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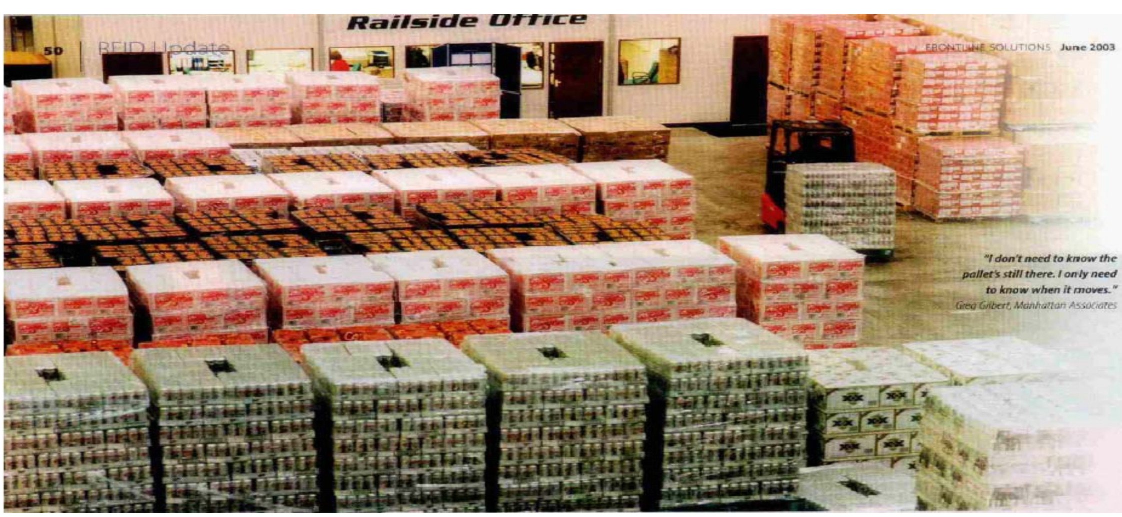
(image from Aimglobal 2003)

The Emergence of RFID Technology

Why switch to RFID?

Radio-frequency identification, known popularly as RFID, is poised to become the next major innovation in device scanning technology since the advent of the bar code. According to the firm VDC (Venture Development Corporation), the market for RFIDs is estimated to grow from $700 million in 2003 to $2 billion by 2007 (Shim 2003).

A revolution in asset management is underway. With RFID technology, truckloads of consumer products will announce their arrival at the loading dock. Boxes will report their movement from location to location. Missing, or snow covered, items will be quickly located by means of their RFID tag. Stolen items will cry out for recovery. Empty store or warehouse shelves signal that replenishment is in order (Roberti 2002).



(image fromTierney 2003)

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In short, RFID is predicted to constitute the backbone of a worldwide infrastructure for the real-time management of individual items numbering in the quadrillions. According to *Information Week* (Evans 2003), this substitution could impact "efficiency, security, timeliness, paper reduction, accuracy, automation, visibility, tracking, load optimization, and collaboration," to name just a few of the potential advantages of RFID technology.

In this paper, we explore what an RFID system is and describe how it works, how RFID systems are classified, who the suppliers and purchasers of RFID tags are, what some of the major applications of RFID are, how much RFID costs, what some of RFID's overall advantages and disadvantages are, and when and where RFID will become available.

What is RFID, and how does it work?

RFID technology dates back to World War II. Attempting to reduce incidents of "friendly fire," radio signals from one aircraft were beamed towards an approaching aircraft's transponder; a corresponding signal from the second plane identified it as a friendly aircraft. Sixty some years later RFID has finally begun to gain widespread popularity, primarily because of recent reductions in size and cost, as well as more sophisticated functionality. This has led to the widespread applications noted below and in Appendix B (Cohen 2003).

Today, RFID tags are usually viewed as a wireless link to uniquely identify objects or people[1]. The basic RFID system consists of two basic components – a transponder (i.e., the tag itself) and a transceiver (i.e., the reader). The tag consists of an antenna and an integrated circuit which requires a small quantity of electrical energy to function. The power source, in this case, is not a battery, but a low-level radio frequency magnetic field which is emitted by a tiny antenna on the reader. When the tag is brought into the vicinity of the reader, at a range of typically three to four feet for passive tags (see classification of tags section below), the transponder gathers energy from the magnetic field, processes the information, and emits a radio frequency signal back to the reader for processing (HiPoint 2002).

The current standard operating frequency of low-frequency RFIDs is 13.56 MHz. At this frequency (and at frequencies less than 135 kHz), the operating principle involved in RFIDs is inductive coupling, illustrated below (AIM 2000).

[1] Another name for RFID is DSRC – dedicated short range communication (d'Hont 2002).

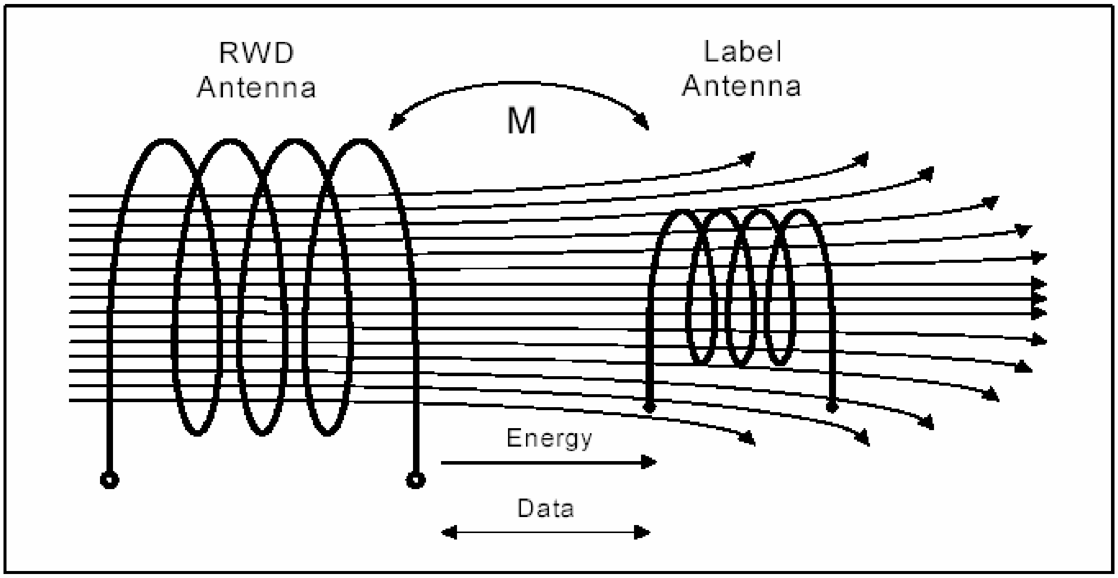

Exhibit 1: Inductive coupling (from Aimglobal 2000)

While 13.56 MHz is expected to become the commercial standard, UHF RFID, operating between 300 and 1000 MHz, is also growing in popularity. Within this range, RFID technology consists of conventional electromagnetic wave propagation, as seen below. UHF RFID tags may or may not contain batteries (AIM 2000).

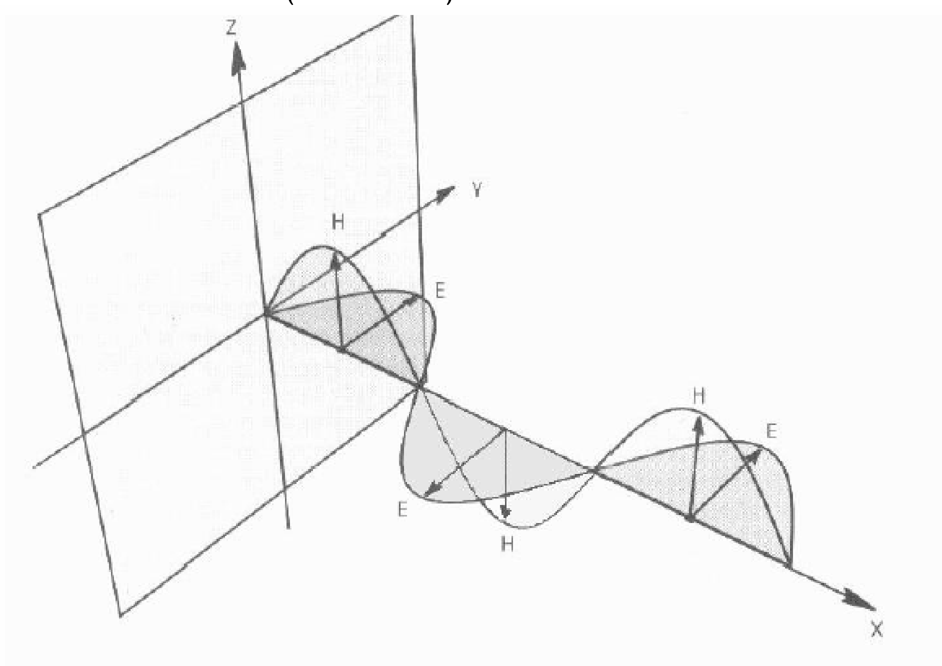

Exhibit 2: Electromagnetic wave propagation (from Aimglobal 2000)

A view of the complete reader/transponder system is given below.

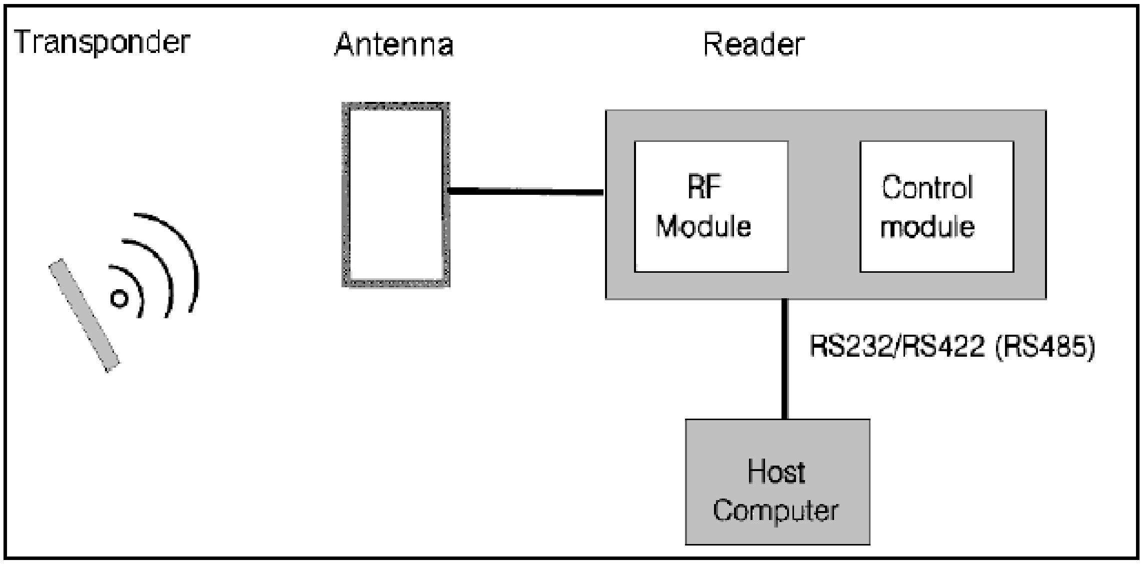

Exhibit 3: Components of the reader/transponder system (from d'Hont 2002)

Once the reader has activated the transponder, the transponder responds by emitting a signal to the reader's antenna, which is converted to an electrical signal in the rf module. This signal, in turn, is sent for further processing to the host computer by the control module.

A more detailed look at the back-end databases involved can be seen in the following diagram:

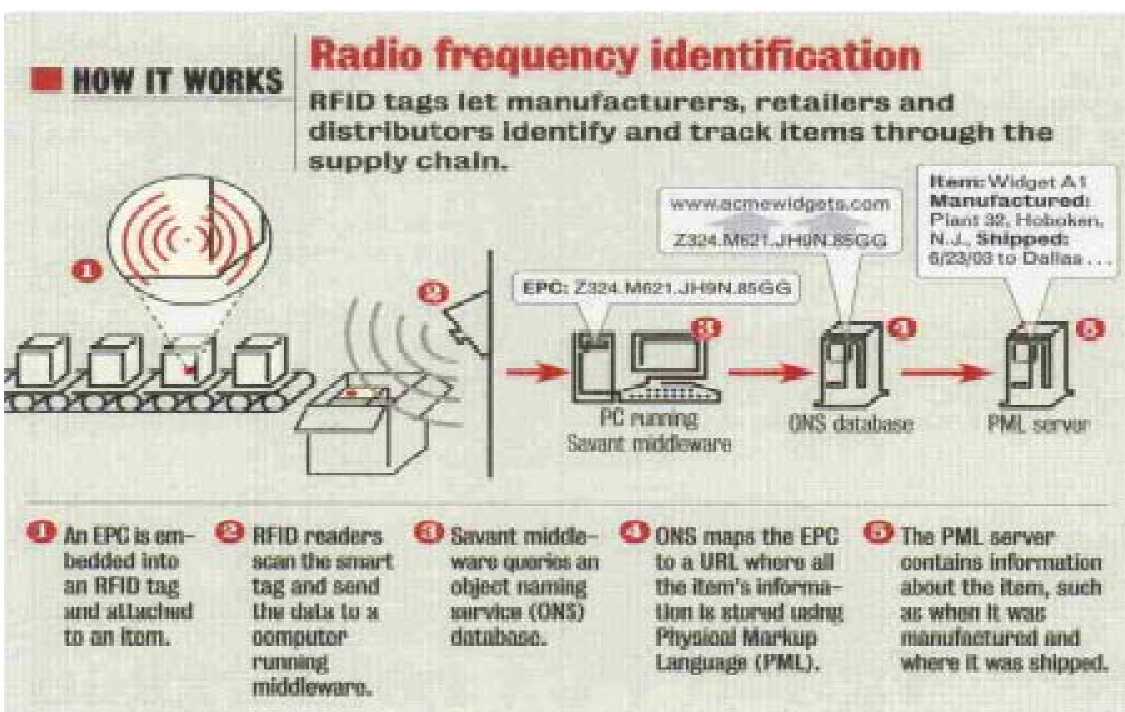

Exhibit 4: RFID data handling (from Fowler 2003)

A model of the flow of data throughout the entire life cycle of reusable RFID tags is given in Appendix A.

Classification of Tags

RFID tags can be active, passive, or semi-passive. Active tags contain a battery, while passive tags operate by drawing energy from the electromagnetic field of the reader. Passive tags are the cheapest to produce, in the tens of cents range each currently, and must be within 4 feet of the reader. Like active tags, semi-passive tags also contain a battery, but the tag lies dormant until receiving a signal from the reader. This has the desirable effect of conserving battery power.

Since reader/tag distance separation can be longer for active tags, they lend themselves well for applications such as electronic tollbooth payment systems (e.g., EZTag). The economic benefits, but short range, of passive tags make them the likely candidate for tracking consumer goods. Ford Motor Company uses semi-passive tags to track parts bins once they have arrived in their massive assembly plants (Roberti 2002).

Tags can also be classified as read-only or read-write. Read-only tags cannot be reprogrammed. However, they are much cheaper to produce than read-write tags.

RFID tags can also be classified by frequency band used. The following table summarizes the characteristics and example applications of each band.

Frequency Bands and Applications

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 immobilizer
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

Table 1 (from Aimglobal 2003)

Some additional trade-offs between high and low frequency devices include that high-frequency devices are orientation sensitive, are less able to penetrate than the low frequency devices (which read through non-metallics), require high power levels, but are not noise sensitive. (d'Hont 2002)

Low frequency tags can be read by an interrogation unit (within 4 feet) at a maximum relative speed of approximately 20 miles per hour, while high-frequency tags can be read at a distance of 250 feet and at a relative speed in excess of 150 miles per hour (Sabetti 2003).

The memory capacity of RFID tags can range from the order of a single bit to kilobits. Data transfer rates increase with increasing frequency. At the 2.45 GHz level, a transfer rate of two megabits per second may be attained (AIM 1999).

Read range and memory capacity are just two of several design parameters shown in the table below.

Performance Requirements/Attributes

Read range	Penetration
Centralized vs. distributed	Form factor
Memory capacity	Collision avoidance
Speed/Data rate	Security
Line-of-sight	Interoperability
Cost	

Table 2 (d'Hont 2002)

Compared to bar codes, RFID poses advantages related not only to speed, but also to greater accuracy, less breakdown/maintenance, and longer life (Harrop 2003).

Adoption by Industry

To get a better sense of the need for low-cost identification tags, consider the following table summarizing number of units in the supply chain:

END USER	ESTIMATE NO. OF UNITS IN SUPPLY CHAIN (BILLIONS)
CHEP	0.2
JOHNSON & JOHNSON consumer goods division	3.0
KIMBERLY CLARK*	10.0
WESTVACO*	10.0
THE GILLETTE COMPANY	11.0
YFY*	15.0
TESCO	15.0
THE PROCTER & GAMBLE COMPANY	20.0
UNILEVER	20.0
PHILIP MORRIS GROUP*	25.0
WAL-MART*	30.0
INTERNATIONAL PAPER	53.0
COCA-COLA*	200.0
SUB-TOTAL	**412.2**
(Adjust for double counting @15%)	– 61.8
United States Postal Service	205.0
TOTAL INCLUDING USPS	**555.3**

Table 3 (Clinton 2002)

Wal-Mart is currently investing heavily in RFID tags to aid in trimming supply-chain management expenses, reducing inventories, preventing theft, and avoiding misdirection of shipments. In a strategy that could ripple across multiple industries, Wal-Mart announced in June of 2003 that it will require its top 100 suppliers to equip incoming crates and palettes with RFID chips by January 2005 (Vijayan 2003). However, just one month later, the company dealt a minor blow to RFID hopes by canceling a joint smart shelf trial with Gillette (Gilbert and Shim 2003). Nevertheless, Wal-Mart recently affirmed its June proclamation by announcing it would require all its suppliers to include RFID tags on pallets and cases by the end of 2006 (RFID Journal, August 2003). In support of this new policy, Wal-Mart insists that RFID tags can be acquired in bulk for 10 cents per tag, demonstrating strong support for the technology. Another benefit Wal-Mart and other retailers would like to harvest is self-checkout, a cost-cutting opportunity already being used in the grocery industry using bar codes.

Despite the glitch with the Wal-Mart test, Gillette has reportedly ordered 500 million passive tags to be attached to their razors (*The Economist* 2003). Gillette estimates that $30 billion are lost per year by retailers because shelves stand empty. By including RFID tags which signal empty shelves, these losses, as well as losses from petty theft, could be drastically reduced (*The Economist* 2003).

Delta recently (June 2003) announced that it would test RFID tags on passenger luggage this fall. The airline plans to use passive tags which may have an effective range of 10 feet, thus providing an advantage over existing bar code systems (Brewin 2003).

Ford Motor Company intends to use RFID to track parts to improve manufacturing process control. Examples of data stored on a tag include unique tag ID, part type, plant location, and a time-date stamp. Pilot studies have indicated 100% data accuracy. One difficulty, however, is attaching the tags to metal parts such as engines (Bylinsky 2000).

The fast-food industry is also getting interested in RFIDs. Just as toll booths and gas-stations use Speedpass technology (developed by ExxonMobil) to expedite payment, Taco Bell and KFC are experimenting with similar systems. The tag would have the advantage of encouraging customer loyalty and, if widely adopted, avoids food handlers having to handle dirty cash.

According to Nic Fildes of Dow Jones Newswires (Fildes 2003), the U.S. Department of Defense is employing RFID tags on all its assets moving to the Persian Gulf, thereby improving visibility in the supply chain.

Apple's co-founder Stephen Wozniak has recently announced the development of a wireless tracking device which is being dubbed WozNet. This wireless network can use radio signals and global positioning devices to track tags, which cost under $25 per tag to produce, making it quite viable for the consumer market (e.g., to locate a lost pet) (Markoff 2003).

To meet the growing demand for RFID, over 140 suppliers already exist nationwide. A comprehensive list of suppliers, their websites, and the applications served by each company can be found at: http://rfid-handbook.de/links/companies.php.

Major applications of RFID are summarized in the table below.

Application	Description
Access control	Proximity card facilitates security
Animal identification	By attachment of tag (e.g., to ear or tail) or implantation under the skin
Asset management	E.g., palettes moving in and out of a facility
Container tracking	Keeping track of reusable containers
Corporate/campus cards	E.g., cafeteria vending, parking, etc.
Counterfeit prevention	Ensures genuineness of items
Electrical utilities	To track high-tech assets
Fare collection	For mass transit
Fugitive emission inspection systems	Replaces demanding tasks
Gas cylinder tracking	Identifies objects that undergo rough handling
Hazardous materials	Avoids the need for physical contact
Laundry/textile identification	Garment identification speeds processes
Luggage tagging	E.g., baggage tagging and boarding passes
Meat packing plants	Uses rugged readers for tracking purposes
Preferred customer card/loyalty programs	Transponder attached to card with photo ID
Process manufacturing	Can automatically verify weight and content
Product identification	For high-value items such as furs and skis
Scale interface	E.g., fuel delivery, baking plants
Time and attendance management	To identify in- and out- times
Tool identification/management	For highly regulated tools and clothing
Totes/conveyor	E.g., tracking assembly of sound speakers

Table 4 (from Hi-point 2003)

As evident from the above listing, RFID applications can range from access control to tracking pets, livestock, to luggage and razor blades An even more exhaustive list of 47 potential applications is included in Appendix B.

Advantages of RFID

RFIDs offer many advantages over traditional bar code scanning technology. First RFID obviates the need for contact or line-of-sight. And, an entire palette of inventory can be scanned at once and quickly. RFID systems can process as many as 50 tags per second – 40 times faster than bar-code scanning (Bylinsky 2000). A high level of data integrity is provided as error rates are lowered and labels are unlikely to be damaged. The difficulty of counterfeiting RFIDs bestows a high level of security. Portable scanning devices such as the RFID wand (shown below) also facilitate scanning, supporting use of RFID in libraries (Records Associates 1999).

Exhibit 5: The RFID wand (from RecordsAssociates 1999)

The passive tags are very durable, with some able to survive temperature ranges from minus 40 degrees Centigrade to 200 degrees Centigrade (HiPoint 2002).

An RFID chip can hold approximately 128,000 characters of data, as opposed to the 1000 characters of more recent bar codes (Cross 2001, Bylinsky 2000). The size of chips to be used in clothes at Benetton is smaller than a grain of rice (Dow 2003).

Even early RFID implementations have provided significant economic rewards. The firm AMR Research Corp. indicates that supply chain costs have been reduced by 3-5% and that sales have increased 2-7% as a result of improved inventory control (Fildes 2003). Thus, RFID displays the potential to cut costs and increase revenues simultaneously.

Drawbacks

Despite the advantages, RFID tags do have drawbacks. At thirty to fifty cents per tag (for passive tags) cost is a major concern. To be economically viable, for many consumer product applications the cost will have to be brought down to about five cents per tag.[2]

The cost of a tag can be broken down into three major elements: the silicon chip, the copper antenna, and the process of joining the two. While most attention is focused on reducing the cost of the chip to ten cents or less, use of conductive inks may drive down the cost of an antenna to a penny or possibly even less. Use of such printed antennas would also reduce the cost of joining the antenna to the chip (RFID Journal, December 2002).

A proposed approach to the cost problem of smart tags is a variety of the smart tag known as the "smart label" (pictured below). One advantage of the thinner smart labels over conventional smart tags is that they can be manufactured in bulk by special printers. Current costs of these are in the thirty to fifty cent range. These can be produced in high volumes, are thin and flexible, can be read/write, and can easily be integrated into the barcode infrastructure. Current manufacturers of smart labels include Avery Dennison, Moore, and METO (d'Hont 2002).

Exhibit 6: A smart label (d'Hont 2002)

One technological drawback of RFID tags (and labels) is that radio waves cannot pass through metal, or even water, at certain frequencies. Noise from other distracting radio signals can also disrupt tag-reader interaction. The four-foot range of the passive tag reader would also ideally be extended.

[2] By contrast, Bar code labels cost anywhere from 1/10th of a cent to a penny each (Fildes 2003).

The total cost of Wal-Mart's June announcement to its top 100 suppliers to adopt RFID is an estimated $2 billion. This includes not only the cost of tags and readers, estimated at $5 to $10 million per manufacturer, but also system integration, changes to current supply chain applications, and storage system upgrades, which may amount to $13 million per manufacturer (RFID Journal, September 2003).

Despite these high costs, the market for RFID systems worldwide reached $965 million in 2002, while RFID hardware sales attained nearly $89 million in 2002 (Hickey 2003).

Standardization is another major stumbling block. All major vendors currently offer systems that are proprietary, resulting in many systems that come in a variety of shapes (rod, screw, square) and sizes (on the order of millimeters to inches).

Exhibit 7: RFID chip alongside a penny (Clinton 2002)

Frequencies and protocols are now subject to intense competition. Across industries, incompatible RFID systems exist for truck, rail, air traffic control, tolling authorities' usage, and the Department of Defense's Total Asset Visibility system (HiPoint 2003). Interoperability is thus a major source of concern.

International standards are still in their infancy; the few existing standards include ISO (International Standards Organization) 11784 and 11785 for animal tracking. Passed in January 2003, ISO 18000-6 covers the air interface for UHF, which may pertain most to supply chain applications.

The ISO has joined the IEC (International Electrotechnical Commission) to form a Joint Technical Committee. Workgroup (WG) 4 has been assigned the task of developing all aspects of standards related to RFID, with subgroups in the areas of data syntax (SG 1), unique id for RFID tags (SG 2) and air interfaces (SG 3). According to a standard developed by ANSI (American National Standards Institute), ANSI/NCITS T6 256-2001 RFID should minimally identify the tag in its range, read data, write data or handle read-only systems, select by group or address, handle multiple tags in the field of view, and detect errors (ANSI 2001).

The Electronic Product Code (EPC) which seems to be gaining the most widespread currency is that developed by MIT's Auto-ID Center. Matrics and Alien Technology are conforming to this standard, and Gillette has purchased conforming products (RFID Journal, February 2003).

An outcry has been raised about privacy issues regarding customer data. For example, if a consumer product such as a hot dog package retains its tag beyond checkout, marketers could use the tag to signal a ketchup ad to flash on a billboard as a consumer is walking down the street (Gilbert 2003). While this may sound hi-fi, it is technologically quite feasible in the near future.

Wal-Mart's cancellation of its smart-shelf trial with Gillette may be a consequence of this danger. The Wal-Mart mandate to its suppliers, therefore, requires tags only for crates and pallets. Under similar pressure to answering an objection from a consumer advocates' group, Benetton announced that its plans to include tags on clothing are still in the early testing stages (Gilbert and Shim 2003). Thus, supply chain management (as opposed to smart shelves) is poised to be the major application of RFID in the near future. Consumer advocates have also proposed requiring the means to disable tags upon checkout through use of "kill switches."

Future Directions

The two major issues plaguing the RFID industry are price and standardization. In trying to reduce tag costs from 50 cents to 5 cents, Alien Technology has developed a low-cost manufacturing technique in which chips are suspended in liquid, followed by passing the liquid over chip mounts (*The Economist* 2003). Standardization is still a long way off, though low frequency RFID has been standardized at 13.56 MHz.

Nevertheless, RFID is becoming more and more omnipresent. In the Dallas and Houston areas, Texas Instruments is already a major supplier of RFID products. Schlumberger is incorporating RFID for access control. The tollway EZTag and Mobil Speedpass are commonly encountered RFID applications. At this stage, privacy may not be a major concern, but as RFID moves from the warehouse to store shelves, kill switches, whereby a tag's data can be switched off permanently, are growing in demand.

Given that there are in excess of a quadrillion units globally, the prospects for the industry are very good. However, retailer support has been slow to gather, and it is estimated that RFID will not be economically feasible for a company's entire supply chain before 2006 (Fildes 2003). So far, Wal-Mart stands as the only retailer that has required suppliers to include RFID in their products, although Benetton has also begun to move in this direction (Dow 2003). The advantages of speed and ease of use should lead to widespread adoption in the near future if costs can be brought down and the privacy issues resolved.

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Appendix A:

The RFID Data Flow Model

Source Data
(in binary form)

⇩

Source Encoding
(Data + data structure format, data identifiers, commands and error control)

⇩

Channel Encoding

(Bit encoding scheme, e.g. Non-return to zero, Manchester, Miller, ….)

⇩

Modulation ← ← ← ←
(e.g. Amplitude, frequency & phase shift keying) ↑

↓⇩

Transmit ↑

Read/interrogate

Communication ↑
(Air interface - frequency and power

considerations and issues of legislation)

Two-way communication protocols ↑

↓⇩

Demodulation ⇨ ⇨ ⇨ **Store to Transponder**
(Reader/Interrogator)

↓

Anti-contention management

(as appropriate)

↓

Channel Decoding

↓

Source decoding

↓

Recovered source data
(Error control management)

Key: ⇩ Programming
↓ Interrogation

(AIM 2001)

Appendix B

Applications of RFID - 47

- Access Control
- AFC
- AGV positioning
- airline ticketing
- Animal ID
- anti-theft
- assembly line id
- asset tracking
- automotive
- baggage tags
- Car Immobilizer
- car manufacturing
- configuration management
- Container
- conveyor belt clothes hangers
- electronic Keys
- e-purse
- factory automation
- fleet management
- Forklift positioning
- gambling
- gas cylinder
- healthcare
- Industrial ID
- logistics
- loyalty schemes
- maintenance logs
- medical device
- Membership Cards
- mining
- paint shop
- pallet tagging
- park and ride metering
- payphones
- people locating
- pigeon races
- process control
- road toll
- security areas
- Ski tickets
- T&A
- toll collection
- traffic management
- truck fleet tracking
- university cards
- vehicle access control
- vehicle movement

(AIM 1998)