# 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

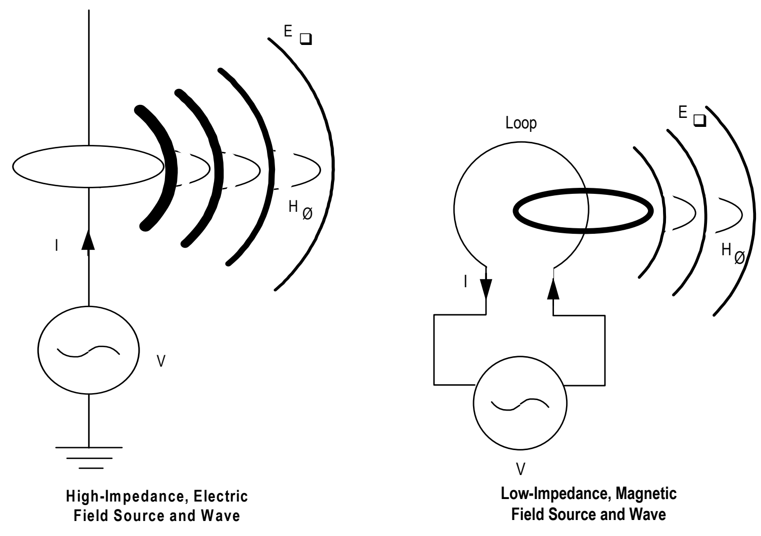
The interaction between the range, power and frequency of operation for RFID systems is complex, but the following sections indicate their importance in the selection of an appropriate RFID device technology.

#### 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 $1/r^2$ |

***Near Field***

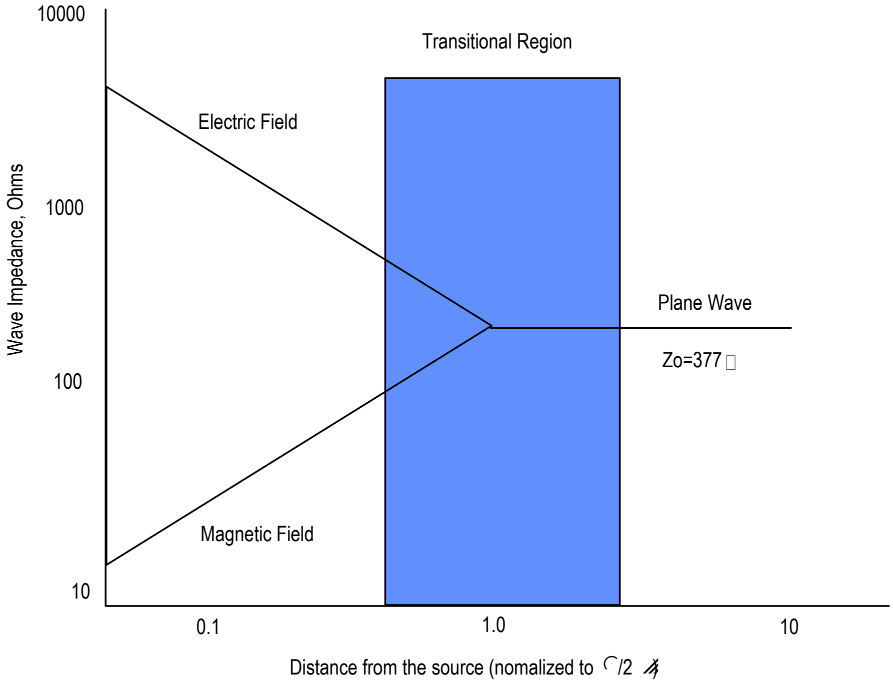
The near/far field boundary is defined as the point where the $1/r^2$ and$1/r^3$ terms in the field equations become comparable with the 1/r far field term, and is given by the formula:

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 (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.




*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.

| | | **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 "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:

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:

$$\text{Energy density (W/sq m)} = \frac{Pt \, {*}Gt}{4 * PI * range(m)^2}$$

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 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.

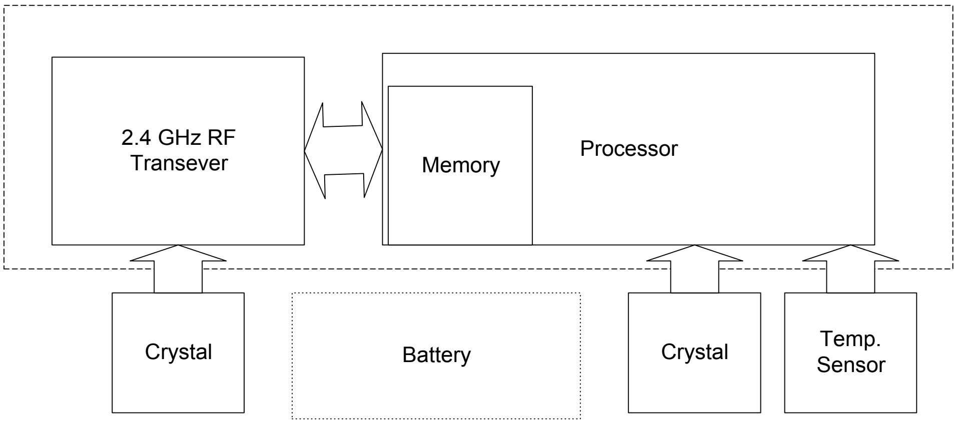
In an attempt to overcome the limitations of passive transponders, such as limited range, ***active transponders*** drive their onboard circuitry from energy derived from a battery or another wired supply. The transponder then functions like a transceiver radio unit, and system coupling is based on the 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 /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.

Case Study

Free2move used an active RFID tag solution in its product used for tracking the storage temperature of food or other perishable items though the distribution chain. The use of a 2.4 GHz active tag solution provided the company with a product that was accepted worldwide and with long read ranges.




## 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.

**Case Study**
Contronics used an RFID mode of data transfer for use its system for monitoring the temperature of items in transit that:

- Provided a reliable, quick data transfer mechanism.
- A mechanism that is hermetically sealed so as to survive harsh environments, including possible cleaning processes.
- Minimised power requirements to provide a product life of at least 3 years.

By utilising passive RFiD technology all the above requirements were met, as it relies on measuring back-scattered radiation, with the power for the communications being provided by the reader. The tag does not consume power whilst transmitting data, but the tag is required at all times to perform the temperature monitoring, data storage and formatting tasks required to provide the data recording functionality required for this application. The design solution integrates a low cost RFID transponder interface with a microcontroller to provide an innovative system utilising passive transponder data transfer mechanisms to provide a semi-passive tag solution.