LARAN RFID

Supply Chain Smart Label EPC Code

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**White Paper**

# A BASIC INTRODUCTION TO RFID TECHNOLOGY AND ITS USE IN THE SUPPLY CHAIN

**April 2005**

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## Executive Summary

In 2003 RFID seemed to have appeared from nowhere, and into the spot light as one of the hottest technologies around. Everyone from journalists, analysts, VC's, technology companies and retail giants like Wal-Mart were making public statements, mandates, predications and investments based on the promise that RFID was set to revolutionize the global supply chain on a scale not seen since the internet revolution in the 1990's.

Equally surprising is that RFID is not new, its been around for well over 10 years, and is already in use in applications such as access control and transport ticketing. Whilst there have been many false starts and promises in the past, what has made the difference this time around is the creation of the EPC (electronic product code) coupled with lower tag costs, and the mandated adoption of RFID by Wal-Mart and Tesco for all their suppliers by 2005-6. Furthermore, the European Parliament has announced legislation which obliges all goods to be traceable throughout the supply chain by 2005. These initiatives and others like the recent US-DOD announcements are now driving the market and inciting many companies to develop strategies for RFID compliance.

The use of RFID combined with the EPC promises to provide data about products never available before. Many items produced will eventually have their own unique ID numbers. All parts of the supply chain including manufactures, distributors and retailers will be able to have instant access to information about an individual product. RFID is not expected to replace bar codes simply because tags are still too expensive even though their prices have fallen to around 20 cents in volume versus 0.2 cents for a bar code label. Adoption is therefore likely to happen first at the Palette and Crate level, then as technology advances and costs reduce further, we can expect to see tags on higher value items.

The wide adoption of RFID across the supply chain will bring significant benefits leading to reduced operational costs and hence increased profits. Many analysts suggest that this will happen in three primary areas.

- Reduced inventory and shrinkage
- Benefit from a reduction in store and warehouse labor expenses
- A reduction in out-of-stock items

With so much high profile backing, momentum and indisputable benefits, can RFID fail? Most analysts think not, but are aware of the many obstacles, misconceptions and issues to be resolved on the way including;

- Tag prices and efficiencies
- Harmonization of RFID standards,
- Interoperability throughout the supply chain
- IT infrastructure to handle large volumes of data
- Change of work and labor practices
- Shared cost of deployment
- Privacy issues

This paper is aimed at both technical and business professionals who want to understand how RFID basically works, the various building blocks and the potential the technology has for the supply chain. Finally I hope that it will also shed light on some of the mysteries and confusion surrounding RFID and all that it promises.

# Introduction to RFID

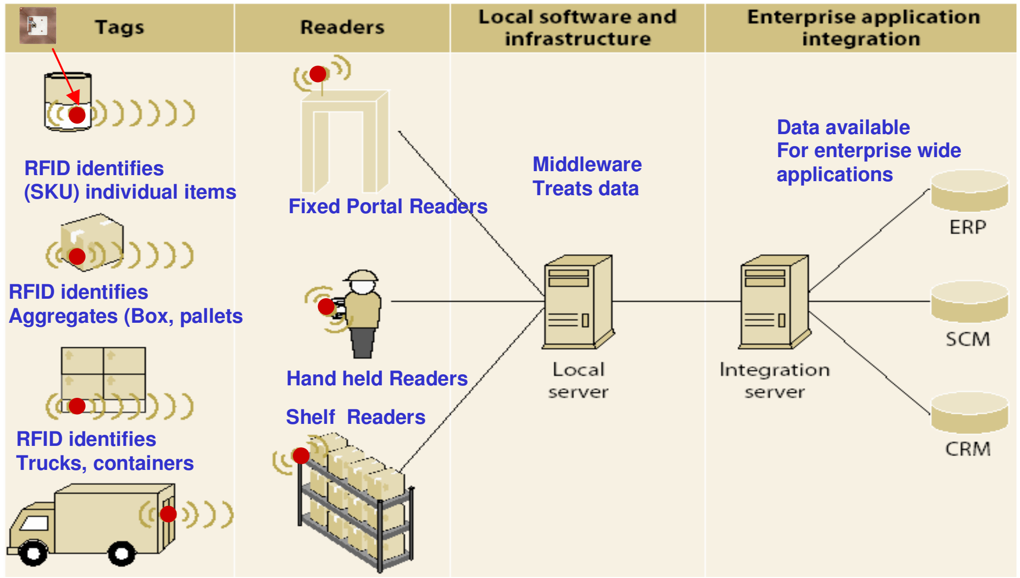
In general terms, RFID (*Radio Frequency Identification*) is a means of identifying a person or object using a radio frequency transmission. The technology can be used to identify, track, sort or detect a wide variety of objects. Communication takes place between a reader (*interrogator*) and a transponder *(Silicon Chip connected to an antenna)* often called a tag. Tags can either be active (powered by battery) or passive (powered by the reader field), and come in various forms including Smart cards, Tags, Labels, watches and even embedded in mobile phones. The communication frequencies used depends to a large extent on the application, and range from 125KHz to 2.45 GHz. Regulations are imposed by most countries (grouped into 3 Regions) to control emissions and prevent interference with other Industrial, Scientific and Medical equipment (ISM).

**Table 1. Most commonly used RFID frequencies for passive tags – Performance overview**

| | LF | HF | UHF | Microwave |
|---|---|---|---|---|
| Frequency Range | < 135 KHz | 13.56 MHz | 860 - 930 MHz [1] | 2.45GHz |
| Standards Specifications | ISO/IEC 18000-2 | ISO/IEC 18000-3 AutoID HF class 1 ISO 15693, ISO 14443 (A/B) | ISO/IEC 18000-6 AutoID class 0, class 1 | ISO/IEC 18000-4 |
| Typical Read Range | <0.5m | ~ 1m | ~4 -5 m[2] | ~ 1m |
| General | Larger Antennas resulting in higher cost tags. least susceptible to performance degradations from metals and liquids | Less expensive than LF tags, Best suited for applications that do not require long range reading of high number of tags. This frequency has the widest application scope. | In volume UHF tags have the potential to be cheaper than LF or HF due to recent advances in IC design. Good for reading multiple tags at long range. More affected than LF and HF by performance degradations from metals and liquids | Similar characteristics to UHF but faster read rates. Drawback is microwaves are much more susceptible to performance degradations from metals and liquids. |
| Tag power source | Mainly passive using inductive coupling (near field) | Mainly passive using inductive coupling (near field) | Active and passive tags using E-Field back scatter in the far field | Active and passive tags using E-Field back scatter in the far field |
| Typical applications | Access Control, Animal tagging, Vehicle immobilizers | Smart cards, Access Control, Payment, ID, Item level tagging, baggage control, Biometrics, Libraries, laundries, Transport, Apparel | Supply Chain- pallet and Box tagging, Baggage Handling, electronic toll collection. | Electronic toll collection, Real Time Location of goods. |
| Notes | Largest installed base due to mature technology. However will be overtaken by higher frequencies | Currently the most widely available high frequency world-wide due to the adoption of smart cards in transport. | Different frequencies and power allocated by different countries US 4W(EIRP) 915MHz, Europe 0.5W (ERP) 868 MHz, [2] | 5.8 GHz more or less abandoned for RFID |
| Multiple Tag Read Rate | Slower ←――――――――→ Faster | | | |
| Ability to read near metal or wet surfaces | Better ←――――――――→ Worse | | | |
| Passive Tag Size | Larger ←――――――――→ Smaller | | | |

[1] Japan has recently announced allocation for 950 MHz band for RFID
[2] 4 -5m is for unlicensed readers and 10m for site license in the US. In Europe with current power restrictions only around 33cm is achievable. However this is expected to improve to near 2m as power emissions increase from 0.5Watts to 2 watts.

## How RFID works




### RFID systems

In a typical system, tags are attached to objects. Each tag has a certain amount of internal memory (EEPROM) in which it stores information about the object, such as its unique ID (serial) number, or in some cases more details including manufacture date and product composition. When these tags pass through a field generated by a reader, they transmit this information back to the reader, thereby identifying the object. Until recently the focus of RFID technology was mainly on tags and readers which were being used in systems where relatively low volumes of data are involved. This is now changing as RFID in the supply chain is expected to generate huge volumes of data, which will have to be filtered and routed to the backend IT systems. To solve this problem companies have developed special software packages called savants, which act as buffers between the RFID front end and the IT backend. Savants are the equivalent to middleware in the IT industry.

### Communication

The communication process between the reader and tag is managed and controlled by one of several protocols, such as the ISO 15693 and ISO 18000-3 for HF or the ISO 18000-6, and EPC for UHF. Basically what happens is that when the reader is switched on, it starts emitting a signal at the selected frequency (typically 860 - 915MHz for UHF or 13.56MHz for HF) . Any corresponding tag in the vicinity of the reader will detect the signal and use the energy from it to wake up and supply operating power to its internal circuits. Once the Tag has decoded the signal as valid, it replies to the reader, and indicates its presence by modulating (affecting) the reader field.

### Anti-collision

If many tags are present then they will all reply at the same time, which at the reader end is seen as a signal collision and an indication of multiple tags. The reader manages this problem by using an anti-collision algorithm designed to allow tags to be sorted and individually selected. There are many different types of algorithms (Binary Tree, Aloha....) which are defined as part of the protocol standards. The number of tags that can be identified depends on the frequency and protocol used, and can typically range from 50 tags/s for HF and up to 200 tags/s for UHF.

Once a tag is selected, the reader is able to perform a number of operations such as read the tags identifier number, or in the case of a read/write tag write information to it. After finishing dialoging with the tag, the reader can then either remove it from the list, or put it on standby until a later time. This process continues under control of the anti collision algorithm until all tags have been selected and treated.

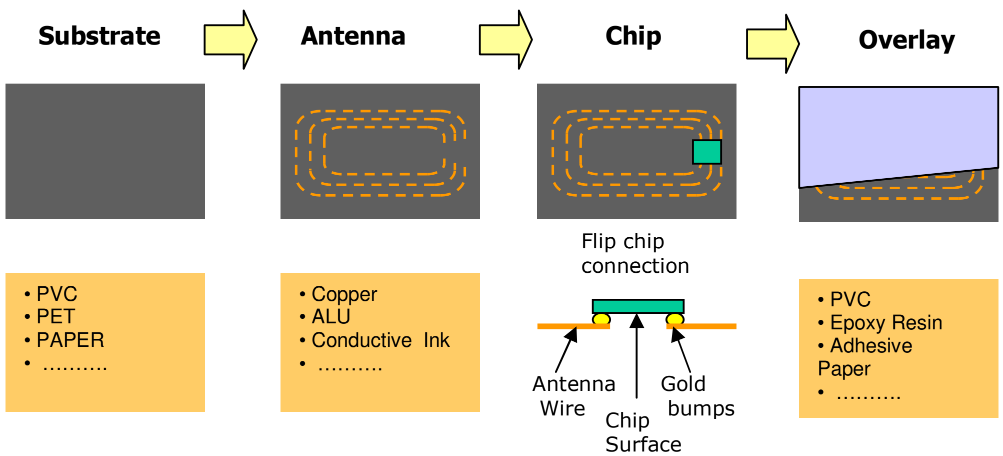
# RFID Building Blocks

## RFID Tags.

### Packaging

Every object to be identified in an RFID system will need to have a tag attached to it. Tags are manufactured in a wide variety of packaging formats designed for different applications and environments. The basic assembly process (see Fig 2.) consists of first a substrate material (Paper, PVC, PET...), upon which an antenna made from one of many different conductive materials including Silver ink, Aluminum and copper is deposited. Next the Tag chip itself is connected to the antenna; using techniques such as wire bonding or flip chip (see Fig 4.). Finally a protective overlay made from materials such as PVC lamination, Epoxy Resin or Adhesive Paper, is optionally added to allow the tag to support some of the physical conditions found in many applications like abrasion, impact and corrosion.

**Fig 2. Basic Tag Assembly**




### Examples of different formats

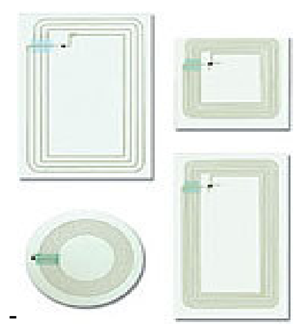
- Credit card size flexible labels with adhesive backs
- Tokens and coins
- Embedded tags – injection molded into plastic products such as cases
- Wrist band tags
- Hard tags with epoxy case
- Key fobs
- Tags designed specially for Palettes and cases
- Paper tags

### Tag Cost

The type of materials and assembly methods used to package tags impact directly on the final cost (around 30%), and to some extent on the communication performance. In the supply chain, the cost of tags is one of the main considerations for mass adoption, with the 5 cent tag being the much talked about target. How to achieve this figure is currently one of the great debates. Traditionally chip die size has always been the key focus, and IC companies have managed to get die sizes (chip area) down to around 0.3mm2 for UHF chips, resulting in a manufacturing cost of about 1-2 cents depending on the Silicon process. This leaves 3 cents for the rest! Which is where the real challenge now seems to lie. There are solutions in the pipeline from companies like Alien Technology and Philips Semiconductors, whom have both developed new chip assembly techniques which when used with the very large volumes (billions of tags) expected in the supply chain promises to optimize costs to the levels required in order to reach the 5 cent goal.

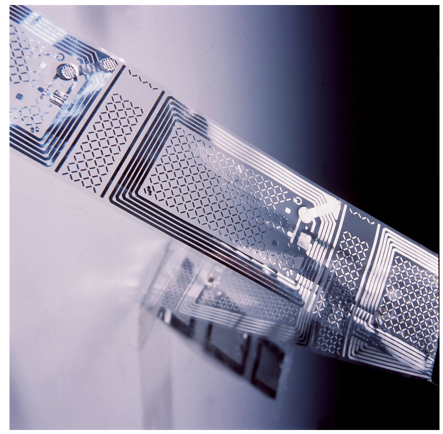
**Fig 3. HF (13.56 MHz) Tag examples**

Paper labels with conductive silver ink antennas



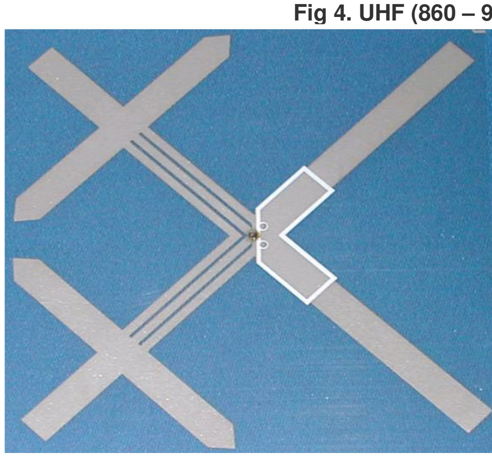
*Courtesy of ASK*

Flexible label with an aluminum antenna

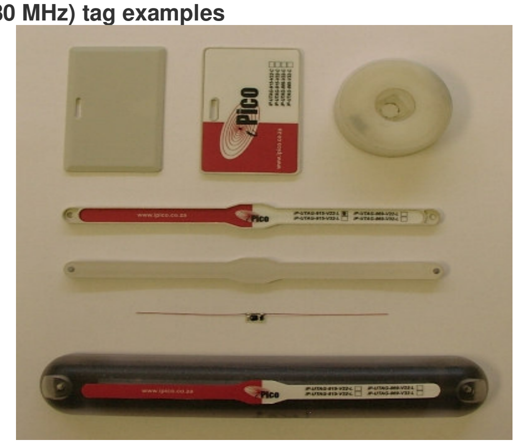


*Courtesy of Inside Contactless*

**Fig 4. UHF (860 – 930 MHz) tag examples**



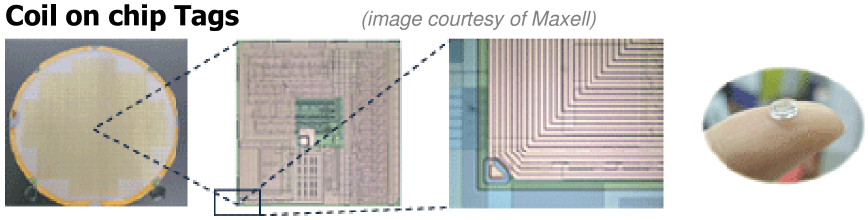
*Courtesy of MATRICS*



*Courtesy of IPICO*

## Coil on chip Tags

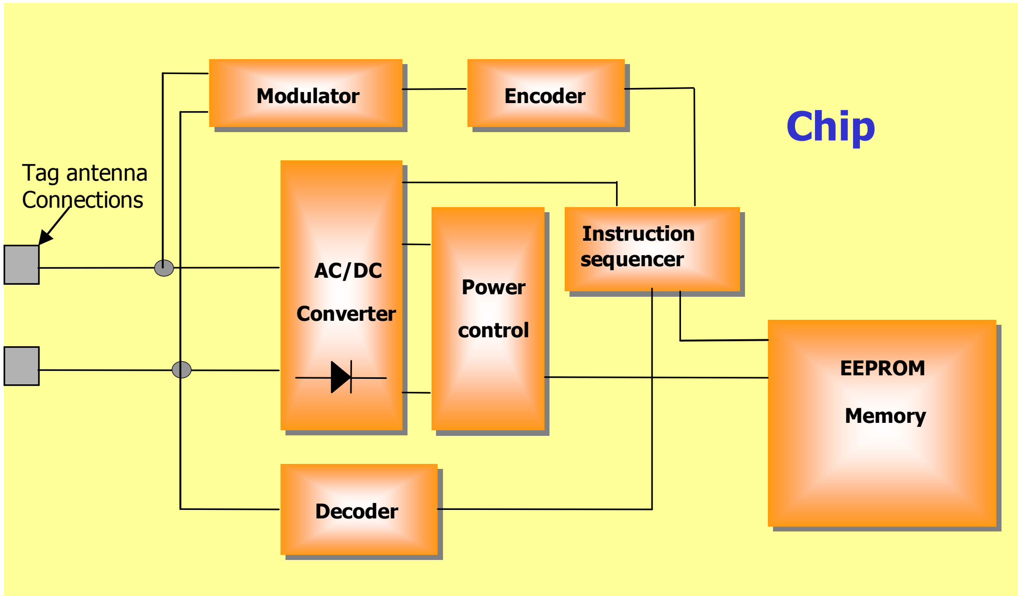
*(image courtesy of Maxell)*




A new and fascinating development for tags is based on having the antenna deposited directly onto the tag chips surface. Although the communication distance is limited to around 3mm, the result is a microscopic tag which can be concealed for example in bank notes, as proposed recently by Hitachi-Maxell. Both Maxell and Inside contactless have developed working versions of these tags at UHF, HF (Maxell) and HF (Inside).

## Tag IC's

**Fig 5. Basic Tag IC architecture**




RFID tag IC's are designed and manufactured using some of the most advanced and smallest geometry silicon processes available. The result is impressive, when you consider that the size of a UHF tag chip is around 0.5 mm2 i.e. about the size of the square below


*Image courtesy of Impinj inc*

In terms of computational power, RFID tags are quite dumb, containing only basic logic and state machines capable of decoding simple instructions. This does not mean that they are simple to design! In fact very real challenges exist such as, achieving very low power consumption, managing noisy RF signals and keeping within strict emission regulations. Other important circuits allow the chip to transfer power from the reader signal field, and convert it via a rectifier into a supply voltage. The chip clock is also normally extracted from the reader signal. Most RFID tags contain a certain amount of NVM (Non volatile Memory) like EEPROM in order to store data.

The amount of data stored depends on the chip specification, and can range from just simple Identifier numbers of around 96 bits to more information about the product with up to 32 Kbits. However, greater data capacity and storage (memory size) leads to larger chip sizes, and hence more expensive tags. In 1999 The AUTO-ID center (now EPC Global) based at the MIT (Massachusetts Institute of Technology) in the US, together with a number of leading companies, developed the idea of an unique electronic identifier code called the EPC (Electronic Product Code) . The EPC is similar in concept to the UPC (Universal Product

Code) used in barcodes today. Having just a simple code of up to 256 bits would lead to smaller chip size, and hence lower tag costs, which is recognized as the key factor for wide spread adoption of RFID in the supply chain.  Tags that store just an ID number are often called ¨ License Plate Tags ¨

## Tag Classes

One of the main ways of categorizing RFID tags is by their capability to read and write data. This leads to the following 4 classes. EPC global has also defined five classes which are similar to the ones below.

CLASS 0 – READ ONLY. – Factory programmed

These are the simplest type of tags, where the data, which is usually a simple ID number, (EPC) is written only once into the tag during manufacture. The memory is then disabled from any further updates. Class 0 is also used to define a category of tags called EAS (electronic article surveillance) or anti-theft devices, which have no ID, and only announce their presence when passing through an antenna field.

CLASS 1 – WRITE ONCE READ ONLY (WORM) – Factory or User programmed

In this case the tag is manufactured with no data written into the memory . Data can then either be written by the tag manufacturer or by the user – one time. Following this no further writes are allowed and the tag can only be read. Tags of this type usually act as simple Identifiers

CLASS 2 – READ WRITE

This is the most flexible type of tag, where users have access to read and write data into the tags memory. They are typically used as data loggers, and therefore contain more memory space than what is needed for just a simple ID number.

CLASS 3 – READ WRITE – with on board sensors

These tags contain on-board sensors for recording parameters like temperature, pressure, and motion, which can be recorded by writing into the tags memory. As sensor  readings must be taken in the absence of a reader, the tags are either semi-passive or active.

CLASS 4 – READ WRITE – with integrated transmitters.

These are like miniature radio devices which can communicate with other tags and devices without the presence of a reader. This means that they are completely active with their own battery power source.

**Table 2. Different tag classes**

| Class | Known as | | Memory | | Power Source | Application | |
|---|---|---|---|---|---|---|---|
| 0 | EAS | EPC [1] | None | EPC | Passive | Ant-theft | ID |
| 1 | EPC | | Read -Only | | Any | Identification | |
| 2 | EPC | | Read-Write | | Any | Data logging | |
| 3 | Sensor Tags | | Read-Write | | Semi-Passive/Active | Sensors | |
| 4 | Smart Dust | | Read-Write | | Active | Ad  Hoc networking | |

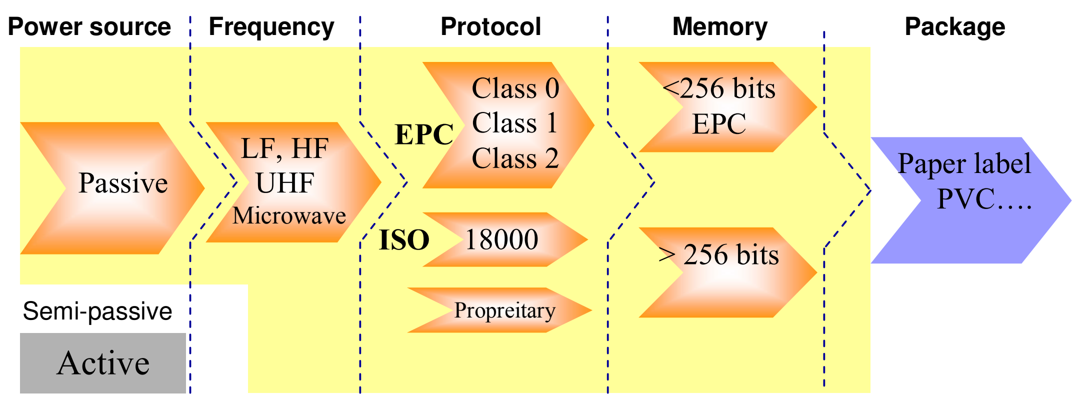
[1] The section on EPC standards evolution shows that the EPC class 0 is likely to evolve to a read-write

## Selecting a tag

Choosing the right tag for a particular RFID application is an important consideration, and should take into account many of the factors listed below:

- Size and form factor - *where does the tag have to fit?*
- How close will tags be to each other
- Durability - *will the tag need to have a strong outer protection against regular wear and tear.*
- Is the tag re-usable
- Resistance to harsh environments *(corrosive, steam...)*
- Polarization - what will be the tags orientation with respect to the reader field
- Exposure to different temperature ranges
- Communication distance
- Influence of materials such as metal and liquids
- Environment *(Electrical noise, other radio devices and equipment)*
- Operating Frequency *(LF, HF or UHF)*
- Supported Communication Standards and protocols (ISO, EPC)
- Regional Regulations (US, Europe and Asia)
- Will the tag data need to store more than just an ID number like an EPC
- Anti-collision - *how many tags in the field at the same time and how quickly must they be detected.*
- How fast will tags move through the reader field
- Reader support -*which reader products are able to read the tag*
- Does the tag need to have security - *Data protection by encryption*

**Fig 6. How passive tags are defined**




## Active and passive tags

Fig 6, shows that the first basic choice when considering a tag is between either passive, semi-passive or active. Passive tags can be read at a distance of up to 4 - 5m using the UHF frequency band, whilst the other types of tags (semi-passive and active) can achieve much greater distances of up to 100m for semi-passive, and several kilometers for Active . This large difference in communication performance can be explained by the following;

- Passive tags use the reader field as a source of energy for the chip and for communication from and to the reader. The available power from the reader field, not only reduces very rapidly with distance ,but is also controlled by strict regulations, resulting in a limited communication distance of 4 - 5m when using the UHF frequency band (860 Mhz - 930 Mhz).

- Semi-Passive (battery assisted backscatter) tags have built in batteries and therefore do not require energy from the reader field to power the chip. This allows them to function with much lower signal power levels, resulting in greater distances of up to 100 meters.

Distance is limited mainly due to the fact that tag does not have an integrated transmitter, and is still obliged to use the reader field to communicate back to the reader.

- Active tags are battery powered devices that have an active transmitter onboard. Unlike passive tags, active tags generate RF energy and apply it to the antenna. This autonomy from the reader means that they can communicate at distances of over several kilometers.

This paper focuses on passive tags. The experience gained by different companies running various trails and evaluations has so far shown, that out of the different RFID frequencies LF,HF,UHF and microwave (see fig 1). HF and UHF are the best suited to the supply chain. Furthermore, it is expected that UHF due to its superior read range, will become the dominant frequency. This does not mean however that LF and microwave will not be used in certain cases.

**Table 3. Comparison of Passive and Active Tags**

<table>
<tr><th></th><th>Advantages</th><th>Disadvantages</th><th>Remarks</th></tr>
<tr><td>Passive</td><td>▪ Longer life time<br>▪ Wider range of form factors<br>▪ Tags are more mechanically flexible<br>▪ Lowest cost</td><td>▪ Distance limited to 4 - 5m (UHF)<br>▪ Strictly controlled by local regulations</td><td>Most widely used in RFID applications.<br>Tags are LF ,HF or UHF</td></tr>
<tr><td>Semi-Passive</td><td rowspan="2">▪ Greater communication distance<br>▪ Can be used to manage other devices like sensors (Temp°, pressure etc)<br>▪ Do not fall under the same strict power regulations imposed on passive devices</td><td rowspan="2">▪ Expensive - due to battery, and tag packaging<br>▪ Reliability - impossible to determine whether a battery is good or bad, particularly in multiple transponder environments.<br>▪ Widespread proliferation of active transponders presents an environmental hazard from potentially toxic chemicals in batteries.</td><td>Used mainly in real time systems to track high value materials or equipment throughout a factory.<br>Tags are UHF</td></tr>
<tr><td>Active</td><td>Used in logistics for tracking of containers on trains, trucks etc..<br>Tags are UHF or microwave</td></tr>
</table>

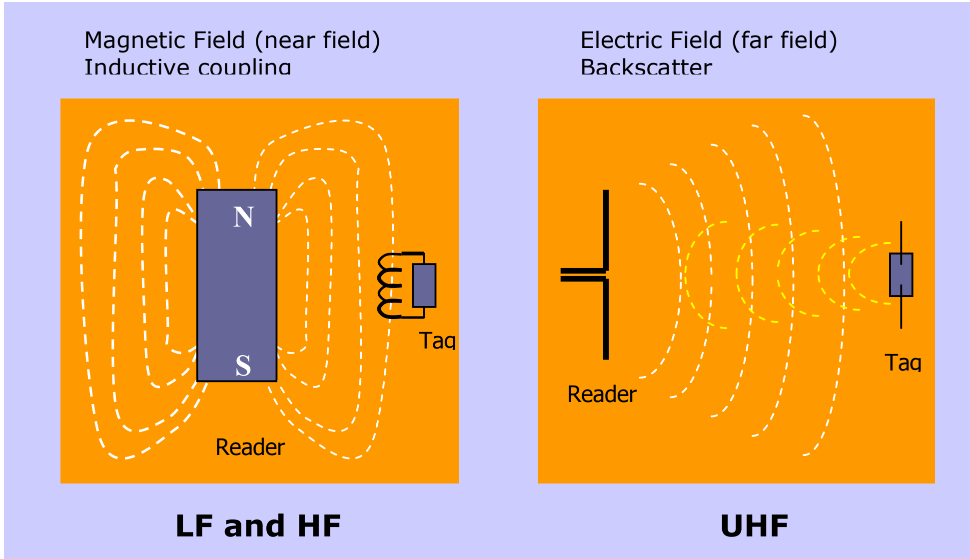
## How tags communicate

### Near and Far fields

In order to receive energy and communicate with a reader, passive tags use one of the two following methods shown in fig 7. These are *near field* which employs inductive coupling of the tag to the magnetic field circulating around the reader antenna (like a transformer), and *far field* which uses similar techniques to radar (backscatter reflection) by coupling with the electric field. The near field is generally used by RFID systems operating in the LF and HF frequency bands, and the far field for longer read range UHF and microwave RFID systems.
The theoretical boundary between the two fields depends on the frequency used, and is in fact directly proportional to $\lambda/2\pi$ where $\lambda$ = wavelength. This gives for example around 3.5 meters for an HF system and 5 cm for UHF , both of which are further reduced when other factors are taken into account. (see Table A-1 Appendix A)

*Note: A more detailed explanation on near and far fields can be found in Appendix A.*

**Fig 7. Two different ways of Energy and information transfer between reader and tag**

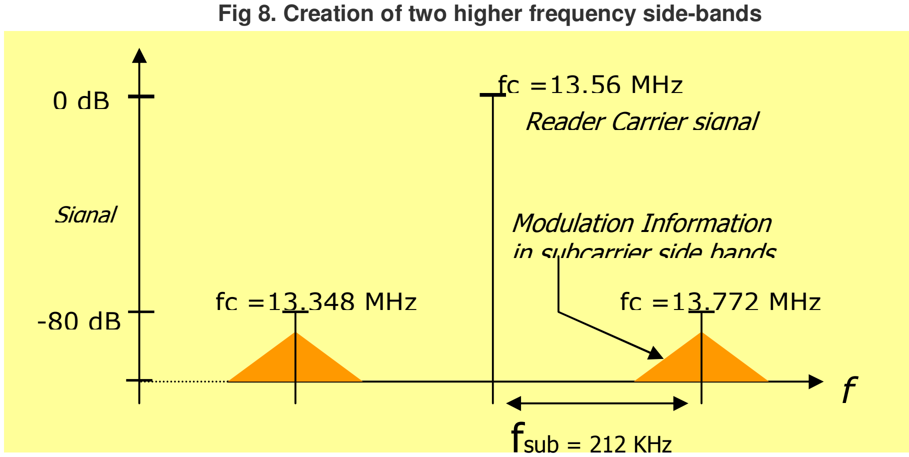



**LF, HF Tags**

Tags at these frequencies use inductive coupling between two coils (reader antenna and tag antenna - see fig 7) in order to supply energy to the tag and send information. The coils themselves are actually tuned LC circuits, which when set to the right frequency (ex; 13.56 MHz), will maximize the energy transfer from reader to tag. The higher the frequency the less turns required (13.56 MHz typically uses 3 to 5 turns). Communication from reader to tag occurs by the reader modulating (changing) its field amplitude in accordance with the digital information to be transmitted (base band signal). The result is the well known technique called AM or Amplitude Modulation. The tags receiver circuit is able to detect the modulated field, and decode the original information from it. However, whilst the reader has the power to transmit and modulate its field, a passive tag does not. How is communication therefore achieved back from tag to reader?.

The answer lies in the inductive coupling. Just as in a transformer when the secondary coil (tag antenna) changes the load and the result is seen in the Primary (reader antenna).The tag chip accomplishes this same effect by changing its antenna impedance via an internal circuit, which is modulated at the same frequency as the reader signal. In fact its a little more complicated than this because, if the information is contained in the same frequency as the reader, then it will be swamped by it, and not easily detected due to the weak coupling between the reader and tag. To solve this problem, the real information is often instead modulated in the side-bands of a higher sub- carrier frequency which is more easily detected by the reader.

**Fig 8. Creation of two higher frequency side-bands**



**UHF tags**

Passive tags operating at the UHF and higher frequencies use similar modulation techniques (AM) as lower frequency tags, and also receive their power from the reader field. What is different however, is the way that energy is transferred, and the design of the antennas required to capture it. We have already mentioned that this is achieved using the *far field* ,which is in fact the region in Electromagnetic Theory where the electric and magnetic field components of a conductor (antenna) break away, and propagate into free space as a combined wave. At this point, there is no further possibility of inductive coupling like in HF systems, because the magnetic field is no longer linked to the antenna. Transmission of this wave in the far field is the basis of all modern radio communication. In some systems such as transmission lines (coaxial cables), the propagation of these waves is restricted as much as possible via special shielding as they constitute a power loss. For antennas its the inverse, propagation is encouraged. When the propagating wave from the reader collides with a tag antenna in the form of a dipole (see fig 7) , part of the energy is absorbed to power the tag and a small part is reflected back to the reader in a technique known as back-scatter. Theory shows that for the optimal energy transfer the length of the dipole must be equal to $\lambda/2$ ,which gives a dimension of around 16 cm. In reality the dipole is made up of two $\lambda/4$ lengths. Deviating from these dimensions can have a serious impact on performance.

Just as for lower frequency tags using near field inductive coupling, a passive UHF tag does not have the power to transmit independently. Communication from tag to reader is achieved by altering the antenna input impedance in time with the data stream to be transmitted. This results in the power reflected back to the reader being changed in time with the data i.e. it is modulated.

From an applications point of view, using the technique of far field back-scatter modulation introduces many problems that are not so prevalent in HF and lower frequency systems. One of the most important of these is due to the fact that the field emitted by the reader is not only reflected by the tag antenna, but also by any objects with dimensions in the order of the wavelength used. These reflected fields, if superimposed on the main reader field can lead to damping and even cancellation.

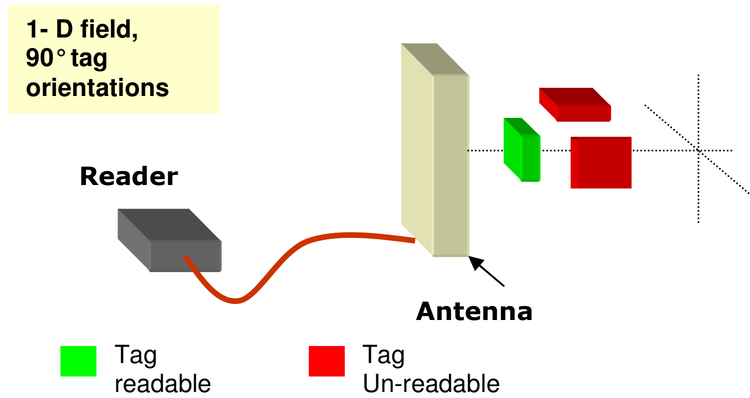
## Tag Orientation (polarization)

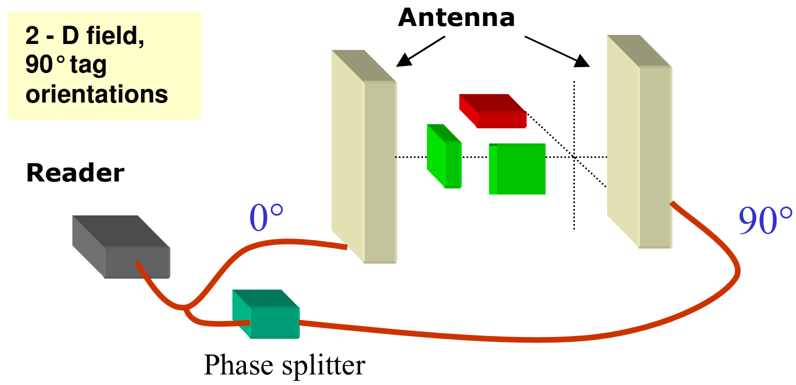
How tags are placed with respect to the polarization of the readers field can have a significant effect on the communication distance for both HF and UHF tags, resulting in a reduced operating range of up to 50%, and in the case of the tag being displaced by 90° (see fig 9), not being able to read the tag . The optimal orientation for HF tags is for the two antenna coils (reader and tag) to be parallel to each other as shown below in fig4. UHF tags are even more sensitive to polarization due to the directional nature of the dipole fields. The problem of polarization can be overcome to a large extent by different techniques implemented either at the reader or tag as shown in table 4 below.

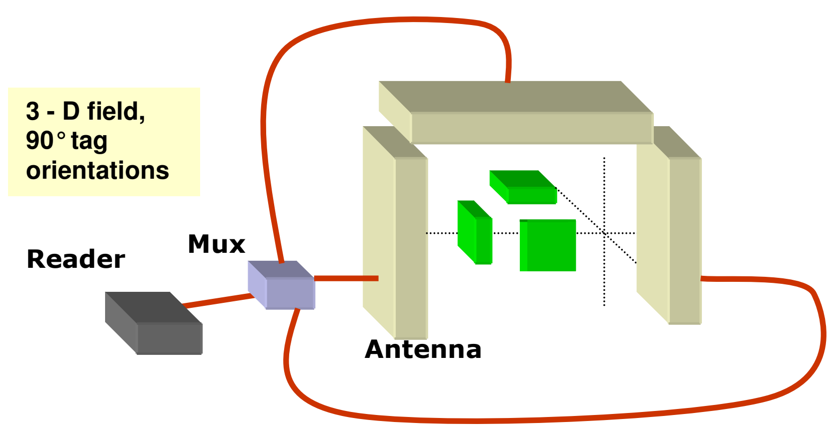
**Table 4. Managing the problem of tag orientation**

| Reader - Antenna | Tag |
|---|---|
| ▪ UHF- Antenna Circular field polarization<br>▪ HF - Antennas physically placed at different locations with in different orientations (XYZ)<br>▪ two antennas 90° out of phase with each other<br>▪ 3D Tunnel readers | ▪ UHF - Two antennas polarized 90° out of phase -eg Matrics double dipole |

Fig 9. HF Tag orientation with different antenna configurations



## Tag standards

A very important aspect of RFID technology, are the associated standards and regulations. They are designed to ensure safe operation with respect to other electrical and radio equipment, and guarantee interoperability between different manufacturers readers and tags. Regulations are mainly concerned with reader power emissions and allocation of frequency bands, whilst standards like the ISO (International Standards Organization) define the Air interface communication between Reader->Tag and Tag->Reader, and include parameters such as;

- Communication protocol
- Signal Modulation types
- Data coding and frames
- Data Transmission rates
- Anti-collision (detection and sorting of many tags in the Reader field at the same time)

The history of RFID standards over the last 10 years has unfortunately been far from ideal ,leading to too many variations and confusion. The situation for the supply chain and Item management is no different due to the two air interface standards currently being proposed by ISO and the EPCglobal (see below). Some initiatives are under way to try and harmonize the two into one global standard, which would certainly be the recommended way to ensure the wide spread adoption, and high volumes of RFID tags within the supply chain.

**Table 5. ISO 18000 -RFID for Item Management - Air Interface**

- 18000 –1 Part 1 – Generic Parameters for Air Interface Communications for Globally Accepted Frequencies
- 18000 – 2 Part 2 – Parameters for Air Interface Communications below 135 KHz
- 18000 – 3 Part 3 – Parameters for Air Interface Communications at 13.56 MHz
- 18000 – 4 Part 4 – Parameters for Air Interface Communications at 2.45 GHz
- 18000 – 5 Part 5 – Parameters for Air Interface Communications at 5.8 GHz
- 18000 – 6 Part 6 - Parameters for Air Interface Communications at 860 – 930 MHz

**Table 6. EPCglobal standards evolution:**

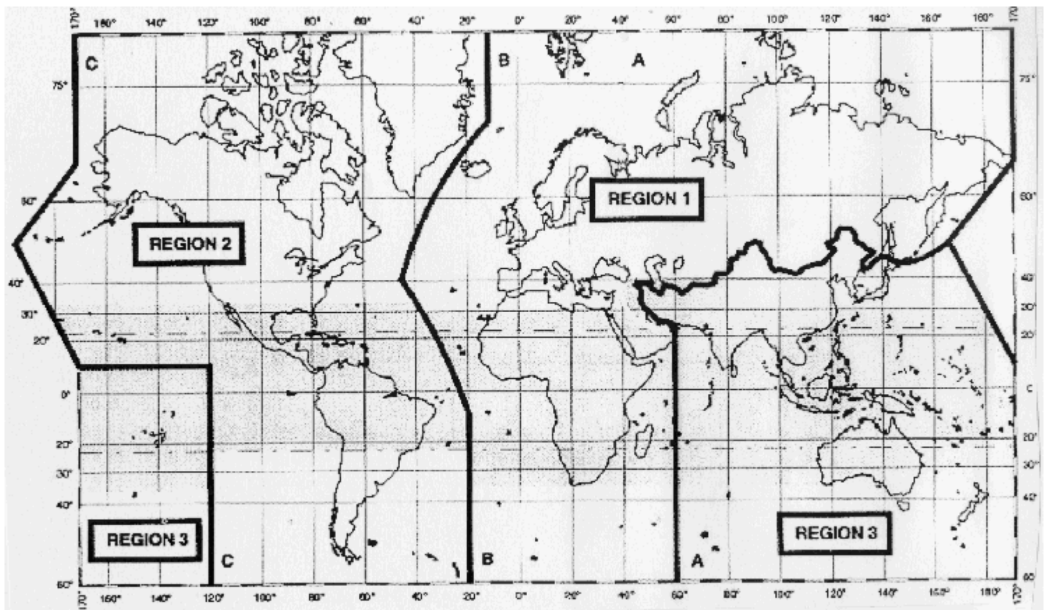
| Protocol | Frequency | Description |
|---|---|---|
| Class 0 | UHF | Read-only, factory programmed |
| → **Class 0 Plus** | **UHF** | Read-write |
| Class 1 | HF, UHF | WORM, (Write-once, read many) |
| → **Class 1, GEN2** | **UHF** | WORM; can be used globally; merges Classes 0 and 1 and some of ISO 18000-6 |
| Class 2 | UHF | A proposed read-write tag |

*Source: RFID Journal Jan 2004 issue*

### Regional Regulations and Frequency Allocation

RFID tags and readers fall under the category of short range devices (SRD's), which although they do not normally require a license, the products themselves are governed by the laws and regulations which vary from country to country. Today, the only globally accepted frequency band is the HF 13.56 MHz. For passive UHF RFID the problem is much more complicated as frequencies allocated in some countries are not allowed in others, due to their proximity to already allocated bands for other devices such as mobile phones and alarms. This discontinuity has resulted in the ITU (International Telecommunications Union) dividing the world into three regulatory regions, these being;

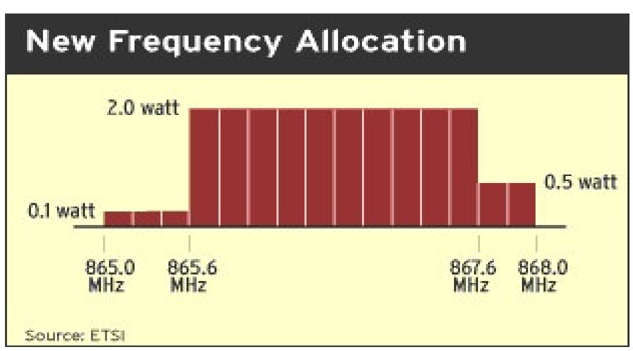
| | |
|---|---|
| **REGION 1:** | **Europe, Middle East, Africa and the former Soviet Union including Siberia** |
| **REGION 2:** | **North and South America and Pacific east of the International Date Line** |
| **REGION 3:** | **Asia, Australia and the Pacific Rim West of the International date line** |




**The main regulatory bodies in the different regions**

REGION 1: In Europe, CEPT (European Conference of Postal and Telecommunications) has the responsibility of frequency assignment and output power.

- For the latest UHF regulations see publication ETSI 302 208-2
  Download: webapp.**etsi**.org/action%5CV/ V20040903/en_**302**20801v010101v.pdf
- Allocated UHF fixed band ( 865 -868 MHz)
- Power emissions limited to 2W ERP for range: 865,6 – 867,6 MHz
- Listen before talk – Reader scans for unoccupied channel before transmitting
- 15 channels available (see diagram below).
- RFID tag communication with 2 Watts ERP (3.28 EIRP) approaches US performance.
- Less efficient in high reader density applications



,

**REGION 2**: In the USA, the Federal Communications Commission (FCC).

- For UHF regulations see the FCC-Part 15 (15.249). which can be found at the following web site: http://www.access.gpo.gov/nara/waisidx_01/47cfr15_01.html
- Allocated UHF band (902-928 MHz)
- Max Power emission 4W EIRP - Frequency Hopping

**REGION 3:** In JAPAN, (MPHPT) Ministry of Public Management, Home Affairs, Posts and Telecommunication.

- Regulation: Japanese Radio Law. Refers to ARIB (Standards Association of Radio Industries and Business
- Japan has only recently announced the allocation of a UHF frequency at 950 MHz

**ERP and EIRP**

These are two reference parameters used to define the permitted radiated power in RF systems . They are often quoted in RFID reader and tag specifications. The US tends to use EIRP and Europe ERP.

The relationship between the two is defined as EIRP = ERP *1.64

More information about ERP and EIRP can be found in Appendix -B-

## RFID Readers

HF Reader


UHF EPC Reader


*Courtesy of SAMSYS*

Readers or interrogators as they are sometimes called, are a key element in any RFID system, and will therefore be part of the product evaluation and selection process. Up until the recent surge in developments for the supply chain and EPC tags, readers were mainly used in access control systems and other low volume RFID applications, which meant that the problem of treating very large numbers of tags and high volumes of data was not such a serious issue. This is now of course all changing, and many reader manufacturers are starting to develop next generation products to handle the application problems that will be specific to the supply chain and EPC infrastructure.

**Main Criteria for readers**

- Operating Frequency (HF or UHF) - some companies are developing Multi-frequency readers

- Protocol Agility - Support for different Tag Protocols (ISO, EPC, proprietary) - Most companies offer Multi- protocol support ,but do not support all !

- Different regional regulations
  - UHF frequency agility 902 – 930 MHz in the US and 869 MHz in Europe
  - Power Regulations: 4 Watts in the US and 500mW in Europe
  - Manage Frequency Hopping in the US and Duty Cycle in Europe

- Networking to host capability:
  - TCP/IP
  - Wireless LAN (802.11)
  - Ethernet LAN ( 10base T)
  - RS 485

- Ability to network many readers together
  - via concentrators
  - via middleware

- Ability to upgrade the reader Firmware in the field
  - via internet
  - via Host interface

- Managing multiple antennas
  - Typically 4 antennas/reader
  - How antennas are polled or multiplexed

- Adapting to antenna conditions
  - Dynamic auto-tuning

- Interface to middleware products

- Digital I/O for external sensors and control circuits

## Handheld Readers

These readers are used for manual intervention where a tag may need to be checked, or even updated off line. Industrial grade products for HF exist today from companies like PSION TEKLOGIX. UHF products do exist, but are mainly either based around commercial PDA devices, which although they function, are not classed as industrial grade products.


*RFID enabled HF Hand Held reader - Courtesy of PSION TEKLOGIX*

## RFID Label Printers

RFID compatible label printers are designed to program data into the paper label-tags, as they pass through the machine for normal printing. The printer has an in built UHF or HF (or both) reader, capable of first running a basic functionality check on the tag, for which if it fails, proceeds to print a visible reject sign on the tags paper surface. Tags will need to have the correct reel format for specific printers. RFID label printers like the one shown from PRINTRONIX below are capable of printing and programming at an average throughput of 1.5 labels/s ,depending on the length of the label.


*Courtesy of PRINTRONIX*

## Reader Antennas

In an RFID system, reader antennas are often the most tricky part to design in. For low power proximity range (< 10cm) HF applications such as access control, antennas tend to be integrated in with the reader. For longer range HF ( 10cm < 1m) or UHF (< 3m) applications, the antenna is nearly always external, and connected at some distance to the reader via a shielded and impedance matched coaxial cable.

**Design**

Whilst antennas may be bought as finished products, it is often the necessary to develop application specific versions. Antenna principles and designs are radically different in LF,HF frequency range than in UHF. In fact its not strictly true to say that inductive coupled systems like HF use antennas, because they work in the near field where there is no EM (Electromagnetic )propagation.

The majority of the RFID antennas need to be tuned to the resonance of the operating frequency. This leaves them prone to many external effects, which can seriously impact the communication distance by de-tuning the antenna. Causes vary depending on the operating frequency and can be due to anything from;

- RF variations
- Skin-effects
- Losses due to metal proximity
- Antenna cabling losses
- Signal fading
- Proximity of other reader antennas
- Environmental variations,
- Harmonic effects
- Interference from other RF sources
- Eddy fields
- Signal reflections
- Cross talk

The problem of antenna de-tuning caused by the effects mentioned above, can be corrected by dynamic auto-tuning circuits which work with feedback from the antennas resonance tuning parameters. This scheme guarantees stability and maximum performance for the selected frequency.

**Performance**

Designing antennas with optimal performance in terms of communication distance will need to take into account the following main parameters;

- Operating frequency range
- Impedance (typically, 50 Ohms)
- Maximum allowed power
- Gain
- Radiation pattern (polarization XY, circular)

These are the key elements which create the RF field strength and field patterns (read zones) which are in turn affected by the efficiency, and type of coupling used (Inductive , Radiation...) between reader and tag.

**Types**

RFID antennas used in Automatic Data Collection (ADC) systems, fall in the following major categories:

- Gate antennas (orthogonal use)
- Patch antennas
- Circular polarized
- Omni directional antennas
- Stick antennas (directional)
- Di-pole or multi-pole antennas
- Linear polarized
- Adaptive, beam-forming or phased-array element antennas

# RFID technology in the Supply chain

## Definition of the Supply Chain.

The supply chain is a complex multi-stage process which involves everything from the procurement of raw materials used to develop products, and their delivery to customers via warehouses and distribution centers . Supply chains exist in both service ,manufacturing and retail organizations. Although, the complexity of the chain may vary greatly from industry to industry and firm to firm. Supply chain management (SCM) can be seen as the supervision of information and finances of these materials, as they move through the different processes, by coordinating and integrating the flows within and among the different companies involved.

The efficiency of the supply chain has a direct impact on the profitability of a company. It is no surprise therefore to find that many large corporate companies have made it a key part of their strategy, and invested heavily in software systems (ERP, WMS..) and IT infrastructure designed to control inventory, track products and manage associated finance.

## How will RFID help improve supply chain efficiency

RFID will bring a new dimension to supply chain management by providing a more efficient way of being able to identify and track items at the various stages throughout the supply chain. It will allow product data to be captured automatically, and therefore be more quickly available for use by other processes such as ASN, stock management and real time billing.

### Comparison of Bar codes and RFID

Bar codes are predominately used today for identifying and tracking products throughout the supply chain. Even though they can achieve efficiencies in the order of 90%, there are still a number of deficiencies in the technology, for which RFID, is able to provide a better solution and further optimization.

| Bar code deficiency | RFID improved solution |
|---|---|
| Line of Sight Technology | Able to Scan and read from different angles and through certain materials |
| Unable to withstand harsh conditions (dust, corrosive), must be clean and not deformed | able to function in much harsher environments |
| No potential for further Technology advancement | Technology advancement possible due to new chip and packaging techniques |
| Can only identify items generically and not as unique objects | EPC code will be able to identify uniquely typically up-to $2^{96}$ items |
| Poor tracking technology, labor intensive and slow | Potential to track items in real time a they move through the supply chain |

## The main benefits of RFID in the supply chain.

Even though RFID applications are still at the early stages of deployment, many companies running pilot systems have been able to demonstrate some of the significant benefits that RFID promises. There is no doubt that more will be discovered as the industry adopts the technology on a wider scale.

The following are examples of what has been identified so far by the different studies and tests/pilots recently completed within the supply chain.

- **Advanced Shipping Notices (ASN)**
  RFID is able to automatically detect when either a pallet or shipment has left the warehouse or Distribution Center. This will allow to not only generate an electronic ASN and notify the recipient, but also to bill clients in real time instead of waiting until the end of the week or month, and doing a batch operation.

- **Shrinkage**
  One of the major problems in the supply chain is product loss or shrinkage, which can account for anything from 2 to 5 % of stock. The causes may vary from misplaced orders, employee and customer theft or inefficient stock management. RFID with its superior tracking and identification capability will be able to localize where losses are occurring.

- **Returned Goods**
  Full visibility and automation can be potentially achieved on returned goods thereby reducing fraud.

- **Anti-counterfeit**
  Illegal duplication and manufacture of high value products, is one of the industries most well known problems. By integrating a tag into items, for example the body of an expensive ladies handbag, RFID has the potential to authenticate a product , and combat the sale of false goods on the black markets.

- **Supply Chain efficiency**
  RFID will enable the traceability and reduction in the number of discrepancies between what a supplier invoiced,  and what a customer actually received.

- **Improved stock management**
  Managing stock is the key priority for many retailers. Studies have shown that on average, products are not on the store shelves 7% of the time due to inefficiencies in stock management, which means of course a potential purchase loss. Implementing RFID at the item level and on shelves will give an automatic way of knowing and managing stock levels. However in order to achieve this on a large scale, it is recognized that tags will have to come down in price to around 5 cents or less, and readers to around 100 USD.

- **Reduction in labor costs**
  At DC 's *(Distribution Centers)* labor accounts for nearly 70% of costs. It is estimated that RFID could reduce this by nearly 30% by removing the need for manual intervention and use of barcodes when loading cases or stocking pallets.

# The EPC ™ – Electronic Product Code

At the heart of the current RFID based technology drive to improve supply chain efficiency and reduce operating costs, is The EPC (Electronic Product Code). Without it and its many giant industrial backers like Wal-Mart, RFID in the supply chain would still be where it was 5 years ago, a technology looking for a business case. The momentum has been tremendous, and has sparked one of the rare technology revolutions where end user companies are in the driving seat.

## EPC Origins

In October 1999 the Auto-ID center was created in the Department of Mechanical Engineering by a number of leading figures at MIT . The potential benefits of RFID tags had been identified long before, what was stopping the adoption of the technology in the supply chain was the cost of the tags. The AutoID recognized that in order to solve this problem, tags needed to be as simple as possible, and act instead as pointers to information held on servers in the same way as information is stored on the internet.

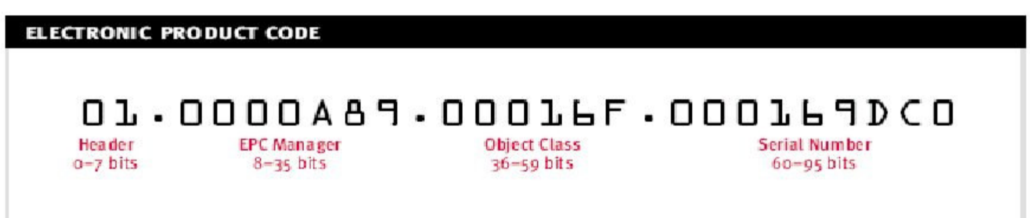
This lead to the idea of the EPC (Electronic Product Code), which would provide fast and detailed information of products anywhere in the supply chain. The goal however, was not to replace bar codes, but rather to create a migration path for companies to move from bar code to RFID.

The Auto-ID Center officially closed on October 26th, 2003. The final board meeting was held in Tokyo, Japan. The Center had completed its work and transferred its technology to EPCglobal (www.epcglobalinc.org), which will administer and develop EPC standards going forward.

## EPC layout

The code is similar to the UPC (Universal Product Code) used in bar codes, and ranges from 64 bits to 256 bits with 4 distinct fields described below in fig 10. .What sets the EPC apart from bar codes is its serial number which allows to distinguish the uniqueness of an item, and track it through the supply chain.

**Fig 10. Layout of an EPC which is 96 bits in length**




- **Header (0- 7) bits**
  The Header is 8 bits, and defines the length of the code in this case O1 indicates an EPC type 1 number which is 96 bits in length. The EPC length ranges from 64 to 256 bits.

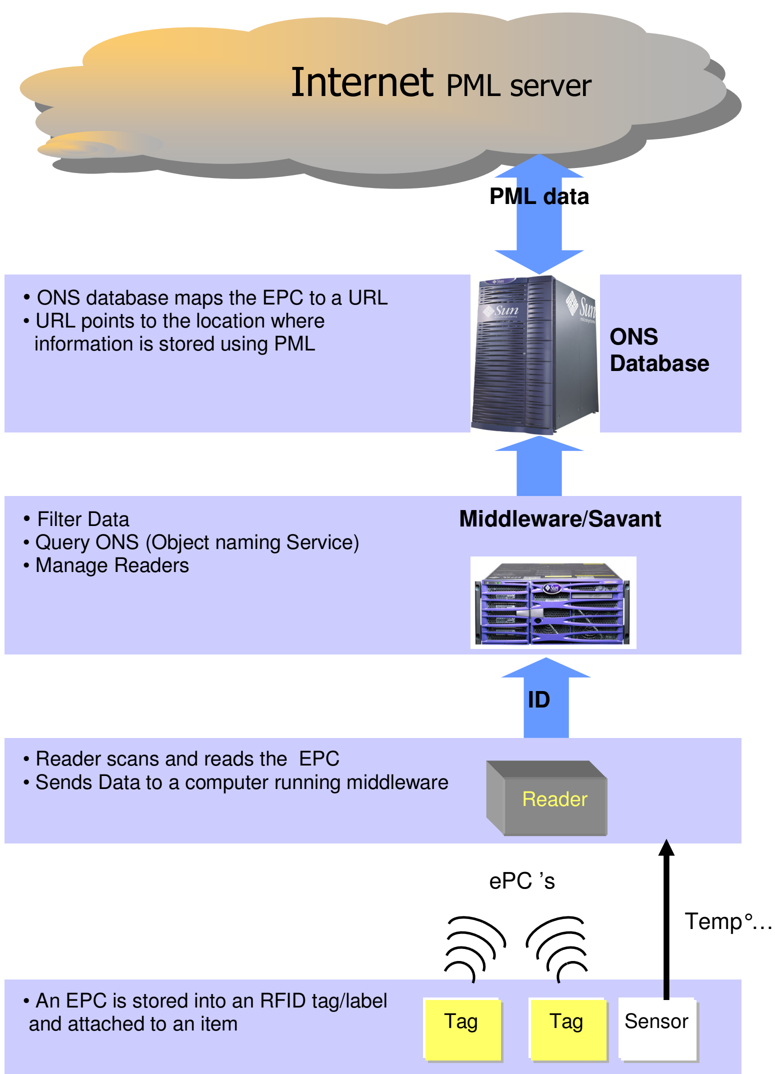
- **EPC manager (8- 35) bits**
  Will typically contain the manufacturer of the Product the EPC tag is attached to

- **Object Class (36-59) bits**
  Refers to the exact type of product in the same way a an SKU (Stock Keeping Unit)

- **Serial Number (60 - 96) bits**
  Provides a unique identifier for up to $2^{96}$ products

## EPC infrastructure

**fig. 11 The basic steps of EPC infrastructure**



EPC infrastructure will allow immediate access to information, which will not only optimize existing services such ASN, but also have the potential to create new services, for example; a retailer could automatically lower prices as the expiry date approaches, or a manufacturer could recall a specific batch of products due to health concerns, and if needed pinpoint the source of the problem down to a unique product.

## Middleware or Savant Software

The sheer potential volume of data created by billions of EPC tags would very quickly grind most existing company's enterprise software and IT infrastructure to a standstill within a matter of minutes. The answer to this problem is middleware or Savants. RFID savants serve as a software buffer which sits almost invisible between the RFID readers, and the servers storing the product information. It allows companies to process relatively unstructured tag data taken from many RFID readers, and direct it to the appropriate information systems. Savants are able to perform many different operations, such as monitor the RFID reader devices, manage false reads, cache data and finally query an Object Naming Service (ONS).

## Object Name Service (ONS)

ONS matches the EPC code to information about the product via a querying mechanism similar to the DNS (Domain Naming system) used in the internet, which is already proven technology capable of handling the volumes data expected in an EPC RFID system. The ONS server provides the IP address of a PML Server that stores information relevant to the EPC.

## Physical Markup Language (PML)

Whilst the EPC is able to identify the individual product, the real useful information is written in a new standard software language called Physical Markup Language. PML itself is based on the widely used and accepted extensible markup language (XML), designed as a document format to exchange data across the internet. It is not surprising therefore that with so much of the infrastructure for EPC being borrowed from the internet (DNS,XML..), it is often referred to as *¨the internet of things¨*.

PML is designed to store any relevant information about a product; for example,

(1) Location information *e.g.*, tag X was detected by reader Y, which is located at loading dock Z;
(2) Telemetry information [Physical properties of an object *e.g.*, its mass; Physical properties of the environment, in which a group of objects is located, *e.g.*, ambient temperature];
(3) Composition information *e.g.*, the composition of an individual logistical unit made up of a pallet, cases and items. The information model will also include the history of the various information elements listed above *e.g.*, a collection of the various single location readings will result in a location trace.
(4) manufacturing and expiry dates

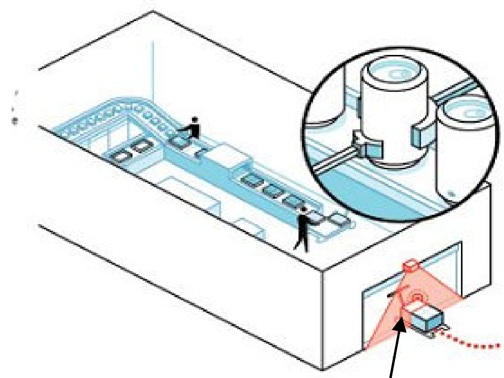
## How the EPC will automate the supply chain *(courtesy of EPCglobal and XPLANE)*

### At the product assembly-packaging line.

**1.**
Each Item contains an RFID tag which has a unique identifier called an EPC stored in its memory.

**2.**
Items can now be automatically and cost-effectively identified, counted and tracked. Cases and pallets can also carry their own unique tags.

**3.**
As pallets leave the manufacturer, an RFID reader positioned at the loading dock door beams a radio wave that ¨ wakes up ¨ the tags.

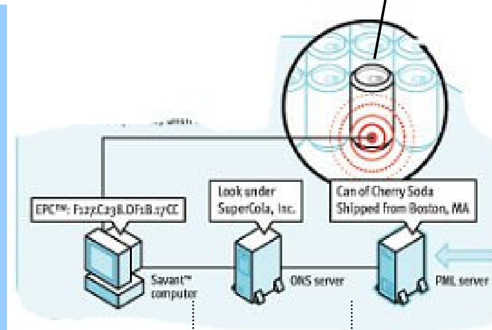


**4.**

a) The Tags communicate their individual EPC’s to the reader, which rapidly switches them on and off in sequence (anti-collision), until all are read.

b) The reader sends the EPC to a computer called Savant ™, which in turn, sends the EPC over the internet to an Object Naming Service (ONS) database, which produces a corresponding address. The ONS matches the EPC to another server (PML), which has the full details about the product.

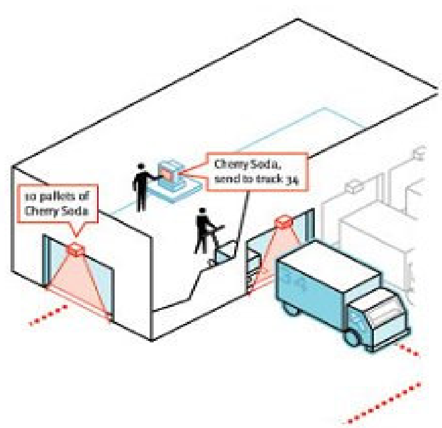
c) The PML (Physical Markup Language) server stores details about the manufacturers products. Because it knows where the product was made, if an accident involving a defect arises, the source of the problem can be tracked and the products immediately recalled.




| Savant Computer | ONS server | PML server |
|---|---|---|
| EPC: Fxyzz3t0nn;4x;CC | Look under Super Cola Inc | Can of Cherry Soda, shipped From Boston,MA |

### 5. At the Distribution Center

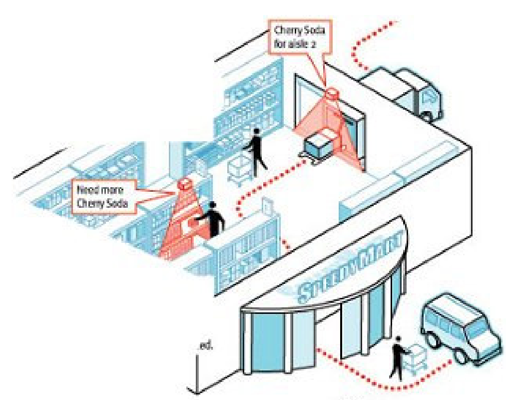
If the unloading area contains an RFID reader, there ‘s no need to open the packages and examine their contents. A SAVANT provides a cargo list, and the pallet is quickly routed to the appropriate truck.




### 6. At the Retail Store

As soon as it arrives , retail systems are updated to include every item. In this way stores can locate their entire inventory automatically, accurately and at low cost.

Reader enabled ¨ smart shelves ¨ can automatically order more product from the system and therefore keep stock to cost-effective and efficient levels.



## Security in RFID Systems

RFID tags used in the supply chain will contain data ranging from simple ID numbers (EPC), to more important information about a product. For example in the health industry, it could be the blood type of a sample. The main goal of any security system designed to protect data stored in mediums such as tags, computer disk drives, or smart cards is basically to prevent any unauthorized person from being able to either;

a) Obtain access and learn the data contents
b) Obtain access and modify/corrupt/erase the data contents
c) Copy the data contents to a similar storage device (duplicate)

In a complete system, security of data as defined above not only involves the storage medium, but also how data is created and transferred from a host to the medium (or vice versa). For example , when an engineer broke the security of a French bank credit card a few years ago, he did it not by compromising the chip security ,but by hacking the reader terminal.

The following are scenarios that could happen in the supply chain.

1) Industrial Sabotage – somebody with a grievance against a company decides to start corrupting data in tags by using a hand held device, and erasing or modifying the contents.

2) Industrial Espionage – A rather unlawful competitor would like to know how many, and what type of products are being manufactured, and shipped by your company. He could possibly achieve this in the following ways

    i. Eavesdropping – listening in on longer range communication systems like UHF which broadcast signals (albeit very weak) up to 100 meters – some protocols have a basic security which ensures that the ID N° is never transmitted completely in one stream.
    ii. Placing bogus well concealed readers linked to a PC somewhere in the proximity of the tags moving through the production line
    iii. Using hand held devices

3) Counterfeiting – Being able to read or intercept data being written into a tag which uniquely identifies or certifies a product. Once the data is known, similar read/write tags could be purchased and updated with the authentic data, thus creating the real possibility of counterfeiting products which are supposed to be protected by a tag.

All the above scenarios are potential risks if no security is implemented in the tag and reader. The importance attached to protecting data in the supply chain will depend on the application, and the company's strategy towards security. In some cases legislation will impose it. Of course bar codes which are used today, can be easily read, decrypted, and even destroyed, but not on the wide-spread and automatic scale possible with RFID.

Even the simplest security costs silicon area, and therefore will impact on the final tag price. This goes against the current trend of trying to produce the smallest and cheapest tag possible. Every company is therefore faced with this tradeoff between cheaper unsecured tags, and the potential security risks they entail.

## Conclusion

The interest in RFID as a solution to optimize further the supply chain is gathering momentum at an ever increasing pace, with more and more companies announcing trials and mandates to their suppliers. The technology is still not yet widely understood or installed in the supply chain, and cost/ROI models far from established. Many companies are therefore now faced with the difficult choice in deciding whether they should be looking at RFID now , or waiting until deployment is more widespread. There is a strong temptation to get carried away by all the hype and publicity surrounding RFID today, which is all the more reason to have a sense of reality as to what it means to integrate RFID, why your company would want to do it, and what would be the acceptable time frames for the perceived benefits.

Investing in RFID on the scale required for the supply chain will be a very costly exercise, and if not managed correctly could lead to unnecessary losses. The technology is not plug_and_play, and will have to be adapted to each application. Furthermore, implementing an infrastructure to support EPC data could have a considerable impact on existing IT systems.

Even at this early stage in the adoption of RFID in the supply chain, there is enough evidence to demonstrate that with the right strategies, RFID will bring benefits. The technology is here to stay and will eventually become widely adopted within the supply chain. Those companies prepared to invest now will not only become the early winners, but also benefit from the experience by being capable of extending the application of RFID into new services

## About the Author.

### *Steve Lewis*

Is the founder of LARAN a company set up to provide professional consulting and marketing services for RFID technology. Qualified with a microelectronics degree from the University of Wales, he has a combined experience of over 20 years in the semi-conductor and RFID industries, having held positions in IC silicon design, product marketing, and business development. He is a veteran of two silicon startups, ES2 and INSIDE Technologies, and has spent the last 8 years working in a wide range of RFID applications and markets including; Vehicle Keyless Entry systems, Access Control, ID and transport.

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Website: www.laranrfid.com

# Appendix –A–

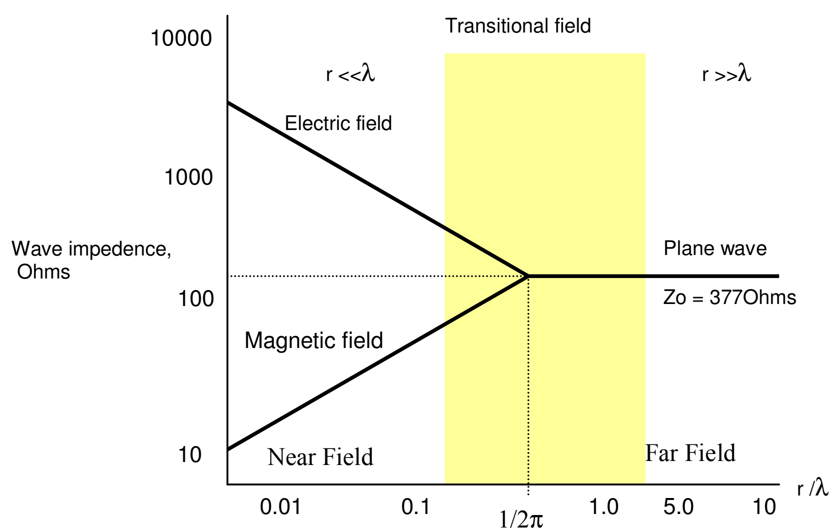
## More about Near and Far fields

Up until recently, nearly all passive RFID systems in production were either LF or HF. Designing systems at these frequencies was based on a few equations relating to inductance , mutual inductance and the knowledge that the magnetic field reduced rapidly with distance ($1/r^3$). With the recent explosion of RFID in the supply chain came the recognition that UHF would allow longer read range, and faster detection of many tags. Engineers used to developing LF and HF systems, are now faced with a completely different concept and set of challenges with UHF.

One of the new concepts encountered when looking at UHF for the first time, is the idea of two distinct and different regions around an antenna called the *near field* and *far field*. Electromagnetic theory developed by Maxwell in the $19^{th}$ century shows that any conductor (e.g. antenna) supplied with an alternating current produces a varying magnetic field (H-field) which in turn, produces Electric Field lines (E-field) in space. This is termed the *near field*.

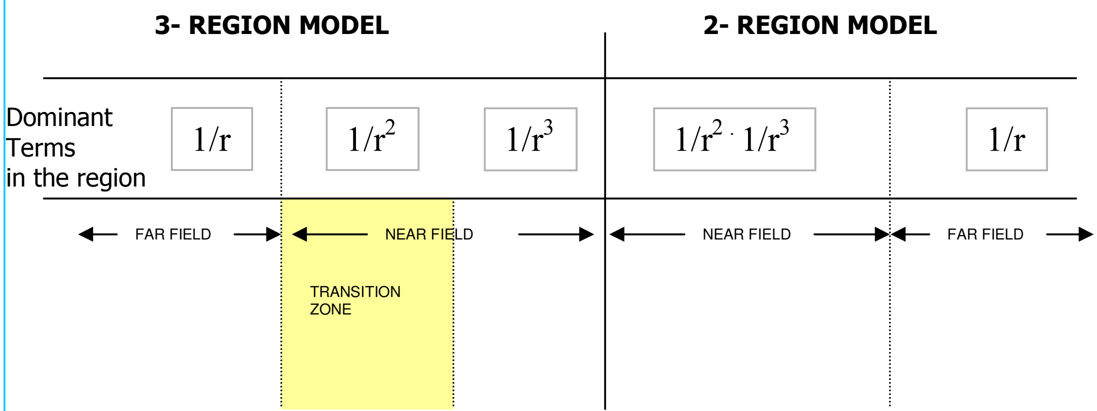
In the near field both the E and H fields are relatively static with no propagation. They only vary in strength as the current varies , with the magnetic flux of the H-field coming out from the antenna, and going back in, and the E-field emanating out-wards. Maxwell also proved that beyond this quasi-static near field, both the E-fields and H-fields at a certain distance, detached themselves from the conductor and propagated into free space as a combined wave, moving at the speed of light with a constant ratio of $E/H = 120\pi$ or $377\Omega$. (Ohms are used because the E-field is measured in volts per meter V/M and the H-field in amps per meter A/M.). The point at which this happens is called the *far field*.

**Fig A-1 Transition region between near and far fields**




Because changes in electromagnetic fields occur gradually, the boundary between the two fields is not exactly defined. The distance at which the two separate out from the source as a fixed plane wave can be modeled in a number of ways. The simpler 2-region model shown in fig A-2 gives a distance of $\lambda/2\pi$ where the fall off is $1/r^3$ (dominant field) and $1/r^2$ in the near field region, and $1/r$ in the far field. The 3-region model is much more complicated with a transition region where components decay as $1/r$, $1/r^2$ and $1/r^3$.

Fig A-2 Different Region models




The distance measure of $\lambda/2\pi$ can be considered as a reference point, where if the tag is in a region much less than 1/20 wavelengths, then we are definitely in the near field. F or distances greater than 5 wavelengths we are definitely in the far field. This is shown in Table A-1

**Table A-1 Near and Far field limits**

| Band | Near Field Region | Far Field Region |
|---|---|---|
| LF | < 120m | >12Km |
| HF | < 1m | >110m |
| UHF | <1.65cm | >1.65m |
| Microwave | <0.25cm | >0.25cm |

Applying some practical sense we can draw the following conclusions for RFID tags

1) At LF ,tags always work in the near field
2) At microwave, tags always work in the far field
3) At HF ,tags work in the near field but some intermediate (transition) field components are effective at antenna emission measurement ranges.
4) At UHF , passive tags operate in the transition field area or the Far field

# APPENDIX – B –

## EIRP and ERP Power Emissions

**EIRP** (Equivalent Isotropic Radiated Power)

EIRP refers to the product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna

*An Isotropic antenna is one which radiates power equally in all directions (e.g a sphere)*

**ERP (Effective Radiated Power)**

ERP refers to the product of the power supplied to the antenna and its gain relative to a half-wave dipole in a given direction.

**EIRP = ERP x 1.64**

**Comment:**

It would make more sense of course to just have one harmonized power term, either ERP or EIRP, however as is often the case with International standards, its not always easy to achieve.

Here is an extract from a recent Bloonston Law Telecom Update from the FCC on this subject.

***ERP/EIRP issues:***
¨Although the Commission recommended in the *2000 Biennial Review Report* that a rule-making proposal be initiated to consider using equivalent isotropically radiated power (EIRP) exclusively in Commission rules, it now tentatively concludes that the costs of implementation and potential for greater confusion that would likely be associated with making a wholesale conversion from effective radiated power (ERP) limits to EIRP limits, outweigh the potential benefits to those licensees who do not possess the scientific or engineering expertise to distinguish between the two standards.

Additionally, the agency states that the conversion from ERP to EIRP is a simple calculation. Such a change in the rules would require extensive modifications, not only for the Commission (*e.g.*, reprogramming the ULS, amending international agreements negotiated in terms of ERP, *etc*.), but also for licensees, frequency coordinators, manufacturers, and others in the wireless industry. Moreover, because an EIRP limit is always a larger number than the equivalent ERP limit, the FCC believes that restating all ERP limits as EIRP limits could likely cause some entities (*e.g.*, licensees, frequency; coordinators, *etc*.) to mistakenly think that the Commission has increased the permitted power ¨