RFID

a week long survey on the technology and its potential

Radio Frequency IDentification

Harnessing Technology Project
Phase I – Research
Interaction Design Institute Ivrea
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This paper was undertaken as part of the *Harnessing Technology* project for Interaction Design Institute Ivrea, in which graduate interaction design students learn how to approach a new technology and how to explore its design opportunities and relevance for interaction design.

In Phase I, research, students are given a week to investigate the past, present, and future of their given technology and produce a report from what they find.

The students responsible for each section follow.

Mario Chiesa	*What is it?*
Ryan Genz	*What is it?*, *Players and Products*
Franziska Heubler	*Players and Products*
Kim Mingo	*What's Happening Today?*, *Market Analysis*, *The Future*
Chris Noessel	*Editing*, *History*, *Patents*, Graphic Overview of History
Natasha Sopieva	*What's Happening Today?*, *Market Analysis*, *the Future*
Dave Slocombe	*Patents*
Jason Tester	*Developer Community*, *Selected Academic Papers*

Contents

RFID—What is it?

Overview

RFID (Radio Frequency Identification) is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit, and is now being seen as a radical means of enhancing data handling processes.

A range of devices and associated systems are available to satisfy an even broader range of applications. Despite this diversity, the principles upon which they are based are quite straight forward, even though the technology and technicalities concerning the way in which they operate can be quite sophisticated.

Physics and Electronic Foundations

System Components

RFID systems have several basic components or technical characteristics that define them. These are:

- A **reader**, including an **antenna**
  The device that is used to read and/or write data to RFID tags.
- A **tag**
  A device that transmits to a reader the data.
- The **communication** between them
  RFID uses a defined radio frequency and protocol to transmit and receive data from tags.

Types of RFID Tags

RFID tags can be segregated into two major classifications by their power source:

- **Active tags**
  Active tags contain both a radio transceiver and battery to power the transceiver. Because there is an onboard radio on the tag, active tags have substantially more range (~300 feet) than passive or “active/passive tags.” Active tags are also considerably more expensive than passive tags and, as with any battery-powered product, the batteries must be replaced periodically.
- **Passive tags**
  Passive tags can be either battery or non-battery operated, as determined by the intended application. Passive tags reflect the RF signal transmitted to them from a reader or transceiver and add information by modulating the reflected signal. A passive tag does not use a battery to boost the energy of the reflected signal. A passive tag may use a battery to maintain memory in the tag or power the electronics that enable the tag to modulate the reflected signal.
  - **Battery-less (“pure passive” or “beam powered”)**
    Pure passive tags do not contain an internal power source such as a battery, and are thus easier, and less expensive to manufacture. These purely passive or

"reflective" tags rely upon the electromagnetic energy radiated by an interrogator to power the RF integrated circuit that makes up the tag itself.

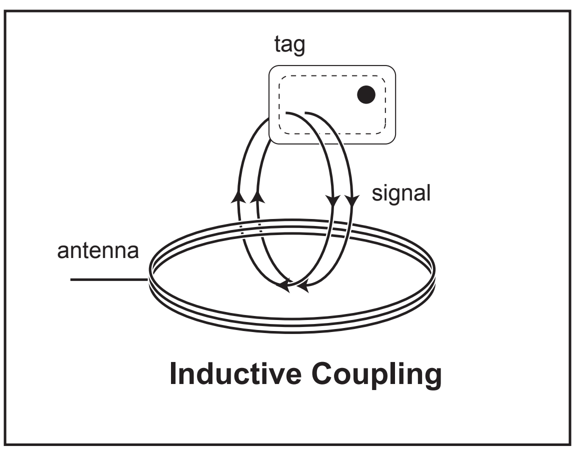
  - **With a battery ("active/passive")**
    There is a version of a passive tag that does contain a battery. This type of passive tag has some of the enhanced, and speed attributes of a true active tag, but still communicates in the same method, as do other passive tags. These active / passive tags that do contain an internal power source, usually are much more complex integrated circuits with multiple components. Consequently, they are more expensive to make and purchase.

RF tags can also be distinguished by their memory type:

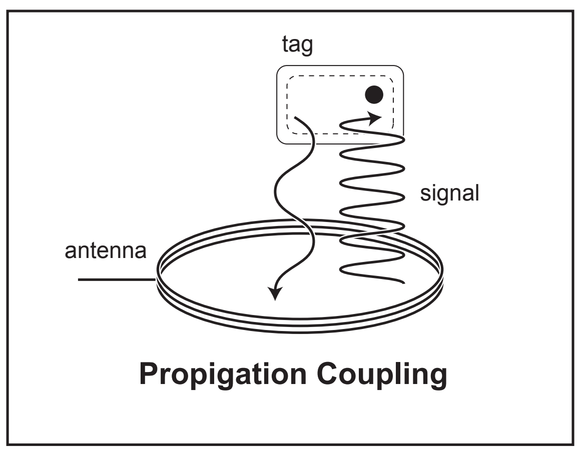
- **Read / write**
  Read / write memory just as the name implies, can be read as well as written into. Its data can be dynamically altered.
- **Read only (typically "chipless")**
  Read only type of tag memory is factory programmed and cannot be altered after the manufacturing process. Its data is static.

Read only memory is the less expensive of the two. As RFID markets and applications grow, this price difference will become less for overall system cost justification.

Types of Communication



Inductive Coupling



Propigation Coupling

Tags and a reader communicate by wireless signal in a process known as *coupling*.

Two methods of wireless signal distinguish and categorise RFID systems:

- Close proximity electromagnetic, or inductive coupling
- Propagating electromagnetic waves.

Coupling is via antenna structures forming an integral feature in both tags and readers.

Transmitted data is influenced by the channels through which it must pass, including the *air interface*. Structuring the bit stream to ensure error-free, asynchronous data transfer through this channel is often referred to as *channel encoding*. Although transparent to the user of an RFID system this coding scheme is important to engineers as often appears in system specifications.

Various encoding schemes can be distinguished, each exhibiting different performance features.

Transferring data efficiently via the air interface requires the data to be superimposed upon a rhythmically varying (sinusoidal) field or carrier wave. This process of superimposition is referred to as *modulation*, and various schemes are available for this purpose. They are essentially based upon changing the value of one of the primary features of an alternating sinusoidal source, its amplitude, frequency or phase in accordance with the data carrying bit stream. In this way it is similar to the way AM or FM radio works.

On this basis one can distinguish amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK).

Radio Frequency and Range

Because RFID uses electromagnetic radio signals to operate, its effective operation is subject to the same physical laws any RF operating device is.

The RF field distance or space between an RFID interrogator antenna and the corresponding RFID tag, and the frequency of operation are directly interrelated.

Thus, different RFID frequencies have different RF effective ranges.
Two terms used often are *near field*, and *far field*.

Frequency Band	Characteristics	Typical Applications
Low 100-500 kHz	Short to medium read range Inexpensive low reading speed	Access control Animal Identification Inventory Control Car immobiliser
Intermediate 10-15 MHz	Short to medium read range Potentially inexpensive medium reading speed	Access control Smart Cards
High 850-950 MHz 2.4-5.8 GHz	Long read range High reading speed Line of sight required Expensive	Railroad car monitoring Toll collection systems

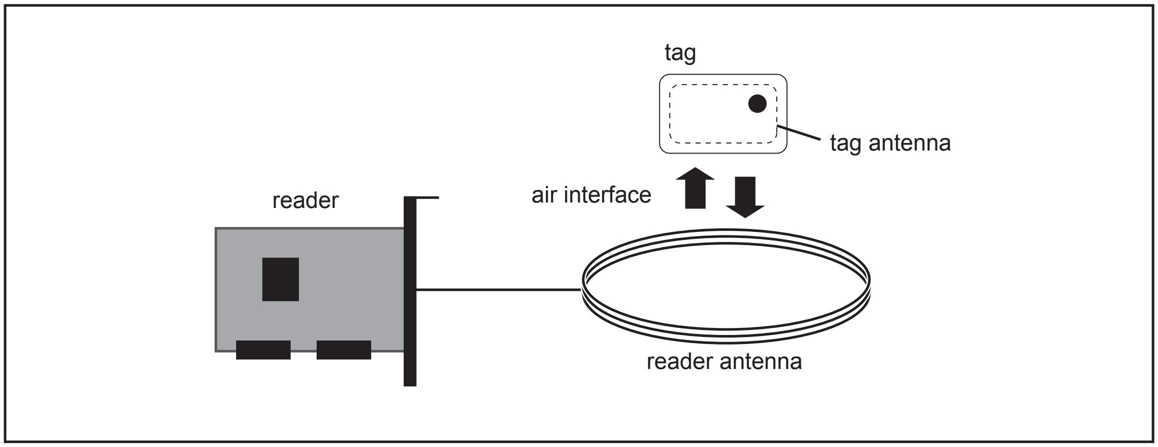
Early in the technology's development, three carrier frequencies were identified and used to refer to different ranges: Low (125kHz), Intermediate (13.56 MHz) and High (2.45 GHz).

Today there are eight frequency bands in use around the world for RFID applications, identified by number and not name. Despite this, many companies still organize their products by low, intermediate, and high range.

The rate of data transfer is influenced primarily by the frequency of carrier wave used to carry the data between the tag and its reader. The higher the frequency the higher the data transfer or throughput rates that can achieved.

The channel bandwidth needs to be at least twice the bit rate required for the application in mind.

A Typical Transmitting Sequence



A typical transmission sequence consists of a system handshake, data modulation, and data encoding.

SYSTEM HANDSHAKE

The typical handshake of a tag and reader is as follows:

- The reader continuously generates an RF carrier sine wave, always watching for modulation to occur. Detected modulation of the field indicates the presence of a tag.
- When a tag enters the RF field generated by the reader, once the tag has received sufficient energy to operate correctly, it begins clocking its data against an output transistor, which is normally connected across coil inputs.
- The tag’s output transistor shunts the coil, in a way which corresponds to the data stored in the memory array.
- Shunting the coil causes a momentary fluctuation (dampening) of the carrier wave, which is seen as a slight change in amplitude (or frequency) of the carrier.
- The reader peak-detects the amplitude-modulated data and processes the resulting bitstream according to the encoding and data modulation methods used.

DATA MODULATION

A modulation is a periodic fluctuation in the amplitude of the Radio Frequency carrier sine wave, which is used to transmit data back from the tag to the reader.

Data are transferred to the host by amplitude-modulating the carrier. For passive RFID tags, it’s called *backscatter modulation*. In this case the RF link behaves essentially as a transformer; as the secondary winding (tag coil) is momentarily shunted, the primary winding (reader coil) experiences a momentary voltage drop.

The reader must peak-detect this data at about 60 dB down (about 100 mV riding on a 100V sine wave). This amplitude-modulation loading of the reader's transmitted field provides a communication path back to the reader. The data bits can then be encoded or further modulated in a number of ways.

Although all the data is transferred to the host by amplitude-modulating the carrier, the actual modulation of 1's and 0's is accomplished with three additional modulation methods:

- Direct
  In direct modulation, the Amplitude Modulation of the backscatter approach is the only modulation used.

- FSK (Frequency Shift Keying)
  This form of modulation uses two different frequencies for data transfer; the most common FSK mode is Fc/8/10. In other words, a '0' is transmitted as an amplitude-modulated clock cycle with period corresponding to the carrier frequency divided by 8, and a '1' is transmitted as an amplitude-modulated clock cycle period corresponding to the carrier frequency divided by 10.

- The amplitude modulation of the carrier thus switches in the bitstream, and the reader has only to count cycles between the peak-detected clock edges to decode the data. FSK allows for a simple reader design, provides very strong noise immunity, but suffers from a lower data rate than some other forms of data modulation.

- PSK (Phase Shift Keying)
  This method of data modulation is similar to FSK, except only one frequency is used, and the shift between 1's and 0's is accomplished by shifting the phase of the backscatter clock by 180 degrees. Two common types of PSK are: Change phase at any '0', or Change phase at any data change (0 to 1 or 1 to 0). PSK provides fairly good noise immunity, a moderately simple reader design, and a faster data rate than FSK.

DATA ENCODING

Data encoding refers to processing or altering the data bitstream in between the time it is retrieved from the RFID chip's data array and its transmission back to the reader. The various encoding algorithms affect error recovery, cost of implementation, bandwidth, synchronization capability, and other aspects of the system design.

For reference, the most used methods are:

- NRZ (Non-Return to Zero) Direct
- Differential Biphase
- Biphase L (Manchester).

There are three implementation issues that may impact technical performance of RFID systems.

Collision

In many existing applications, a single-read RFID tag is sufficient.

In a growing number of new applications, the simultaneous reading of several tags in the same RF field is absolutely critical. In order to read multiple tags simultaneously, the tag and reader must be designed to detect the condition that more than one tag is active.

Otherwise, the tags will all backscatter the carrier at the same time, and the amplitude-modulated waveforms would be garbled. This is referred to as a collision. No data would be transferred to the reader.

The tag/reader interface is similar to a serial bus, even though the “bus” travels through the air. In a wired serial bus application, arbitration is necessary to prevent bus contention. The RFID interface also requires arbitration so that only one tag transmits data over the “bus” at one time.

A number of different methods are in use and in development today for preventing collisions; most are patented or patent pending, but all are related to making sure that only one tag “talks” (backscatters) at any one time.

Transmission

The composition or physical make-up of the item to which the RFID tag will be applied needs to be considered.

This is because different materials can affect RF signals in different ways (reflection, cancellation, and absorption).

There are several materials that can effectively detune an RF signal and degrade its performance. In some applications where this is going to be a known contributing factor, the RFID tag’s antenna can be tuned to allow for the potential material detuning affects.

Site Survey

An RFID site survey should be performed to properly implement an RFID system.

In short an RFID site survey will be used to perform a spectral analysis to determine or confirm that the proposed RFID products / technologies meet the intended “specifications of use”:

The *what* - regarding hardware, software, regulatory, and installation requirements.
The *how* - current and future RFID operational scenarios.
The *who* - customer responsibilities for RFID system implementation.
The *when* – when does the RFID system need to be installed, tested, and working.

History

*The following is taken directly from "*Shrouds of Time, The history of RFID*", a document published by [The Association for Automatic Identification and Data Capture Technologies](). Dr. Jerry Landt of TransCore authored the document with assistance from Barbara Catlin. This is the single most thorough and recent document that was found on the topic.*

For a graphic overview of the information contained in this document combined with other information resources, refer to Appendix III.

Introduction

Many things are hidden in the shrouds of time. The task of tracing history and genealogy is arduous and challenging, but, ultimately, rewarding. Our past can open doors to our future. Whether we realize it or not, RFID (radio frequency identification) is an integral part of our life. RFID increases productivity and convenience. RFID is used for hundreds, if not thousands, of applications such as preventing theft of automobiles, collecting tolls without stopping, managing traffic, gaining entrance to buildings, automating parking, controlling access of vehicles to gated communities, corporate campuses and airports, dispensing goods, providing ski lift access, tracking library books, buying hamburgers, and the growing opportunity to track a wealth of assets in supply chain management.

One can trace the ancestry of RFID back to the beginning of time. Science and religion agree that in the first few moments of creation there was electromagnetic energy. "And God said, 'Let there be light,' and there was light" (Genesis 1). Before light, everything was formless and empty. Before anything else, there was electromagnetic energy.

Scientific thinking summarizes the universe was created in an instant with a Big Bang. Scientists deduce all the four fundamental forces - gravity, electromagnetism, and the strong and weak nuclear forces - were unified. The first form in the universe was electromagnetic energy. During the first few seconds or so of the universe, protons, neutrons and electrons began formation when photons (the quantum element of electromagnetic energy) collided converting energy into mass. The electromagnetic remnant of the Big Bang survives today as a background microwave hiss.

Why is this important, you might wonder? This energy is the source of RFID. It would take more than 14 billion years or so before we came along, discovered how to harness electromagnetic energy in the radio region, and to apply this knowledge to the development of RFID.

The Chinese were probably the first to observe and use magnetic fields in the form of lodestones in the first century BC. Scientific understanding progressed very slowly after that until about the 1600s. From the 1600s to 1800s was an explosion of observational knowledge of electricity, magnetism and optics accompanied by a growing base of mathematically related observations. And, one of the early and well known pioneers of electricity in the 18th Century was Benjamin Franklin.

The 1800s marked the beginning of the fundamental understanding of electromagnetic energy. Michael Faraday, a noted English experimentalist, proposed in 1846 that both light and radio waves are part of electromagnetic energy. In 1864, James Clerk Maxwell, a Scottish physicist, published his theory on electromagnetic fields and concluded that electric and magnetic energy travel in transverse waves that propagate at a speed equal to that of light. Soon after in 1887, Heinrich Rudolf Hertz, German physicist, confirmed Maxwell's electromagnetic theory and produced and studied electromagnetic waves (radio waves), which he showed are long transverse waves that travel at the speed of light and can be reflected, refracted, and polarized like light. Hertz is credited as the first to transmit and receive radio waves, and his demonstrations were followed quickly by Aleksandr Popov in Russia.

In 1896, Guglielmo Marconi demonstrated the successful transmission of radiotelegraphy across the Atlantic, and the world would never be the same. The radio waves of Hertz, Popov and Marconi were made by spark gap which were suited for telegraphy or dots and dashes.

20th Century

In 1906, Ernst F. W. Alexanderson demonstrated the first continuous wave (CW) radio generation and transmission of radio signals. This achievement signals the beginning of modern radio communication, where all aspects of radio waves are controlled.

In the early 20th century, approximately 1922, was considered the birth of radar. The work in radar during World War II was as significant a technical development as the Manhattan Project at Los Alamos Scientific Laboratory, and was critical to the success of the Allies. Radar sends out radio waves for detecting and locating an object by the reflection of the radio waves. This reflection can determine the position and speed of an object. Radar's significance was quickly understood by the military, so many of the early developments were shrouded in secrecy.

Since RFID is the combination of radio broadcast technology and radar, it is not unexpected that the convergence of these two radio disciplines and the thoughts of RFID occurred on the heels of the development of radar.

Genesis of an Idea

There is an old adage that success has many fathers but failure is an orphan. The development of technology is messy. The potential for an infinite number of things is present, yet the broader human choices determine how technology evolves. There's no clear, text book perfect, or logical progression, and often developments ahead of their time are not recognized until later, if ever. So it was with the development of RFID.

An early, if not the first, work exploring RFID is the landmark paper by Harry Stockman, "*Communication by Means of Reflected Power*", Proceedings of the IRE, pp1196-1204, October 1948. Stockman stated then that "Evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored."

Thirty years would pass before Harry's vision would begin to reach fruition. Other developments were needed: the transistor, the integrated circuit, the microprocessor, development of communication networks, changes in ways of doing business. No small task. Like many things, timing is everything, and the success of RFID would have to wait a while.

A lot has happened in the 53 years since Harry Stockman's work. The 1950s were an era of exploration of RFID techniques following technical developments in radio and radar in the 1930s and 1940s. Several technologies related to RFID were being explored such as the long-range transponder systems of "identification, friend or foe" (IFF) for aircraft. Developments of the 1950s include such works as F. L. Vernon's, "*Application of the microwave homodyne*", and D.B. Harris', "*Radio transmission systems with modulatable passive responder*." The wheels of RFID development were turning.

The 1960's through the 1980s: RFID Becomes Reality

The 1960s were the prelude to the RFID explosion of the 1970s. R. F. Harrington studied the electromagnetic theory related to RFID in his papers "*Field measurements using active scatterers*" and "Th*eory of loaded scatterers"* in 1963-1964. Inventors were busy with RFID related inventions such as Robert Richardson's "*Remotely activated radio frequency powered devices*" in 1963, Otto Rittenback's "*Communication by radar beams*" in 1969, J. H. Vogelman's "*Passive data transmission techniques utilizing radar beams*" in 1968 and J. P. Vinding's "*Interrogator-responder identification system*" in 1967.

Commercial activities were beginning in the 1960s. Sensormatic and Checkpoint were founded in the late 1960s. These companies, with others such as Knogo, developed electronic article surveillance (EAS) equipment to counter theft. These types of systems are often use '1-bit' tags – only the presence or absence of a tag could be detected, but the tags could be made inexpensively and provided effective anti-theft measures. These types of systems used either microwave or inductive technology. EAS is arguably the first and most widespread commercial use of RFID.

In the 1970s developers, inventors, companies, academic institutions, and government laboratories were actively working on RFID, and notable advances were being realized at research laboratories and academic institutions such as Los Alamos Scientific Laboratory, Northwestern University, and the Microwave Institute Foundation in Sweden among others. An early and important development was the Los Alamos work that was presented by Alfred Koelle, Steven Depp and Robert Freyman "*Short-range radio-telemetry for electronic identification using modulated backscatter*" in 1975.

Large companies were also developing RFID technology, such as Raytheon's "*Raytag*" in 1973. RCA and Fairchild were active in their pursuits with Richard Klensch of RCA developing an "*Electronic identification system*" in 1975 and F. Sterzer of RCA developing an "*Electronic license plate for motor vehicles*" in 1977. Thomas Meyers and Ashley Leigh of Fairchild also developed a "*Passive encoding microwave transponder*" in 1978.

The Port Authority of New York and New Jersey were also testing systems built by General Electric, Westinghouse, Philips and Glenayre. Results were favorable, but the first commercially successful transportation application of RFID, electronic toll collection, was not yet ready for prime time.

The 1970's were characterized primarily by developmental work. Intended applications were for animal tracking, vehicle tracking, and factory automation. Examples of animal tagging efforts were the microwave systems at Los Alamos and the inductive systems in Europe. Interest in animal tagging was high in Europe. Alfa Laval, Nedap, and others were developing RFID systems.

Transportation efforts included work at Los Alamos and by the International Bridge Turnpike and Tunnel Association (IBTTA) and the United States Federal Highway Administration. The latter two sponsored a conference in 1973 which concluded there was no national interest in developing a standard for electronic vehicle identification. This is an important decision since it would permit a variety of systems to develop, which was good, because RFID technology was in its infancy.

About this time new companies began to surface, such as Identronix, a spin-off from the Los Alamos Scientific Laboratory, and others of the Los Alamos team, myself being one of them, founded Amtech (later acquired by Intermec and recently sold to TransCore) in the 80s. By now, the number of companies, individuals and institutions working on RFID began to multiply. A positive sign. The potential for RFID was becoming obvious.

The 1980s became the decade for full implementation of RFID technology, though interests developed somewhat differently in various parts of the world. The greatest interests in the United States were for transportation, personnel access, and to a lesser extent, for animals. In Europe, the greatest interests were for short-range systems for animals, industrial and business applications, though toll roads in Italy, France, Spain, Portugal, and Norway were equipped with RFID.

In the Americas, the Association of American Railroads and the Container Handling Cooperative Program were active with RFID initiatives. Tests of RFID for collecting tolls had been going on for many years, and the first commercial application began in Europe in 1987 in Norway and was followed quickly in the United States by the Dallas North Turnpike in 1989. Also during this time, the Port Authority of New York and New Jersey began commercial operation of RFID for buses going through the Lincoln Tunnel. RFID was finding a home with electronic toll collection, and new players were arriving daily.

The 1990's

The 1990's were a significant decade for RFID since it saw the wide scale deployment of electronic toll collection in the United States. Important deployments included several innovations in electronic tolling. The world's first open highway electronic tolling system opened in Oklahoma in 1991, where vehicles could pass toll collection points at highway speeds, unimpeded by a toll plaza or barriers and with video cameras for enforcement. The world's first combined toll collection and traffic management system was installed in the Houston area by the Harris County Toll Road Authority in 1992. Also a first was the system installed on the Kansas turnpike using a system based on the Title 21 standard with readers that could also operate with the tags of their neighbor to the south, Oklahoma. The Georgia 400 would follow, upgrading their equipment with readers that could communicate with the new Title 21 tags as well as the existing tags. In fact, these two installations were the first to implement a multi-protocol capability in electronic toll collection applications.

In the Northeastern United States, seven regional toll agencies formed the E-Z Pass Interagency Group (IAG) in 1990 to develop a regionally compatible electronic toll collection system. This system is the model for using a single tag and single billing account per vehicle to access highways of several toll authorities.

Interest was also keen for RFID applications in Europe during the 1990s. Both Microwave and inductive technologies were finding use for toll collection, access control and a wide variety of other applications in commerce.

A new effort underway was the development of the Texas Instruments (TI) TIRIS system, used in many automobiles for control of the starting of the vehicle engine. The Tiris system (and others such as from Mikron - now a part of Philips) developed new applications for dispensing fuel, gaming chips, ski passes, vehicle access, and many other applications.

Additional companies in Europe were becoming active in the RFID race as well with developments including Microdesign, CGA, Alcatel, Bosch and the Philips spin-offs of Combitech, Baumer and Tagmaster. A pan-European standard was needed for tolling applications in Europe, and many of these companies (and others) were at work on the CEN standard for electronic tolling.

Tolling and rail applications were also appearing in many countries including Australia, China, Hong Kong, Philippines, Argentina, Brazil, Mexico, Canada, Japan, Malaysia, Singapore, Thailand, South Korea, South Africa, and Europe.

With the success of electronic toll collection, other advancements followed such as the first multiple use of tags across different business segments. Now, a single tag (with dual or single billing accounts) could be used for electronic toll collection, parking lot access and fare collection, gated community access, and campus access. In the Dallas - Ft. Worth metroplex, a world's first was achieved when a single TollTag® on a vehicle could be used to pay tolls on the North Dallas Tollway, for access and parking payment at the Dallas/Ft. Worth International Airport (one of the world's busiest airports), the nearby Love Field, and several downtown parking garages, as well as access to gated communities and business campuses.

Research and development didn't slow down during the 1990s since new technological developments would expand the functionality of RFID. For the first time, useful microwave Schottky diodes were fabricated on a regular CMOS integrated circuit. This development permitted the construction of microwave RFID tags that contained only a single integrated circuit, a capability previously limited to inductively-coupled RFID transponders. Companies active in this pursuit were IBM (the technology later acquired by Intermec) Micron, and Single Chip Systems (SCS).

With the growing interest of RFID into the item management work and the opportunity for RFID to work along side bar code, it becomes difficult in the later part of this decade to count the number of companies who enter the marketplace. Many have come and gone, many are still here, many have merged, and there are many new players ... it seems almost daily!

Back to the future: The 21st Century

Exciting times await those of us committed to the pursuit of advancements in RFID. Its impact is lauded regularly in mainstream media, with the use of RFID slated to become even more ubiquitous. The growing interest in telematics and mobile commerce will bring RFID even closer to the consumer. Recently, the Federal Communications Commission (FCC) allocated spectrum in the 5.9 GHz band for a vast expansion of intelligent transportation systems with many new applications and services proposed. But, the equipment required to accommodate these new applications and services will necessitate more RFID advancements.

As we create our future, and it is bright, let us remember, "Nothing great was ever achieved without enthusiasm" (Ralph Waldo Emerson). We have a great many developments to look forward to, history continues to teach us that.

Patents

The following are ten early patents related to RFID and their abstracts on file with the United States Patent Office.

Transponder apparatus and system

1970

US PN 3,713,148

Abstract: A novel transponder apparatus and system is disclosed, the system being of the general type wherein a base station transmits an “interrogation” signal to a remote transponder, the transponder responding with an “answerback” transmission. The transponder includes a changeable or writeable memory, and means responsive to the transmitted interrogation signal for processing the signal and for selectively writing data into or reading data out from the memory. The transponder then transmits an answerback signal from the data read-out from its internal memory, which signal may be interpreted at the base station. In the preferred inventive embodiment, the transponder generates its own operating power from the transmitted interrogation signal, such that the transponder apparatus is self-contained.

Remotely powered transponder

1971

US PN 3,745,569

Abstract: A transponder having a circuit for the extraction of power from an incident interrogating beam of electromagnetic energy, the extracted power being utilized to operate a digital coding circuit. The transponder further comprises an oscillator circuit for developing a train of pulses of electromagnetic energy with successive pulses occurring in a coded format in accordance with a digital code imparted by the digital coding circuit. The transponder is of sufficiently small size to be affixed in the form of a tag to automobiles, personnel, containers and other objects to be identified. The electronic tag communicates with an interrogation system.

Remotely powered transponder having a dipole antenna array

1973

US PN 3,852,755

Abstract: A transponder having a novel circuit for the extraction of power from an incident interrogating beam of electromagnetic energy, the extracted power being utilized to operate a digital coding circuit. The transponder further
an oscillator circuit for developing a train of pulses occurring in a coded format in accordance with a digital code imparted by the digital coding circuit. The transponder is of sufficiently small size to be affixed in the form of a tag to be affixed automobiles, personnel, containers and other objects to be identified. An interrogation system for utilizing the electronic tag is also disclosed.

Electronic license plate for motor vehicles

1974

US PN 4,001,822

An electronic license tag or plate formed into a unitary structure and including a single antenna system cooperating in a system comprising a harmonic radiator which transmits a pulse coded identification signal in response to an interrogation signal, and in a signal communication path for detecting and decoding code modulations in the interrogation signal and deriving therefrom an information signal which is communicated to the operator of a vehicle to which the tag or plate is affixed.

Passive encoding microwave transponder

1976

US PN 4,068,232

A passive transponder which provides remote identification of objects including cargo and trailers, vehicles or a variety of objects which move through an interrogator beam. The passive transponder is mounted onto the vehicle or object or at the location to be identified. A transmitted beam from the interrogator is directed to the transponder. Some of the beam's energy is rectified and used to power digital electronic circuitry within the transponder which generates a signal with a serially-coded digital waveform. This signal amplitude modulates a harmonic generator in the transponder which produces and emits harmonic energy derived from the incident beam from the interrogator. This harmonic energy is readily identified by an interrogator receiver which is tuned to that harmonic of the incident signal. The transponder information from the interrogator receiver is decoded in the interrogator data processor to provide the desired identification number. An internal clock frequency is generated within the passive transponder as a result of transmitted energy from the interrogator beam, and this clock determines the read-out rate of the encoded data from a field programmable read-only memory.

Identification system using coded passive transponders

1977

US PN 4,096,477

Abstract: An identification system including a transmitter, a receiver, a decoding subsystem, and a passive transponder identifier. One passive transponder identifier of the invention is a surface acoustic wave device provided with pad means for applying and removing pressure on a substrate of the device at preselected locations. A second identifier of the invention is a microacoustic shear bulk wave device. The passive transponder identifiers are programmed to produce a characteristic coded electronic reply in response to an electromagnetic signal interrogation.

Passive transponder apparatus for use in an interrogator-responder system

1978

US PN 4,114,151

Abstract: A passive transponder for use in an interrogator-responder communication system is disclosed, including a first signal receiving element having a variable reflection property, a code signal generator for supplying a code signal, a modulating device responsive to the code signal for varying the signal reflection property of the first signal receiving element, and a power supply for supplying direct-current operating power to the code signal generator and to the modulating device, the power supply including a second signal receiving element for receiving a second electromagnetic signal having a second frequency different from the first frequency, and an a-c to d-c converter for converting the second signal to direct-current power.

Electronic detection and identification system

US PN 4,123,754

1978

Abstract: An electronic detection and identification system for use in the rapid identification of vehicles at a toll stop, and like uses, is provided which employs an electronic identification card that is carried by the vehicle to be identified and a fixed transmitter-receiver unit that transmits a signal to the card and receives a reflected signal therefrom. The card contains passive resonant circuitry for producing an output signal having a frequency which is a selected harmonic of the signal transmitted thereto. In operation, the card is radiated with a signal which has a freqency in the Gigahertz range and which is produced by frequency sweeping and multiplying a frequency stable RF signal. The signal reflected by the card is narrow band-filtered and RF amplitude (envelope) detected. The detection envelope, which is the "signature" of the received signals, is compared with a reference profile to determine whether a match exists. An appropriate action, such as the generation of a "go" signal, is initiated based on the results of the comparison.

Electronic identification system

1980

US PN 4,242,663

Abstract: An electronic identification system includes common transceiver and signal processing apparatus, and relative small electronic circuitry, referred to as a "tag", secured to each item of a population to be identified. Each tag is assigned a multi-bit digital code which may or may not be unique. The common equipment determines whether any desired tag-bearing item is nearby by emitting a phase modulated radio frequency wave embodying the requisite tag code, and examining the output of a homodyne mixer, operating on a radar-like recovered reflection signal, for a predetermined signatory response. Such a response will be generated only by a tag circuit responding to a match between its stored encoding and that of the interrogation signal by changing the effective cross sectional reflecting area of the tag antenna.

Apparatus and method for an electronic identification, actuation and recording system

1982

US PN 4,345,146

Abstract: Dispensing of commodities such as bulk liquids, gases, granules and powders is monitored electronically by identifying receivers of the commodities with specific codes and relating those codes to amounts dispensed by commodity dispensers. The specific apparatus includes a passive module attached to the commodity receiver and a reader linked to the commodity dispenser by radio transmitter or hard-wired. The passive module includes a planar member therein with a code thereon in form of a pattern of conductive and non-conductive areas, the particular organization of which determines the code identifying a particular commodity receiver. The reader includes: an array composed of pairs of opposed inductors for alignment with the conductive and non-conductive areas; a multiplexer for indexing the pairs of opposed inductors to determine if an area is conductive or non-conductive, and a transmitter for relaying the code to the commodity dispenser. The commodity dispenser includes a signal receiver for coordinating the identity of the commodity receiver with the amount of commodity dispensed. The apparatus has a specific application in controlling and monitoring the dispensing of fuel to fleet vehicles.

Electronic identification system

1982

US PN 4,354,099

Abstract: An electronic identification system for reading a pre-defined identifier code. A preferred application provides a credit card sized "identifier" which includes an array of electrical inductors, some of which are electrically connected in a selected pattern to define the identifier code. The identifier may be positioned closely proximate to a substantially identical inductor array included in a "reader" so that each identifier inductor is centered over a corresponding reader inductor. An alternating current is applied to each reader inductor in turn to induce an electromagnetic field in the region surrounding the driven inductor. The electromagnetic field so produced induces a voltage across the identifier inductor centered over the driven reader inductor. If that identifier inductor is electrically connected to another identifier inductor(s) a current will flow in the other inductor(s) and a second electromagnetic field will be generated in the region(s) surrounding the connected inductor(s). The second electromagnetic field induces a voltage across reader inductor(s) centered under the connected inductor(s). Each reader inductor is separately sensed. If a current output signal is sensed at reader inductor(s) other than the driven inductor, it may be assumed that identifier inductor(s) corresponding to the driven inductor and to the reader inductor(s) at which an output signal is sensed have been electrically connected. A master control device may thus determine the identifier code by noting those identifier inductors which are electrically connected.

What's Happening Today?

Current Application Areas

The main features of radio frequency tagging are ability to identify objects without a clear line of sight between tag and reader, read/write capability, and cluster reading.

- **Identification without visual contact**
  People, items, and cartons can be identified even if material comes between the reader and the tag.
- **Read/write**
  Unlike barcode identification technology, certain RFID tags can store data, allowing system designers to place "handling codes" directly on the object as it travels through a system.
- **Cluster reading**
  Specially-designed readers can read many tags at once, increasing the throughput of automated accounting procedures.

These features determine the applications of RFID technology in every industry, commerce and service where data needs to be collected. The three principle areas of application are:

- Transportation and Distribution
- Manufacturing and Processing
- Security and Law Enforcement

Secondary areas of application, some of which are steadily growing in terms of application numbers, include:

- Animal tagging
- Waste management
- Time and attendance
- Postal tracking
- Airline baggage reconciliation
- Road toll management

Some specific applications include:

- Electronic article surveillance - clothing retail outlets being typical.
- Protection of valuable equipment against theft, unauthorised removal or asset management.
- Controlled access to vehicles, parking areas and fuel facilities - depot facilities being typical.
- Automated toll collection for roads and bridges
- Controlled access of personnel to secure or hazardous locations.
- Time and attendance - to replace conventional *slot card* time keeping systems.

- Animal husbandry - for identification in support of individualised feeding programmes.
- Automatic identification of tools in numerically controlled machines - to facilitate condition monitoring of tools, for use in managing tool usage and minimising waste due to excessive machine tool wear.
- Identification of product variants and process control in flexible manufacture systems.
- Sport time recording
- Electronic monitoring of criminal offenders at home
- Vehicle anti-theft systems and car immobiliser

Specific examples of RFID applications

Following selected examples illustrate the applications above.

TRANSPORTATION/DISTRIBUTION

RFID systems are uniquely suited for use in the rigorous rail environment. Field-programmable tags permit the industry standard, 12-character identification of each car by type, ownership and serial number. Tags are attached to the vehicle undercarriage; antennae are installed between or adjacent to the tracks, and readers or display devices are typically located within 40 to 100 feet in a wayside hut along with other control and communications equipment. A primary objective in rail applications is the improved fleet utilization that permits reductions in fleet size and/or deferral of investment in new equipment.

Commercial truckers are using RFID systems to monitor access and egress from terminal facilities. Combined with weigh-in-motion scales, the same systems can be used for transaction recording at refuse dumps, recycling plants, mines and similar operations, or for credit transactions at truck stops or service depots.

INDUSTRIAL

In the plant environment, RF systems are ideally suited for the identification of high-unit-value products moving through a tough assembly process (e.g., automobile or agricultural equipment production where the product is cleaned, bathed, painted and baked). RF systems also offer the durability essential for permanent identification of captive product carriers such as:

- Tote boxes, containers, barrels, tubs, and pallets;
- Tool carriers, monorail and power, and free conveyor trolleys;
- Lift trucks, towline carts, automatic guided vehicles.

Primary applications fall into two basic categories:

- Direct product identification wherein the tag specifically identifies the item to which it is attached (e.g., by part number or serial number or, in the case of read/write systems, assembly or process instructions for the item).

- Carrier identification where content is identified manually (or with a bar code reader) and fed to the control system along with the carrier's machine-readable RF “license plate number.” Strategically deployed RF readers accomplish subsequent load tracking.

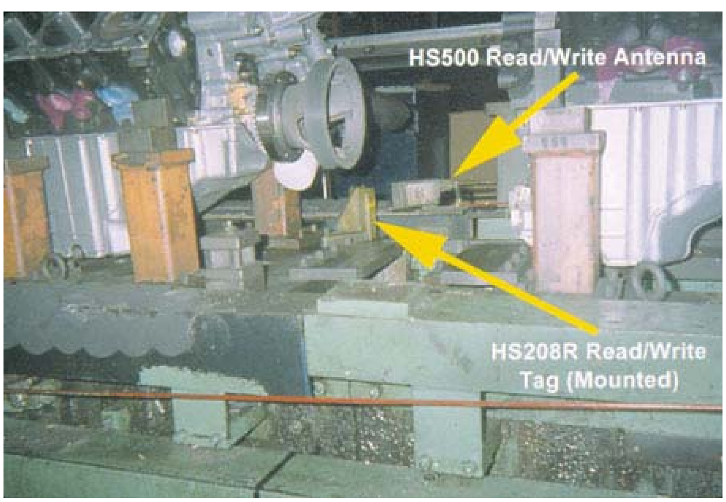
The automotive industry uses RFID systems to track vehicles through assembly, where tags must perform even after repeated subjection to temperatures of 150 to 200 C, painting, etc. A primary objective for use of the technology in this environment is verification of vehicle identity prior to execution of given assembly tasks. Although manufacturers sequentially track vehicles through assembly, undetected removal of a single vehicle from the line could be costly.

Because RFID tags do not need to be seen to be read, they can be buried within pallets, tote boxes, and other containers and provide solid performance for the life of the carrier. As an example, in a casting operation RF tags are attached to wire baskets which travel through a variety of degreasing, etching and cleaning tanks by means of an overhead power and free conveyor - not a job for optical or magnetic identification media.

In a manner similar to carrier identification, RF tags can be used for tool management. Miniature tags can be placed within tool heads of various types such as block or Cat V-flange, or even within items such as drill bits where individual bits can be read and selected by reader guided robot arms.

RFID systems are used for lift truck and guided vehicle identification in a number of installations. One approach buries tags at strategic locations throughout the facility and verifies vehicle location via on-board DC-powered readers. Other users station readers at the ends of warehouse aisles to monitor lift truck activity. Here, throughput rates permit multiplexing multiple antennae per reader.

Ford Motor Co. is using RFID tags to streamline its Essex engine plant in Windsor, ON.



At Ford’s Essex plant in Windsor, Ontario, Escort Memory Systems tags carry all instructions needed to assemble each engine, as well as all test data accumulated during manufacturing.

Supply Chain Systems Magazine
http://www.idsystems.com/reader/1999_05/less0599/index.htm

SECURITY AND ACCESS CONTROL

The movement and use of valuable equipment and personnel resources can be monitored through RF tags attached to tools, computers, etc. or embedded in credit-card-size security badges. This type of monitoring also provides an extra measure of security for personnel working in high risk areas in case of an emergency evacuation.

Nuclear Plant System

The U.S. Department of Energy's Pacific Northwest National Laboratory in Richland, Washington, is developing the Self-Diagnostic Monitoring System with the aim of improving the situation for plant operators. A monitoring system prototype uses radio-frequency tags to communicate performance data in nuclear power plant systems.

Frontline Solutions, February 2001
http://www.frontlinemagazine.com/rfidonline/

Airport Security

Extremely dense traffic of vehicles, people and goods, combined with high security requirements and timing with aeroplanes make low frequency, short-range RFID solutions unfeasible.

When parcel trams need to urgently pass through doors to the runway area, a high-frequency personnel tag on the driver and readers at the gate make extremely efficient access control possible.

When waiters serving both the airside and landside restaurants from the same kitchen need to conveniently pass through doors with their trays, a hands free system with a tag under the clothes and readers in the ceiling makes it possible to keep the doors locked. No violators can slip through the kitchen between airside and landside.

Utility vehicles passing between different security zones want fast access, and need to be registered for security. Tags on the vehicles and readers at the barriers / gates permits quick, yet secure access control. Extra security is obtained if the RFID system can read and verify grouped tags, where a driver tag and a vehicle tag are used next to each other.

The AIM Global Network
http://www.aimglobal.org/technologies/rfid/casestudy/airportsecurity.htm

- **RFID tags send selected bags to an explosive detection system at SeaTac International Airport.**
  Northwest Airlines has installed the first full-time RFID operation for sorting airline passenger bags and is using it to absolutely guarantee that bags marked for enhanced security screening get the attention they warrant (Seattle-Tacoma (SeaTac) International Airport).

CHECKED BAGGAGE passes under RFID scanners at Northwest Airlines' Seattle-Tacoma facility. Any suspicious bag is tagged and pushed off this conveyor belt by diverters (seen in the middle of the photo) and transported to an explosive detection system. The view is through the second, fail-safe set of RFID readers, looking upstream toward conveyors and deflector. Photo courtesy of SCS Corp.

Supply Chain System Magazine
http://www.idsystems.com/reader/2000_02/this0200/index.htm

- **RFID tags attached to valves and pipework allow error-free identification**
  An oil and gas refinery in the UK is using asset management system based on radio frequency identification (RFID) tagging to capture information on pressure safety relief valves in major vessels, pipework and process equipment. More than 80 valves are inspected and re-certified as being fit for use. The system was developed by Oasis (Inverurie, UK) and is based on an Intrinsically Safe (IS) tag reader for use in the hazardous and hostile environments typical for offshore oil and gas platforms, refineries and petrochemical processing.

  Frontline Solutions, February 2001
  http://www.frontlinemagazine.com/rfidonline/

- **RFID-identification of waste bins**
  Minec Systems AB (www.minec.com) has supplied a data collection and transfer solution using Memor2000 hand-held terminals to identify barcoded or RFID (Radio Frequency IDentification) transponder-marked waste bins or skips. Memory in the Hitag 2 transponders selected for this project is partitioned into two sections. The read-only section is permanently programmed by the manufacturer with a unique code which cannot be duplicated, modified or erased. This provides a high degree of security. The read and write memory partition is programmed with a customer and or bin number for accurate identification, which facilitates the generation of correct billing information.

  The AIM Global Network
  http://www.aimglobal.org/technologies/rfid/casestudy/minec-botek.htm

- **Security Access and Convenience for Express Parcel Couriers**
  FedEx couriers use an automatic keyless vehicle entry and ignition system that has RFID transponders embedded within a Velcro wristband.

  The FedEx system uses RFID readers mounted at each of the four doors to the delivery vehicle and a reader mounted on the right side of the steering column near the ignition switch. When the courier places his transponder wristband within 6 inches of the readers, the transponder's code is compared to ones in the system's memory. If it is a match, the door unlocks for five seconds. The courier simply pulls on the door handle to enter the vehicle while the three remaining doors stay securely locked to prevent unauthorized entry. To start the vehicle, the courier pushes a button on the right side of the steering column. The courier pushes another button near the start button to turn off the vehicle.

All exterior door locks can be released from the inside with conveniently located buttons. A fail-safe keyed lock is maintained for the rear roll-up door in case of an electrical failure. Anti-theft features include motion detectors in both the courier and cargo compartments, and a self-contained horn. The system is programmed to ensure that the vehicle will not start until all doors are shut, and all doors automatically lock within five seconds of opening. Each FedEx vehicle is programmed using a master transponder, and can accept up to ten unique transponders. A single transponder can also be programmed to operate multiple trucks.

Texas Instruments Inc. (TIRIS Group)
http://www.ti.com/tiris/default.htm

ANIMAL IDENTIFICATION

A common use for RFID tags is in livestock and animal control. A device resembling a large hypodermic needle inserts a tag encased in a minuscule glass capsule (about 4x30 mm) under the skin of an animal's neck. The tag holds the animal's identity and perhaps additional information, such as vaccination records. To identify the animal and to store or retrieve information about it, handlers only need to "scan" the animal with a handheld device within a distance of about 3 ft.

EDN Access
http://archives.e-insite.net/archives/ednmag/reg/1994/122294/26dfcov.htm

Image from http://www.beitec.com/penguin.htm

AUTOMATED LIBRARY SYSTEMS

Integration of RFID technology into information systems comes from outside traditional supply chain disciplines. RFID technology has found a home in the nation's libraries This integration speeds up the processing of library materials by providing a swift one step motion for issuing books, eliminating the need to locate and scan a barcode.

Simultaneously, the library's circulation system is automatically updated, and the security is disabled in the software.

It allows for automated checkout and check-in, patron self checkout, built-in security, circulation management, and highly efficient inventory, all integrated into one system.

CHECKPOINT SYSTEMS

Checkpoint's RF technology is a standard for source tagging. It is used for product tagging so that security component is invisible to the consumer.

RF technology is used by all types of retailers, including supermarkets, mass merchandisers, apparel stores, department stores, drug stores, sporting goods stores, automotive stores, and hardware stores for theft protection.

For tamper-proof security, RF tags can be incorporated into retail tickets.

An RF-EAS security tag, sandwiched between the branding and tracking components, is invisible to the customer.

www.checkpointsystems.com

TOLL ROAD CONTROL

The goal in toll road control systems is to electronically identify vehicles passing a toll station and to debit their accounts automatically for using the toll road without impeding traffic flow.

A variety of different toll road systems are under development around the world, most probably with 80 different manufactures at present. In the next couple of years many different authorities are introducing such systems on a trial basis. The major difficulty in having a national system is the lack of a national standard, as each manufacturer develops its own solution. The railroad tracking company, Amtech, have for a long time been operating their own toll road to develop their technology. In most of the previous applications, RFID technologies are used in closed solutions. That is, the same manufacturer supplies the transponder and the reader. For toll roads, although many users use the same stretch of road everyday, many only occasionally use that road and therefore they are not likely to have transponders fitted. Many users might pass toll locations of different companies that operate with different transponder protocols requiring them to have numerous different transponders fitted.

In these systems, as the vehicles will be passing at high speed, and as the size and shape of the vehicles differ between manufacturers, a reading range of 4 meters minimum is required. Ideally, reading speed should be high. This implies that the toll road system will need an electric field coupled system, operating at between 900 MHz and 5800 MHz. Transponders are usually mounted in the front window of the vehicle. As of April 1997 it is estimated that there are more than 1.8million toll road transponders already in use.

HEALTHCARE

The healthcare industry is beginning to use RFID labels and tags to track supplies and pharmaceuticals, including their expiration dates, as well as portable diagnostic equipment shared between departments. This enables healthcare institutions to better control inventory and maximize their equipment to keep costs down, while delivering the highest level of patient care.

DIGITAL CARD MAIL

Omron Corporation and Towa Printing Co. Ltd. headquartered in Osaka have agreed to market a newly developed *Exhibition-Visitor Management System*. Under the agreement Omron Corporation, a leading RFID tag supplier will supply the RFID tags, tag readers, and other system equipment. Towa Printing will produce the final Digital Cards to be used for the gathering and management of visitor information at exhibitions.

Digital Card Mail contains both digital data (in IC chip) and visual analog data (text and illustrations), and is presented in the form of a post card. This new system will allow information stored on the card to be sent to the recipient at economical direct mail prices using the existing postal service.

The new Digital Card Mail System simplifies the exhibition entry process and quickly and easily collects and analyzes customer demographics at each booth to provide a total customer information management system.
www.omron.com

TOY INDUSTRY

Toy designers can use lower cost and lower range RF tags to add proximity behaviors to their products. Such systems require a larger, less mobile part of the toy, which in turn is connected to the PC via a USB port, or via a longer range communications links.

For example, when an army action figure is placed inside a fort, the PC will be able to adjust its associated audio and video presentations accordingly.

INTEL: Emerging Trends in Home Computing. PC Enhanced Toys. *A vision for tomorrow*

Market Analysis

There have been a number of market analysis reports created for the RFID and Auto Identification Systems, proving that there is a growing awareness in the field of RFID products and applications. Many of these reports carry a high price tag, indicating that they are seen as valuable information for companies considering the employment of such technology in different application areas. Unable to purchase these expensive reports, the authors carefully studied the available sources, such as a brief report conducted by Venture Development Corporation (VDC) on the growth of RFID technology and implementation from 2000 to 2005.

At present there is no monopoly on RFID innovations, but it is agreed that there is an overall growth in the adoption of RFID. This growth is uneven across economic and vertical markets. Some obstacles include the ability to prove that RFID can be successfully sold and implemented as complete solutions, which would imply cost justification. Another obstacle is the lack of industry and application standards, due to a highly fragmented, competitive environment.

These obstacles are not uncommon to immature technologies, and it is believed that RFID will make enormous advancements in the next 5 years. Currently many vendors are working hard to eliminate these obstacles by creating new partner and standardization initiatives and expanded products lines. End user adoption of RFID technology is key to the growth of RFID

Global Market

Venture Development Corporation (VDC) estimated that in the year 2000 the global market for RFID systems has grown to $900 million in supplier revenue. One of the most significant advancements of RFID in 2000 was in the number of people who began to actually use it. There is proof of many organizations that have been running trials on RFID implementation and many who have really began using it. Most of these implementations are found in the areas of security access control and transportation.

Over the next five years demand will increase based on the understanding of the benefits and greater end user awareness of RFID technology in more consumer based applications. The market is prepared at present to sustain a 24% annual growth rate, which is currently a higher rate than any other auto ID technology according to a study done by VDC.

Regional Markets

Although rate of adoption and level of user acceptance of RFID systems is more advanced in Europe or the Asian Pacific markets, regional studies prove that America benefited from revenues which constitute approximately 48% of the global market. Europe-Middle East-Africa netted 35% and Asia Pacific netted 17% of the market.

The annual growth of the Asian Pacific markets is expected to be greatest due to the small base of RFID systems implementations, and the expansion of many suppliers into this region. In order to make this a reality, suppliers in this market have been building strategic partnerships and upgrading their distribution channels to include experienced RFID integrations.

Economic Sectors

The top three fastest growing RFID economic sectors has been identified (in order) as:

- Retail services
- Commercial services
- Health care services.

When the research was conducted in 2000, RFID hardware shipment revenues were highest among manufacturing, transportation, distributions, and warehousing organizations.

Radio Frequency Spectrum Allocations and RFID standards

One of the biggest obstacles in RFID systems implementation is the allocation of the worldwide radio frequency spectrum, as each country controls its own spectrum allocation. There are currently no worldwide standards, and even Europe, which appears to have a unified system, is controlled by each country of the European Union. Because of this individual control, and the fact that the radio frequency spectrum, a finite resource, is controlled and allocated very carefully, it is difficult to find new spectrum allocations for RFID applications. This also hinders international ease-of-use.

It is also crucial the RFID systems comply with the rules and regulations of the radio frequency spectrum. This means that RFID should not interfere with existing radio frequencies including radio, television, mobile radio devices, and emergency radio services. As a result, the RFID industry is extremely restricted by the availability of operating frequencies for new RFID systems.

To date, very few standards exist for RFID technologies, something very common for immature technologies. Over the last few years there has been a growing interest and focus on the development of these standards. The success of RFID highly depends on such agreement of standards. These standards initiatives attempt to lower the cost of the raw material of RFID, and to enhance widespread adoption and use. International standardization would mean the elimination of duplicate efforts and conflicting systems in markets that will clearly be connected as the world becomes increasingly connected through travel and mobile technologies.

Sources

Venture Development Corporation
Global Market and Applications For Radio Frequency Identification
http://www.vdc-corp.com/autoid/reports/01/br01-23.html
http://www.trimedia.philips.com/markets/identification/

Developer Community

The RFID industry currently can't be said to support a *developer* community, like those communities that exist for programming languages or prototyping tools, as much as an *implementer* community. RFID technology, in its current form, allows for two levels of involvement.

The first level is that of the scientists and engineers working to continually make tagging technology cheaper and smaller. The other level consists of mid- or high-level company managers that want to implement or already have implemented RFID technology in their businesses for inventory tracking and asset management. As for communities for RFID scientists & engineers, there exist the expected high-level forums for scientists to share as-yet-unapplied new developments. RFID engineers, however, work for companies that are trying to distinguish themselves from their competitors, which leaves little room for publicly sharing new developments. This leaves any solid RFID community to businesspeople that are excited by the proven potential of RF tagging but also recognize that the technology is relatively new out of the lab.

Resources

There are a number of resources aimed at these decision makers to help them understand the potential of RF technology and how to implement it in their business. However, since RFID is a lucrative & growing market with many players, some of these resources are not as free of bias as a potential implementer would prefer.

Publications

Two major magazines for information include *Frontline Solutions* and *Supply Chain Systems*. Both cover RFID as one solution to the larger issue of inventory control and asset management & security. The latter magazine also features a "buyer's guide" to the many companies in the RFID marketplace. Publications more specifically focused on RFID include the RFID Newsletter from AIM (a global trade organization for the automatic identification and data capture (AIDC) industry), *Global ID* magazine, newsletters from the RFID group at Texas Instruments, and a website called *Transponder News*.

- Frontline Solutions magazine
  http://www.frontlinetoday.com/
- Supply Chain Systems magazine
  http://www.idsystems.com/
- RFID Newsletter (AIM)
  http://www.aimglobal.org/technologies/rfid/
- Global ID magazine
  http://www.global-id-magazine.com/
- Texas Instruments RFID news
  http://www.ti.com/tiris/
- Transponder News
  http://rapidttp.com/transponder/

Conferences

There are also several conferences to help inform potential RFID implementors and give them a chance to see and test various RFID implementations. These conferences include many RFID vendors but also representatives from companies and government organizations who are there to share success stories after incorporating RFID into their infrastructure.

- *Frontline Solutions* magazine sponsors conferences of the same name in the US and Europe focused on "supply chain IT solutions in manufacturing, warehousing, logistics, and field service." The US conference in 2001 included a breakout subsection called the RFID Summit, a daylong event dedicated to RFID technology. The Summit advertised itself as spanning RFID from understanding the very basics to selecting the right company and implementation for one's particular business needs.

  Frontline Solutions conference
  http://www.frontlineexpo.com/

- AIM sponsored its first RFID Implementation conference in 2002. The conference promised that companies interested in RFID "will be able to increase their competitive advantage through the reduction in costs and increases in operational efficiency." Sessions at this 3-day event had names such as "RFID Frequency and Standards: HF or UHF – which way should you go?" and "Employing RFID to Replace or Supplement an Existing Bar Code System." The conference also followed the typical format of mixing successful case studies along with topics geared to help the corporate manager choose the right RFID system for their organization's needs.

RFID Implementation conference
http://www.aimglobal.org/memberpressreleases/jan02/RFID_Conf_Feb_2002.pdf

- Billing itself as the world's largest conference on low-cost RFID, the *SmartLabels US* conference is being held in March 2002. In contrast to other RFID conferences, the SmartLabels conference has somewhat more of a focus on relatively low-cost, flexible tags; the conference's subtitle is "A conference on smart labels, tickets and cards." There are the usual sessions on case studies and understanding various products, but this conference also includes one day more focused on technical innovations and future potential breakthroughs in low-cost, small, and flexible RFID tags. These sessions included "The realisation of Ultra Low Cost Smart Labels in 2002" and "The Hitachi Mu chip: the smallest RFID chip in the world." The conference is run by *IDTechEx*, an RFID consultancy focused on low-cost tags that publishes the monthly web journal *Smart Labels Analyst* and produces industry reports for sale.

SmartLabels 2002 USA
http://www.idtechex.com/conference.html

Players and Products

The major players for RFID tag technologies are the most influential companies bringing products to market. The major companies that are considered here are Texas Instruments, Phillips Semiconductors, Intermec, Gemplus (Tagsys), and Hitachi. The last company considered in this paper is the only manufacturer of iButtons, Dallas Semiconductor.

In the RF tag market the major companies are primarily competing for market of products that operate in the three main frequencies: low (125 kHz), intermediate (13.56 MHz), and High (2.45 GHz) also known as UHF. Additionally, Texas Instruments is creating a hybrid tag that transmits on one frequency and receives on another.

Texas Instruments

Texas Instruments, the self-proclaimed "leading supplier of the broadest range of RFID products in the industry" started in the RFID market with a division called TIRIS (Texas Instruments Registration and Identification System) creating products for animal identification in the early nineties and later became a major player in electronic toll collection via RFID. In January 2001, TIRIS renamed to TI-RFID.

The current lineup of Texas Instruments products follows.

Series	**Size/shape**	**Bits**	**Frequency**	**Read distance**	**Read/write**
Glass Capsule Series	23mm or 32mm	64 – 1360	Low	3 – 5 feet	Read or Read/write
Compact Series	Little plastic wedge	64 or 48	Low	8 inches	Read or Read/write
Disk Series	1 inch disk with hole	64 or 48	Low	2 feet	Read or Read/write
Badge and Card Series	Credit card size	64 (read only) 80 (read/write) 1360 (multi-page)	Low	3 feet	Read or Read/write
Low Profile Series	3.5 inch diameter, 0.25 inch thick (for windshield)	?	UHF/LUHF (?)	5 feet	Read or Read/write
Vehicle and Container Series	10cm cylinder	60, 80, 1360	UHF/LUHF (?)	7 feet or 4 feet	Read or Read/write
Tag-It RFID	1.8 inch square label or 1.8x3 inch label	256 (in 8x32 bit blocks)	13.56mHz	?	Read or Read/write
LUHF system	?	?	LUHF	8 feet	Read or Read/write

Some Texas Instruments products use an interesting two-frequency system called *LUHF* for communication where the tag uses the 134.2kHz downlink but a 903mHz uplink. This system is capable of employing a challenge/response system for authentication where more security is required.

Also notable in the Texas Instruments lineup of is the Tag-it RFID series of products. These tags are very low cost, thin enough to be laminated between sheets of paper, and the same reader can read multiple tags simultaneously.

Texas instruments also make a full range of readers for their line of tags.

Philips Semiconductor

Philips Semiconductor entered into the RFID tag market when it purchased Mikron Integrated Microelectronics, a company who specialized in RFID technology since 1982. Since then Philips has also teamed with Intermec and Gemplus to be able to produce RFID tags in several different frequencies. They claim to make tags in “all three frequency ranges”. They also claim to be the only semiconductor manufacturer able to do this, underscoring the fact that while other companies can offer a full range of products they are not manufacturing their own integrated circuits for the product.

These strategic partnerships are helping Philips to create international standards that will position them well in the market. For example, they are currently developing a proposal for an international RFID tag protocol known as the Global Tag (GTAG™). This protocol allows readers to operate with large numbers of tags and rapid transactions. It may be an important step toward developing markets where multiple vendors can create components that will work together in the same system.

According to Philips:

> “The common protocol specified in these two proposals meets the demands of a wide range of applications within the supply chain management market. Supporting large populations of tags and rapid transactions with multiple tags in a dynamic environment, it is suited to products that offer optimized performance and operating ranges for different regulatory requirements worldwide.
>
> …
>
> Standardization of UHF smart label technology in all markets means that manufacturers will be able to build RFID systems that combine components from more than one vendor. Thanks to this interoperability, a reader constructed by one manufacturer will be able to decode smart labels made by any other manufacturer.”
>
> http://www.semiconductors.philips.com/markets/identification/articles/articles/a14/index.html

An overview of the Philips Semiconductor product line follows.

Series	Size/shape	Bits	Frequency	Read distance	Read/write	Read Time	Battery
HITAG 1	Credit Card size	2048	125 kHz	1000mm	Read/write	20 mS	N

HITAG 2	Credit Card size	256	125 kHz	?	?	?	N
ICODE	Low cost plastic or paper label	384 w/64 bit ID	12.56 mHz	?	?	?	N

Intermec Technologies

Probably the oldest player in the RFID industry is Intermec Technologies. Intermec has been purchased and is currently a subdivision of Unova but was originally founded in 1966. The company was the purchaser of critical technology for being able to create microwave RFID tags that contained only a single integrated circuit from IBM.

Intermec has been successful at creating a number of strategic partnerships in it’s history. At one time they owned Amtech and are currently in a strategic partnership with Philips and Gemplus. Currently their company focuses on portable computing devices, wireless communication and tagging technologies.

An overview of the Intermec RFID product line follows.

Series	**Size/shape**	**Bits**	**Frequency**	**Read distance**	**Read/write**
915 MHz Tag for RPC	Reusable Plastic Containers 8mm (LWH) (3.3 x .75 x .31 in)	1024	915 MHz	45 m	Read/write
2450 MHz Metal Mount Tag	Metal Mount Tag (LWH) 82 x 10 x 8 mm (3.2 x .4 x .3 in)	1024	2450 MHz	100 cm	Read/write and Rewrite
2450 MHz Meander RFID Label	Meander RFID Label ?	?	2450 MHz	?	Multiple Read/write
2450 MHz Dipole RFID Label	Dipole RFID labels ?	?	2450 MHz	?	Read/write

TagSys (formerly Gemplus)

TagSys is the recently created name for the company that was formerly known as Gemplus. TagSys sells itself as a leading provider of smart cards and focuses it’s RFID production on this market. The Company offers memory cards and microprocessor smart cards, smart contactless cards, electronic tags, smart objects and magnetic stripe cards to simplify and secure a wide range of applications.

An overview of the TagSys product line follows.

Series	Size/shape	Bits	Frequency	Read distance	Read/write
Ario™ Industrial Smart Labels	Varies. Designed to withstand harsh industrial environments	80, 128, and 256	13.56 MHz	Varies according to label size and type	Read and Read/write
Ario™ Garment Tag Ario 10 SL	17mm x 17mm (.68 x .68 inches)	64	13.56 MHz	30 cm	Read/write and Rewrite
Ario™ Garment Tag Ario 40 SL	17mm x 17mm (.68 x .68 inches)	128	13.56 MHz	25 cm	Read/write and Rewrite
Ario™ Garment Tag Ario 20 SL	17mm x 17mm (.68 x .68 inches)	2 kB	13.56 MHz	15 cm	Read/write and Rewrite

Hitachi

Hitachi is a recent entry into the RFID industry by developing the world's smallest, cheapest RFID integrated circuit chip called the *Mu-Chip.* This chip is 0.5 square millimeters in size, small enough to be embedded in paper, and sells for under U.S. $0.20.

Series	Size/shape	Bits	Frequency	Read distance	Read/write
Mu-Chip with on-chip antenna	0.4 mm^2	128	2.45 GHz	1 cm	Read
Mu-Chip with off-chip antenna	0.5 mm^2	128	2.45 GHz	25cm – 1 m	Read

Dallas Semiconductor

Dallas Semiconductor Corporation founded in 1984. The Company is wholly owned subsidiary of Maxim Integrated Products. They design, manufacture, and market electronic chip and chip-based subsystems. They produce a diverse list of different products in electronics field. For the context of this report we are interested in them as the only providers of the iButton product.

The iButton is a small silicon chip encased in a steel enclosure about the size of a coin. It can receive and transmit data through this steel shell as a contact interface. Because it is encased in steel, it is very strong and survives many different environmental conditions.

iButton is read by a variety of differently-shaped readers to function in different markets. Each form factor must be snapped into a reader before it can be read.

The iButton come is marketed in three types.

1. The “Memory iButton” works as a digital storage device with a variety of different memory types. The most basic has 64bits of data that is an unalterable unique ID number. Examples of features on other buttons include up to 4k of re-programmable memory, another with memory split into three secure password protected areas to act as three keys, and yet another with a built in clock that can track the number of hours and times when it is being accessed.
2. The second series is the “Java Powered Cryptographic iButton”. This is a button with larger memory that contains “a microprocessor and high-speed arithmetic accelerator generate the large numbers needed to encrypt and decrypt information.” All of which runs a Java Virtual Machine, to operate a challenge/response security system.
3. The third series is the “Thermochron iButton”, which constantly tracks temperature and time and date and stores this data in the button for later retrieval. This particular product is aimed at industries like food distribution where temperature is important for insuring freshness of goods.

These tags are all competing for similar markets and it should be noted that there are a list of other technologies that may also be used in similar applications that may very soon be mature enough to compete in the same market areas.

For reference, these technologies include:

- Biometric Identification
- Contact Memory
- Machine Vision
- Magnetic Ink Character Recognition (MICR)
- Optical Character Recognition (OCR)
- Optical Mark Recognition (OMR)
- Voice

The Future

Due to new emerging possibilities that come with RFID and Internet connectivity, RFID has celebrated a renewed interest and resurgence in the market. RFID has moved past the limited market of manufacturing logistics and security access, and gained acceptance in the consumer market with such applications as automatic toll payments and fueling applications. Research into future visions for RFID technology, showed however, that although the market is rapidly growing, there is a limited number of compelling future visions for RFID systems. In fact, based on a study conducted by Venture Development Corporation (VDC), it is agreed among many industry players that a killer application has yet to be defined for RFID.

With the exception of the extension of current applications such as e commerce and tracking, there is little "blue sky" thinking going on in the field of RFID implementation. The most interesting and visionary thinking of RFID implementation is currently being conducted by Xerox PARC, some telecommunications companies such as Nokia, and MIT's Auto ID Group who is currently funded by a number of large companies such as Coca Cola, Johnson & Johnson, Pfizer, UPS, Wal-Mart, Intel, NCR Corporation, and Philips Semiconductors.

This involvement of large corporations and key players indicates that there is an agreement that RFID technology does have the potential of becoming a very prominent technology with some strategic thinking and innovative applications.

Obstacles and challenges for the vision

There are of course obstacles in the development, implementation and acceptance of RFID, as is the case with any immature technology. These obstacles include standardization, cost, and privacy/ethical issues.

Standardization

To date there has been no standardization set for the implementation of RFID, though some efforts are underway. There are two areas that require attention when discussing RFID standardization. They are the allocation of the radio spectrum and the standardization of RFID communication systems. Standardization of the RF spectrum allocation is a difficult task to accomplish, as each country owns and controls it's own radio spectrum, the means of communication for RFID systems. As the radio frequency use changes constantly, each of these countries individually has to consider the allocation of the spectrum based on their particular needs. Simultaneously, the manufacturers of RFID systems have also avoided creating a standard, as they each rush to develop competing products. As RFID implies infrastructures and networks, it is crucial to the future of RFID that the issue of standardisations is considered carefully. In the past few years there has been a renewed effort to explore and come to an agreement of RFID standards.

Cost

In order for adoption of RFID to become ubiquitous, the cost needs to be low enough that it is a viable solution for both small and large businesses. This means both a reduction in the hardware costs, as well as (again) the standardization of systems, eliminating duplicate efforts, conflicting systems, and eventually more costly development. Currently, the Auto ID group is working to make the technology cost efficient through researching both hardware and systems integration to promise a greater return on investment for companies interested in RFID technology.

However, these are clearly the visions of cost for the future, while today's reality is very different. The ability to reach Auto ID Center's goal of a 5 cent RFID tag is questionable according to some current research in RFID smart tag manufacturing. Supply Chains Systems magazine January 2002 issue states that for a million smart labels today you'll pay about 75 cents or a dollar each, depending on tag size and capability. The path to the development of a 50 or 40-cent tag, is clear, whereas the 5-cent tag timeframe is unclear if even possible. If we are to reach the 5 cent smart tag, the capabilities are most likely to be very different from what we currently expect from an RFID smart tag.

Ethics and Privacy Issues of the Future

The term *function creep* is used to describe the act of implementing technologies for particular purposes, only to find these purposes are soon expanded into other unintended areas. One of the obstacles for RFID technology is overcoming the privacy and ethical questions from groups, such as religious and privacy advocacy groups who fear the phenomena of function creep in RFID technology. Currently there is a debate as to whether or not the human implant chip is an ethical solution for secret codes to obtaining sensitive medical information. Imagine a day when your personal banking information becomes a part of you, and payment for particular services becomes as simple as being recognized as present. Applied Digital, based in Palm Beach, Florida, says it soon will begin the process of getting Food and Drug Administration approval for the VeriChip, a human implant chip, and intends to limit its marketing to companies that ensure its human use is voluntary.

E commerce solutions

Visionary thinking in RFID implementation includes e commerce solutions that aim to benefit both the consumer and the retailer. With Smart Shelves, a system that includes the tagging of individual products, the retailers will be able to obtain important marketing information, such as how often a product is looked at, and know when to restock shelves. In addition, they can track the product life and the destination of the product. This can improve safety for the consumers as well as cut down on theft of products, which can literally be tracked.

Shoppers will also be able to point their cell phones, such as a Nokia phone equipped with a Smart Cover, to pay for or learn more information about products. The vision of removing the checkout process from the shopping experience is also being considered, with the products each being automatically accounted for through an RFID tag and billed directly to a predetermined credit card.

Innovative products for the home

RFID technology is also finding a place in the home, with products that communicate. For example, RFID is able to provide cooking and washing instructions to appliances, or supply information of contents in a refrigerator or medicine cabinet. With the knowledge of what's inside, or what items have expired, an appliance can automatically replenish the supplies needed, linking directly to a local pharmacy or supermarket.

Imagine that a consumer purchases a jacket, brings it home, and puts it into the washing machine. The jacket can immediately communicate its particular washing instructions directly to the machine. If there is a conflict with washing particular items together, it could also alert you to remove an item. This is a similar application that one can imagine with cooking food, or filling the refrigerator.

Implantable Chips

The chip as an implant is not a new concept. In the 1970s RFID implants were used in cattle to monitor body statistics and location. The reality of a human implant chip has become a near future vision for many RFID manufacturers. The concept is that an RFID chip could be harmlessly implanted into a human to maintain identity codes or to store critical medical information. Perhaps a person with an RFID chip could attend a sporting event and automatically be charged for a ticket. It could also protect users against credit card fraud or theft. Similarly, the identification of particular health risks could be tracked and maintained through RFID technology. These solutions imply a number of ethical and privacy issues which have been mentioned earlier in this paper.

Tracking and safety

December 19, 2001 issue of *EETimes* discussed the integration of RFID and European bank notes in the form of tiny fibers woven into the paper of the note. Philips Semiconductors and Infineon Technologies are working closely with the European Central Bank to realize this vision. This would give the government the ability to trace illegal transactions. It would also be used to thwart counterfeiting initiatives. There is still doubt as to weather or not the cost of implementation will be worth the effort.

Research Projects

Much of the unique exploration in RFID technology and implementation is being conducted in research institutes and schools. The exploration and developments are both technical- and design-oriented, to further consider the unique opportunities for the implementation of RFID systems. Xerox PARC has explored the creation of an interactive book, which contains RF tags embedded in the pages. Reading unique RF tags simultaneously, and detecting for their presence as a user turns the pages simultaneously affected the ambient nature of the room.

Xerox PARC extended their research on RF tags to consider also the improvement of the electronic guidebook interfaces. They accomplished this using RFID and combining automatic personal- and context-based references with manual selections. It is easy to imagine how the experience can become more personalized and rich through tailoring the information directly to the user.

Visions

Today's research RFID landscape is limited, but promising. The unique identification combined with the internet connectivity proves to be the area where most of the visionary thinking is concentrated. The growing market and the new interest in creating standards for RFID technology is an indication that the visionary thinking for this technology is just beginning.

Sources for The Future

Supply Chains Systems Magazine January 2002
http://209.35.212.232/reader/2002/2002_01/smar0102/smar0102.htm

Venture Development Corporation
Global Market and Applications For Radio Frequency Identification
http://www.vdc-corp.com/autoid/reports/01/br01-23.html

MIT Auto ID Center
http://www.autoidcenter.org

CNN.com / Sci Tech
Computer chip implanted in humans? – February 27, 2002
http://www.cnn.com/2002/TECH/ptech/02/27/human.computer.chip.ap/index.html

Texas Instruments Radio Frequency Identification Group
http://www.ti.com/tiris/default.htm

EETimes
Euro Banknotes to Embed RFID chips by 2005
By Junko Yoshida
December 19, 2001
http://www.eetimes.com/story/OEG20011219S0016

Nokia and 2Scoot begin trial of new technology application to enable m-commerce transactions – press release
http://press.nokia.com/PR/200101/803668_5.html

Xerox PARC
Page Detection using Embedded Tags – white paper
http://www.parc.xerox.com/red/members/back/papers/UIST_RFID.pdf

XEROX PARC
Improving Electronic Guidebook Interfaces Using a Task-Oriented Design Approach
http://www.parc.xerox.com/csl/members/woodruff/publications/2000-Aoki-DIS2000-GuidebookTaskAnalysis.pdf

PC Magazine
Tag It, January 2002, By Christina Wood
http://www.pcmag.com/print_article/0,3048,a%253D21374,00.asp

Appendix I – Glossary

Appendix compiled from:
AmaTech: A Guide to RF-ID
AIM Glossary of Radio Frequency Identification Terms.

Active Tags
Tags which use batteries as a partial or complete source of power. They are further differentiated by separating them into those with replaceable batteries and those which have the batteries inside a sealed unit or what may be termed unitized active tags.

Addressability
The ability to address bits, fields, files or other portions of the storage in a tag.

Alignment
The orientation of the tag to the reader in pitch, roll, and yaw.

Antenna
Antennas are the conductive elements that radiate and/or receive energy in the radio frequency spectrum to and from the tag.

Bi-directional
Capable of operating in either of two directions which are the opposite of each other. For example, a tag which can be read or written from either side is bi-directional.

Capacity
The number of bits or bytes that can be programmed into a tag. This may represent the bits accessible to the user or the total number including those reserved to the manufacturer e.g. parity or control bits.

Capture Window/Field
Region of the scanner field in which a tag will operate.

Closed Systems
A system in which relevant data regarding the attributes of the object is stored in a common data base, accessible via data link by referencing the individual ID code. It usually refers to a system under the control of a single owner or authority.

Code Plate
See *Tag*

Controller
See *Multiplexer*

Coupling
See *Electromagnetic Coupling*

Electronic Identification, or EID
The particular application of tagging animals is called EID.

Electromagnetic Coupling
The use of a magnetic field as a means of transferring data or power.

Electronic Label
See *Tag*

Electrostatic coupling
The use the inducing of a voltage on a plate as a means of transferring data or power.

Error
Any operation or data that is not in accord with the design or input to the system.

Error Correcting Code (ECC)
Supplemental bits in a data transfer used in conjunction with a polynomial algorithm, in order to compute the value of missing or erroneous data bits (e.g. for a 32 bit data transmission, 7 additional bits are required.)

Error Correcting Mode
Mode of data communication in which missing or erroneous bits are automatically corrected.

Error Correcting Protocol
The rules by which the *error correcting mode* operates.

Error Management
Techniques used to ensure that only correct information is presented to the user of the system.

Error Rate
The number of errors per number of transactions.

Exciter
The electronics that drive an antenna are called the *exciter* or *transmitter*. Together with the antenna they are called a *scanner*.

Expansion Port
A plug accessing additional 1/0 capability on a computer or peripheral device.

Factory Programming
The programming of information into a tag occurring as part of the manufacturing process resulting in a read only tag.

Field Programming
Programming information into the tags may occur after the tag has been shipped from the

manufacturer to an OEM customer or end user or in some cases to the manufacturer's distribution locations. Field programming usually occurs before the tag is installed on the object to be identified. This approach enables the introduction of data relevant to the specifics of the application into the tag at any time; however, the tag would typically have to be removed from its object. In some cases, change or duplication of all data in the tag is possible. In other cases, some portion is reserved for factory programming. This might include a unique tag serial number, for example.

Field Protection
The ability to limit the operations which can be performed on portions or fields of the data stored in a tag.

Flat Panel Antenna
Flat, conductive sheet antennas, usually made of metal plate or foil.

Frequency
The number of times a signal executes a complete excursion through its maximum and minimum values and returns to the same value (e.g. cycles).

I.D. Filter
Software that compares a newly read ID with those in a database or set.

Inductive Coupling
The use the inducing of a current in a coil as a means of transferring data or power.

In Use Programming
Many applications require that new data or revisions to data already in the tag, be entered into the tag, while it remains attached to its object.

The ability to read from and write data to the tag while attached to its object is called in-use programming. Tags and systems with this capability are called read/write tags and systems.

Interrogator
See *Reader and Programmer*

Life
Functional period within which no maintenance, adjustment or repair is to be reasonably expected.

Memory Cards
A read/write or reprogrammable tag in credit card size

Memory Modules
A read/write or reprogrammable tag

Misread

A condition that exists when the data presented by the reader is different from the corresponding data in the tag.

Mobile Inventory Vehicle
Vehicle equipped with a system for locating tagged vehicles, containers, and other objects for the purpose of inventory control.

Modulation
The methods of modulating or altering the carriers in order to carry the encoded information are quite varied. They include amplitude modulation (AM)/ phase modulation (PM), frequency modulation (FM), frequency shift keyed (FSK), pulse position (PPM), pulse duration (PDM) and continuous wave (CW). In some cases, different modulating techniques are used in each direction (to and from the tags).

Modulation, amplitude (AM)
Data is contained in changes in amplitude of the carrier.

Modulation, phrase (PM)
Data is contained in the changes in the phrase of the carrier.

Modulation, frequency (FM)
Data is contained in the changes in the frequency of the carrier.

Modulation, frequency shift keyed (FSK)
Data is contained in the changes between two frequencies of carrier.

Modulation, pulse duration (PDM)
Data is contained in the duration of pulses.

Modulation, phrase (PM)
Data is contained in the changes in the phrase of the carrier.

Modulation, frequency (FM)
Data is contained in the changes in the frequency of the carrier.

Modulation, frequency shift keyed (FSK)
Data is contained in the changes between two frequencies of carrier.

Modulation, pulse duration (PDM)
Data is contained in the duration of pulses.

Modulation, pulse position (PPM)
Data is contained in the position of pulses relative to a reference point.

Modulation, continuous wave (CW)
Data is contained in a carrier which is switched on and off.

Multiplexer (multiplexor)
A device which supports multiple scanners or antennas by checking each in accordance with some scheduling scheme which may be either round robin or priority based. This reduces the total amount of electronics in the system at the expense of having all scanners being "blind" part of the time. These devices are called multiplexers or multichannel readers or just controllers.

Nominal
The value at which a system is designed to assure optimal operation. Tolerance considers the "normal" deviation of variable factors.

Nominal Range
The range at which a systems can assure reliable operation, considering the normal variability of the environment in which it is used.

Omnidirectional
Capability of a tag to operate in any orientation.

Open Systems
Application in which reader/writers do not have access to a common database.

Orientation
Alignment of the tag with respect to the scanner, measured in pitch, roll, and yaw.

Orientation Sensitivity
The range of degrees between the orientation of the tag to the antenna at which coupling can occur.

Passive Tags
Passive tags contain no internal power source. They are externally powered and typically derive their power from the carrier signal radiated from the scanner.

Port Concentrator
A device that accepts the output from a number of communication interfaces and introduces them into a communication network.

Power Levels
Levels of power radiated from a scanner or tag, usually measured in volts/meter.

Programmability
In order to be identifiers of specific objects, tags must at some point have their identity and/or other data entered into them. This capability is called programmability.

Programmer
Some tags can have their contents changed by a set of electronics in close proximity or in electrical contact with it. Those electronics and their packaging are called a programmer.

Projected Life
This is defined in terms of number of read and/or write cycles, or in active tags this may include shelf life.

Proximity sensor
A device that detects and signals the presence of a selected object at or near the sensor's location.

RF/DC
Systems which communicate over a radio link between a host computer and a data source e.g. keyboards, data terminals, readers for OCR, Bar Codes, Mag Stripes, RF/ID etc. RF/DC enhances the capabilities of Automatic ID Systems by providing the capabilities of hard-wired data communications without the physical restrictions interconnecting wires.

RF/AIS
Radio Frequency Automatic Identification Systems

RFID
Systems that read or write data to radio frequency tags that are present in a radio frequency field projected from RF reading/writing equipment. Data may be contained in one (1) or more bits for the purpose of providing identification and other information relevant to the object to which the tag is attached. It incorporates the use of electromagnetic, or electrostatic coupling in the radio frequency portion of the spectrum to communicate to or from a tag through a variety of modulation and encoding schemes.

Range
The distance at which successful reading and/or writing can be accomplished.

Read
The decoding, extraction and presentation of data from formatting, control and error management bits sent from a tag.

Read Only
See *Factory Programming*

Read Rate
The maximum rate at which data can be read from a tag expressed in bits or bytes per second.

Read/Write
Many applications require that new data or revisions to data already in the Tag, be entered into the Tag, while it remains attached to its object.

Tags with this capability are said to be reprogrammable and are called read/write tags, memory cards or memory modules.

Readability
The ability to extract data from a tag, often under less-than-optimal conditions.

Reader
The device containing the digital electronics that extract and separate the information from the format definition and error management bits.

The digital electronics perform the actual reading function. These read electronics may also interface to an integral display and/or provide a parallel or serial communications interface to a host computer or industrial controller.

Reader/Writer
The set of electronics can change the contents of tags while they remain attached to their object are called a reader/writer. (See also reader).

Reprogrammable
Many applications require that new data or revisions to data already in the tag, be entered into the tag, while it remains attached to its object.

The ability to read from and write data to the tag while attached to its object is called in-use programming. Tags with this capability are said to be re-programmable and are called read/write tags, memory cards or memory modules.

Surface Acoustic Wave, **or SAW**
Surface Acoustic Wave. A technology in which radio frequency signals are converted to acoustic signals in a piezoelectric crystalline material. Variations in phrase shift ion the reflected signal can be used to provide a unique identity.

Scanner
The antenna's, transmitter (or exciter) and receiver electronics integrated in a single package called the scanner. They may be combined with additional digital electronics including a microprocessor in a package called a reader.

Separation
Operational distance between two tags.

Signaling Technique
A complete description of the modulation, encoding, protocol, and sequences required to communicate between two elements of a system.

Tag
The transmitter/receiver pair or transceiver plus the information storage mechanism attached to the object is referred to as the tag, transponder, electronic label, code plate and various other

terms. Although transponder is technically the most accurate, the most common term and the one preferred by the Automatic Identification Manufacturers is tag.

Transponder
See *Tag*

Verify
To assure that the intended operation was correctly performed.

Write
The transfer of data to a tag and the tags internal operation of storing the data. This may include reading the data in order to verify the operation.

Write Rate
The rate at which information is transferred to a tag, written into the tag's memory and verified as being correct. It is quantified as the average number of bits or bytes per second in which the complete transaction can be performed.

Appendix II – Selected Academic Papers

Tagging and identification technologies have been used in many academic research projects, particularly those focused on innovations in human-computer interaction. The last decade has seen many ideas for taking computer inputs away from the keyboard and mouse and making inputs more natural. One term that describes these alternative, physical interfaces is tangible user interface, or TUI. Experiments in tangible user interfaces have taken many forms, but a universal characteristic is assigning some form of digital control to a physical object. Even though RFID has only been used as the identification technology in some of these experiments, the lessons and design rules learned from TUI experiments are contributing to a growing body physical computing knowledge. Below are several key papers on physical computing and tangible user interfaces.

"Bridging physical and virtual worlds with electronic tags." Roy Want, Kenneth P. Fishkin, Anuj Gujar, Beverly L. Harrison. *Proceedings of the CHI 99 Conference on Human Factors in Computing Systems: The CHI is the Limit*, May 1999.

> This paper describes a series of small implementations of RFID technology in an office environment, with an overall goal of bridging the divide between physical and virtual aspects of work. Tagged items include books, printed documents, business cards, and a watch, all interacting with a tablet computer and able to provide greater information and more updated information in digital form than is possible physically.

"Palette: A Paper Interface for Giving Presentations." Les Nelson, Satoshi Ichimura, Elin Rønby Pedersen, Lia Adams*. Proceedings of the CHI 99 Conference on Human Factors in Computing Systems: The CHI is the Limit*, May 1999.

"PaperButtons: Expanding a Tangible User Interface." Elin Rønby Pedersen, Tomas Sokoler, Les Nelson. *Conference proceedings on Designing Interactive Systems: Processes, Practices, Methods, and Techniques*, August 2000.

> Palette is an implementation of a paper-based system for controlling a digital slide presentation. Paper representations of slides were tagged with barcodes and the presenter was able to control a presentation by holding a paper up to a reader. The authors describe this as tacit interaction, and particularly useful when the digital-only interface is cumbersome or difficult to learn. PaperButtons is an expansion of the Palette system, with changes and additions based primarily on user feedback. The authors also propose guidelines for the creation and expansion of tangible user interfaces.

“mediaBlocks: Physical Containers, Transports, and Controls for Online Media.” Brygg Ullmer, Hiroshi Ishii, Dylan Glas. *Proceedings of the 25th annual conference on Computer Graphics and Interactive Techniques*, July 1998.

mediaBlocks describes a system employing small physical blocks used to reference and transport digital media. In the test setting, monitors, scanners, and printers were each fitted with a mediaBlock slot to accept a mediaBlock and load the piece of media references by the block. The mediaBlocks themselves were blocks of wood, and the tagging technology is contact-required iButton from Dallas Semiconductor.

Appendix III – Graphic Overview of History

Included below is an image referencing an Adobe Acrobat document. The original file, titled "RFID_timeline.pdf" should be used for detailed viewing and printing.