identification of Animals, Advanced transponders - applications

This standard defines the technical concept of advanced transponders for animal identification using RFID methods and is an extension of the standards ISO 11784 and ISO 11785. Apart from the transmission of the identification code of an animal the specification defines facilities for the storage and retrieval of additional information, and the implementation of authentication methods and reading of the data of integrated sensors.

CASE STUDIES TO BE INTEGRATED IN TEXT

Case Study

A company manufacturing chemical samples processing equipment identified that the probability of incorrect loading of samples into a 100 tray unit before analysis was low. This would result in samples processed in an incorrect fashion and loss of information collected from sample points over a long time period. The cost of the error was therefore very high. The use of a RFID technical solution integrated into the product prevented errors in the loading process because machine level checks could be performed and also ensured that the appropriate processing could be applied to a particular sample. The low cost product enhancement will improve the product's competitiveness and increase sales significantly through its cost reductions for the customer.

Case Study

A company producing emergency light fittings identified the need to be able to record the data recorded for mandatory emergency light tests in an efficient, and auditable fashion. The application of RFID interface solutions allowed the transmission of this data to a PC without the need for contact based data transfer which would have been unacceptable in many physical locations or for safety purposes. The new product solved a significant user problem and will allow the widespread adoption of the product.

Case Study

An UK company involved in the design and manufacture of temperature monitoring and logging equipment identified an opportunity to utilise their product to ensure that blood transfusion bags used in hospitals and clinics were stored at an appropriate temperature. However, each monitoring system would require both an unique identity code and enough internal memory to maintain a record of the bloods storage conditions over a prolonged period. The use of RFID technology allowed the company to unique identification of individual blood bags and also to use the passive data transfer facility to maintain low power consumption whilst transferring the information to a remote reader unit. The new monitoring system has the potential to deliver significant efficiency improvements to the handling of blood transfusion supplies and opens up a new market for the company.

Case Study

The manufacturing of occlusal dental prosthesis often causes problems, resulting in prosthesis that may not fit sufficiently, be damaged by use or even cause chronic headaches in patients related to this dental problem. The fitting of dental prosthesis is a complex process, requiring measurement of the movements of the lower jaw in relation to the upper jaw and the copying of this information in dental laboratories. An innovative jaw movement registration system was developed using an optical sensor system to register the jaw movement, and a transmitter and a sensor module fitted to the upper and lower jar of the patient. Data is contactlessly transmitted to a reader earpiece worn by the patient and jaw movements are recorded by a PC connected to the reader. Dentures can now be made with an occlusal accuracy never

previously achievable, and at a reduced cost through reductions in grinding and other processing.

Case Study

A company producing Smart Cards for use by end-customers for processing companies, value added reseller, credit institutes and insurance cards. The objective of the project was to incorporate a thin profile switch in the card so that physical activation of credit transactions was required before the read / write operations were conducted. This integration of an authorisation switch in a thin profile smart card opened up new market opportunities for the use of the product in cashless transactions.

Case Study

The aim of the project was to develop a miniature, non-contact data communication module that is worn by a patient to provide wireless communication between the patient and a vital-signs cardio-respiratory monitor. This reduces the problems with training cables being tangled around the patient, and improves the acceptability of the system when the patient is asleep. The other benefits included increased overall reliability by eliminating the cable and improved customer perception reinforcing the company's image as a provider of cutting-edge solutions.