INFORMATION SOCIETY TECHNOLOGIES (IST) PROGRAMME

Best Practice Action

D2.2 SIDCOM Training Material
Design Considerations
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SIDCOM Design Considerations

1 Introduction

RFID systems generally use transponder and reader systems that fall into the following broad categories

- Inductive RF tag solutions. These systems
- Back Scatter

1.1 Inductive RFID Tags

Inductive tags are energised by the coupling of an activation field generated by the reader unit. The tag systems generally have limited information storage capabilities but can provide unique identification code information.

These systems are often applied in low cost applications such as security surveillance systems. Typical read ranges are less than a metre. The typical application areas for such systems include anti-theft systems, pet or wild animal identification, and vehicle entry and security products.

1.2 Back Scatter Operation RFID Tags

Back scatter tags can include passive or active, battery powered solutions. These systems reflect some of the RF energy transmitted by the reader unit, so as to modulate the reflected signal with the required information to be transferred. These systems are more expensive than the inductive RFID solutions.

Back scatter tags can contain varying amounts of information, and have applications in road toll collection, traffic management and asset tracking.

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. The use of the identified supplier contact list in the Appendix will however provide an opportunity to evaluate various market offerings.

2 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.

???????????????? (reference www. ?????????) argues that the acceptable cost estimate on a per tag basis need not be precise. As indicated in Table 1 below 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 1000
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

(Adapted from reference www.??????????????????)

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.

3 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:

3.1 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.

3.1.1 Memory Types

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

1. ROM (Read Only Memory). These devices have an 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 than 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 an 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.

3.2 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.

3.3 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.

3.3.1 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.

3.4 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.

3.4.1 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 fag orientation can be controlled.

3.5 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.

3.5.1 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.

3.6 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.

3.6.1 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.

3.7 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.

3.8 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.

3.8.1 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.

3.8.2 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.

3.9 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.

The information is therefore not all encompassing, and the a reader of this document, is advised to conduct his / her own review prior to technology selection and implementation. No warrantees are expressed or given with this document as the information contained herein probably became out of date the moment it was published.

3.9.1 Standards

The standards defined world-wide 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. Relevant standards include:

ISO 15693-2

Recently, the International Standards Organisation has officially defined the way data is exchanged between the RFID tag and its reader. ISO 15693-2 (13.56MHz contactless Smart Card standard) has been proposed and accepted by the two industry leaders, Texas Instruments and Philips Semiconductor. This new standard will clear the path for other companies to create value-added components to integrate into an open RFID system.

ISO 18000

ISO 18000 is now being developed by an ISO/IEC joint technical committee to include a range of frequencies such as 125kHz and 13.56MHz for RFID label tagging. ISO 18000 is expected to be ratified during 2001.

The ISO 18000 (, Radio-frequency Identification Standard for Item Management -- Air Interface) specification series will address 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

At each of these different common RFID operating frequencies there will different specifications of the sir interface requirement to reflect the different operating performances and antenna design, and allowable power levels. The documents will also system considerations to address operation under adverse environmental conditions such as noise or interference.

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.

The standard therefore addresses the numbering system required to identify uniquely an RF tag. This number is encoded in the Integrated Circuit of the RFID Tag.

SO 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. This specification defines the structure of the identification code (the definition of bits transmitted by a transponder, including data bit definitions, defining the identification code and a code correction bits).

This l standard does not specify the characteristics of the transmission protocols between the transponder and the reader unit itself. These characteristics are defined in ISO 11785.

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.

The standard describes the air interface between the reader and the transponder so as to ensure upward compatibility with ISO 11784 and ISO 11785. The standard can therefore be regarded as an extension of ISO 11785 and should be used in conjunction with it.

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.

3.9.2 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.

3.10 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 in Sections 2 and 3.1. to 3.9 above.

4 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.

4.1 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

4.1.1 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 contract the he 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.

4.2 Range / Power/ Frequency Interactions

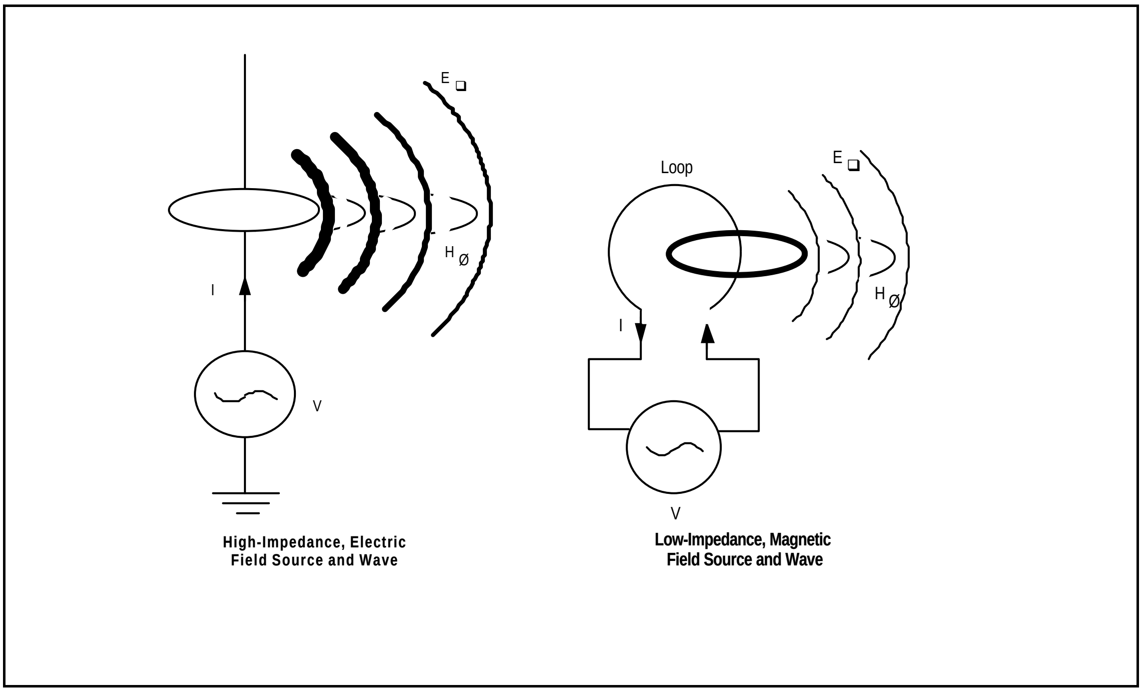
The interaction between the range, power and frequency of operation for RFID systems is complex, but the following sections indicate their importance in the selection of an appropriate RFID device technology.

4.2.1 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 $1/r^2$

4.2.1.1 Near Field

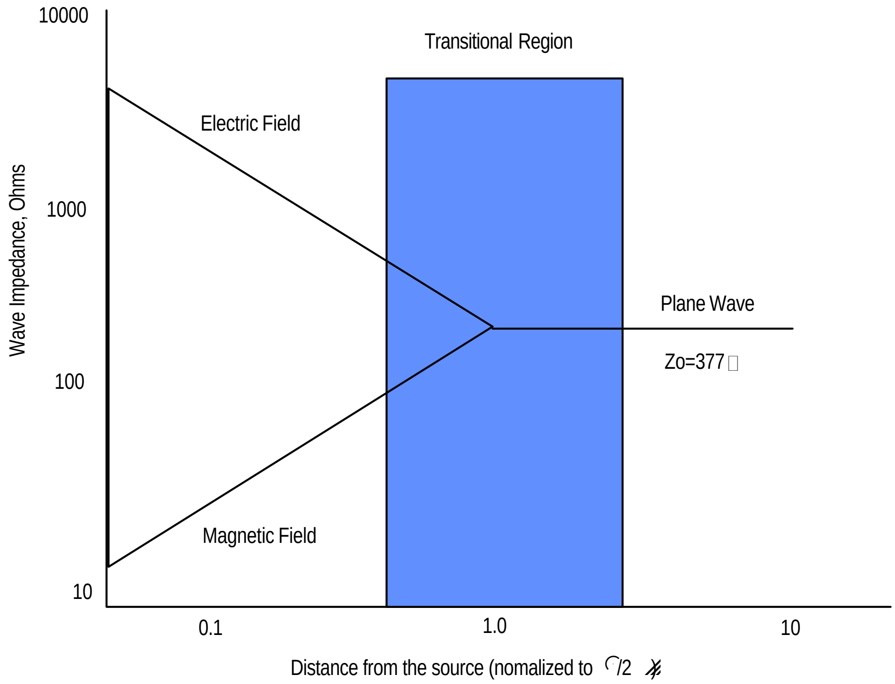
The near/far field boundary is defined as the point where the $1/r^2$ and$1/r^3$ terms in the field equations become comparable with the 1/r far field term, and is given by the formula:

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

This is often approximated to one sixth of the wavelength (λ/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. "One of the benefits of near field is you get a nice localised read range so you can pick up items in a specific area," (quote – R. Roebuck, Technical Sales Manager at Texas Instruments.



4.2.1.2   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 ??? below).

4.3 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.

4.3.1 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.

	Transponder Size						
		12 Round	18 - 20 Round	28 - 32 Round	80 x 50 Card	75 x 50 x 20	230 x 140
Antenna Size	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 ??????????????????????)

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.

4.3.2 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:

Length (centimetres) = 15000 / 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:

$$\text{Energy density (W/sq m)} = \frac{Pt * Gt}{4 * PI * range(m) * range(m)}$$

Where:

Pt is the transmitted energy

Gt is the antenna gain

PI 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:

Energy received(W) = Energy density at range(W/sqm) *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 $134cm^2$.

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 fiield 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

(reference ????????????????????)

4.4 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.

The standards appropriate to RFID products have previously been defined in this document.

The major issues to be aware (referenced time 2000) are:

- Safety limits mean that the transmitted power is constrained. The application of these limits mean that for really long range passive tag operation the frequency of operation will be in the 100Mhz to 500Mhz range. (reference www: rapidttp.com/transponder/freqpwr.html)
- For frequencies at 2.45Ghz and above, the ranges are likely to be much less than 1 metre and it is likely that active tags will be needed.
- The European and North American 13.56 MHz band regulations are at present quite different. European regulations currently permit more power and a higher communication bandwidth at this frequency than do North American regulations. Proposed changes to FCC regulations should harmonise the U.S. and European environment in 2002/3.
- Systems based on 2.4 GHz are popular in European and Japanese facilities because the 902 MHz systems conflict with GSM cellular telephone systems.

(Reference “What you need to know about RFID”, Larence S Gould, pub. Automotive Design & Production)

4.5 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.

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

5 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 /s mart 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.

5.1 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.

5.2 Capacitive Coupling

This document has concentrated on the use of traditional RFID systems. However, an alternative low cost solution is the use of the capacitive coupling. This is based on a capacitive voltage divider, and is an analogy of the inductive transformer coupling of the low frequency inductive tags.

The BiStatix RFID tagging system, developed by Motorola, uses capacitive coupling instead of inductive coupling. The RFID tag devices use plate antennas, which can be produced by printing conductive ink on to a surface. The range of data transfer using this technology, using a 5.5 cm by 5.5 cm tag is approximately 20 cm from the reader; the read range was the same when the small cardboard box separated the tag from the reader and the tag faced away from the reader (reference www.princeton.edu/~ssaar/bistatix.htm).

An interesting conclusion derived from the assessment of the BiStatix technology solution was that when the capacitive tag was attached to an object, that in some instances the object in itself provided a larger surface which can act like a larger capacitor plate than the tag's antenna. This could result in an improvement in reading range in some cases.

To increase read range using capacitive coupling two potential solutions can be used; one is to use larger panels, and the is to increase the field strength. There are however limitations on field strengths that must be adhered to.