Wireless in Packaging

(RFID Technology, Applications and Implications)

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Summary: This paper concentrates on wireless technology and the impact of its integration with packaging, on the production, packaging and retail world. Since all new technologies need to work with existing ones, the paper discusses the technology as well as implementation issues, array of applications and related challenges. Finally, it tries to succinctly comprehend the possibilities that future brings.

I. Introduction

Packaging has evolved along the history as mankind has evolved itself. From the simple days of packing products in organic natural materials such as leaves and hollowed out shells to the present day has been a long and arduous journey. Even though the times have changed the motivation for developing better packaging remains the same, i.e. control. This is one feature that has been common to all the stages of progress in packaging. Human desire for better control – control over packaged goods' quality, their environment, costs and so forth. The constant innovation in the field of packaging has led to an increasing amount of human understanding and hence the successful prediction about the quality of goods, their flow and their behavior under different conditions. One of the most recent innovations in packaging has been its integration with wireless technology. This has been made possible by the development of Radio Frequency Identification (RFID) technology.

Essentially RFID is a term used to refer to a chip (primarily silicon) based technology that assigns a unique number to each object/unit that "flows" through the RFID system. This is similar to many technologies available today, like the Universal Product Code (UPC) (commonly known as the barcode), and Electronic Data Exchange (EDI). All these technologies work on computer based writing and reading of codes, storage of information in the codes and exchange of that information with a database(s). However, RFID is markedly different from the other technologies. Not only is it different in the nature of the technology used i.e. Radio Frequency waves, but it also allows for expanded capabilities. These enhanced capabilities provide operational, logistical and processing advantages to the organization deploying it. RFID in near future might become a technology that is expected to replace the barcode.

There are some specific advantages that RFID offers over the barcode system (Li et al, 2004). In RFID larger amounts of data is stored in the chip. Also this data can be read and the component can be tracked from a remote location by a reading device. This range (from where the data can be read) depends on a host of parameters including the power of the RFID chip, power of the reading device, type of product and most importantly the type of packaging. Also the RFID chips can be reused (while barcodes cannot be) and also offer much more security of operation.

Commercially RFID has become available only fairly recently but actually RFID was developed at almost the same time as the radar during the Second World War. RFID traces its origin to the military Identification Friend or Foe (IFF) system (Glidden et al, 2004). In the last few years RFID technology has gained momentum and penetrated variety of industries. According to recent industry studies (VDC, 2004) the total revenues generated by RFID related activities i.e. hardware, software and services have been steadily increasing over the last few years and will continue to grow. Fig. 1 (Costlow, 2004) shows this trend and provides information on the business value of the present and prospective RFID market.

Led by the world's largest retailer Wal-Mart and United States Department of Defense (DoD), RFID is all set to become the standard in military and commercial tracking mechanism in the respective logistical operations.

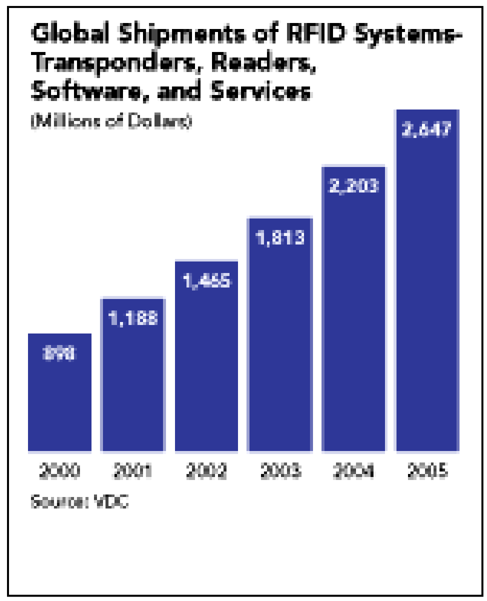

Fig. 1 RFID global shipments

However, U.S. Food and Drug Administration (FDA) has been a strong proponent of RFID for a slightly different purpose, i.e. security. In a recent report (FDA, 2004), RFID is stated as one of the strategic countermeasures against counterfeiting of pharmaceuticals. This may have far reaching consequences for the pharmaceutical packaging industry and eventually for the food packaging industry. Already, Wal-Mart has mandated it's top 100 suppliers to switch to RFID by early 2005 in order for them to be eligible to do business with Wal-Mart.

II. Technology

The technology associated with RFID is based on a fairly simple idea of wireless technology – transmittance and reception. However, as is the case with all developing technologies, the supporting infrastructure and related issues such as those of protocol and security are the bigger obstacles that need to be overcome. Also, since the incoming technology will have to be integrated into existing logistical chains of customers, packaging companies will have to figure out methods to overcome practical integration issues. Fig. 2 (Tuttle, 1997) is a generic representation of how a simple RFID system hardware might work. The RFID tags are attached to the products/units that "flow" through the system and are actively tracked by a reader (interrogator). The reader further converses with the computer that contains the database of the entire inventory.

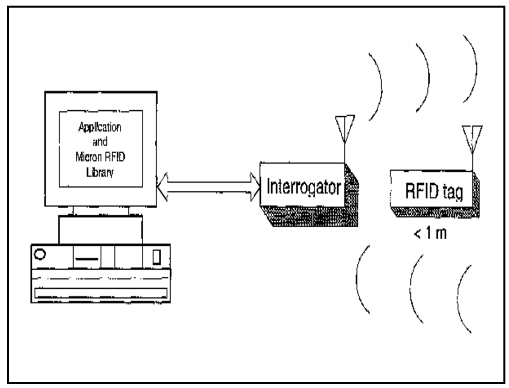

Fig.2 Generic RFID system

The computer is further connected to other online systems within the organization and also with the information systems of both upstream and downstream partners (manufacturers, suppliers and retailers).

II. (A) Components of a RFID system:

The RFID components can be divided into two parts, namely hardware and software. Hardware consists of a tag (on the packaging), a reader and the related computer systems. The tag is further comprised of a microchip (integrated circuit) that stores all the information, an antenna for transmitting the information and a substrate. The reader consists of a control unit, an interface and an antenna for scanning the immediate surroundings and receiving signals from the tags present in the vicinity (Penttila, 2004). The radio interface is the most crucial of all the sub components.

It's functions include detection, modulation and demodulation of the signals emanating from the tags. Put simply, it is the nervous system of the entire operation and hence the focus of attention in research. There are primarily two different kinds of tags- "active" and "passive". Active tags have onboard power sources (battery) and transmit information to the reader proactively. Passive tags however, use modulated backscatter (MBS) transmit to reflect energy transmitted by the reader (Tuttle, 1997). The major differences between active and passive tags are that active tags have fewer Input/Output mechanisms such as synchronization ports, keypads or display docks. Also, independence from battery life restrictions allows for much longer shelf life for passive tags and hence the choice of passive tags in packaging non-perishable goods. On the other hand, due to no radio power source the range of passive tags is limited. Also the functioning environment features such as walls, temperature and moisture levels have a significant impact on passive tags. Physical obstacles are a big concern, because for one, the signal from the tags is not self-powered and secondly the information in a passive system has to pass through the obstacles twice-once from the reader to the tag and then back to the reader. So the type of application and working environment dictate the nature of tag used. The most important component of the RFID tag is the antenna. The range of the tag and it's power requirements depend on the type of antenna used. There is a wide variety of antennas available. From general purpose antennas such as the miniaturized meander-line antennas (Marrocco et al, 2002), and slot ring antennas (Padhi et al, 2002) to a specific purpose antenna such as the planar wire type inverted antennas (Ukkonen et al, 2004) for metallic packaging; it is the application that defines the tag and corresponding antenna. The antenna is the most complicated and challenging to design and debug. Impedance values and radiation patterns are the critical factors in deciding the range and effectiveness of antennas. For maximum power transfer the impedance value of the antennas must match that of the on board Application Specific Integrated Circuit (ASIC). More recently designers have been able to deploy antennas with high impedance of up to 70 ohms and hence match the ASIC demands (Foster & Burberry, 1999). There are primarily two different kinds of antennas: omnidirectional and unidirectional. Omnidirectional antennas offer same signal strength in all directions while unidirectional antennas have a high strength in a single chosen directional parameter but almost no strength in other directions. The use of unidirectional antennas though preferred due to the generation of a higher strength signal, does mandate a condition on its use. The packager must know the orientation of the moving packages at all times. This ability to predict the exact orientation will be critical to the tag performance and hence impact signal strength.

The software associated with the RFID system is of two types:

- Component based software which provides operating platforms for individual components like computers and readers
- Interactive software that defines the rules of interaction between systemic components

The interactive software is known as middleware and is the most important software of the system. Simply put it is the traffic controller of all the data flow in the system. It defines the capacities, protocols and exceptions that govern the data exchange and helps in "collection, filtering, aggregation, routing and eventual reconciliation of data" (Liard, 2004). The role of middleware is not only data management but also event management. This means that apart from analyzing the data, middleware has inbuilt protocols to initiate decisions regarding inventory control. This is further helped by its ability to interact with information systems across the supply chain (vendors, suppliers etc.) resulting in an automated inventory management for retailers and a production order system for manufacturers and packaging suppliers. It is given that the security and stability of the middleware will be critical to the entire system. From simple operations like preventing unauthorized tags and readers to interact with each other to the prevention of the spreading of a computer virus through system will be within the realm of the middleware functionality. One of the recent demonstrative examples of these capabilities has been intelligent software named 'Savant' developed by Massachusetts Institute of Technology's (MIT) Auto-ID center (Atock, 2003). This system automatically monitors inventory levels and places a reorder with the suppliers. It can also be customized to accommodate seasonal patterns of demands on different products and packaging. The center has also developed a complementary signature service called Object Name Service (ONS) that lets the computers track items stored in distant locations. A special communication language, Physical Markup Language (PML) based on eXtensible Markup Language (XML) has been developed for information standardization of these transactions.

II. (B) RFID technology deployment models (for product and packaging manufacturers):

The practicality of RFID technology will depend on the ability of manufacturers and packaging suppliers to accept and integrate the technology into their present production and supply chain systems. This will be difficult given some of the stringent requirements that this technology dictates. These include

- The mandatory presence of a RFID tag on all units (depends on what is defined as a unit: individual product, case or pallet).
- The standardization of data stored onto each tag across the supply chain
- The transmission and effective sharing of product data in order to integrate the various stakeholders.

These requirements have somewhat slowed the progress of technology acceptance in the industry. There are primarily three different approaches evolving in the industry towards deployment of RFID technology. These include (but are not limited to):

- Slap and Ship (before shipping) Model: This is the simplest of all models and hence the most widely used. It does not interfere with the existing production systems of manufacturers and suppliers. The products are produced as they are in a non-RFID system and packaged as well. Finally, the most external packaging (if the unit is at pallet level) is broken down and the RFID tags are attached. Once the process is complete the palletizing is done again. This model is suited for small to medium scale RFID operations. Also, this is a standalone operation, based typically in the warehouses and not the production facilities.
- Slap and Ship (at the end of production line) Model: This involves attaching the tags just before packaging, as the product is coming off the production line. This is a slight

improvement as it avoids the wastes of the previous model. Obviously this will be costlier as tagging operation will occupy shop-floor space and drain packaging resources.

- Integrated Systems Model: This model includes the integration of the RFID tagging equipment with the existing packaging systems. This could be easily achieved by making the different packaging lines share the tagging equipment, by either keeping the equipment mobile or by integrating the equipment into the packaging line processes. This will significantly affect the current state of affairs in the packaging line and will involve redesign of some high speed packaging lines including packaging machinery. This may be the future model of choice because of its ability to produce tagged packages (or integrated packaging) at high speeds and hence meet volume demands.

II. (C) Technological Standards and Protocols:

Due to the various agencies involved with the development of hardware and software associated with RFID and also due to a lack of consensus (in the industry), there is a wide variety of standards being currently followed. These include from the type of antennas used to the frequency of the radio waves. There has also been a long standing debate over the comparative advantages of using High Frequency (HF) Vs. Ultra High Frequency (UHF). Commercially available RFID tags communicate in different Industrial, Scientific and Medical frequency bands. Table 1 (Bridgelall, 2003) summarizes the different parameters associated with the various frequency ranges. Due to standardized protocols, expanded range and greater data transfer rates UHF has clearly gained an increasing acceptance. Also due to recent mandates by Wal-Mart and DoD the industry is moving towards standardizing the protocols as well as moving towards standardizing the information stored in RFIDs. This latest initiative has led to the creation of

Table 1. Comparison of different frequency ranges

Characteristic	LF (~125 kHz)	HF (~13 MHz)	UHF (~900 MHz)	Microwave (2.45 GHz)
Uniform Allocation	✔	✔	869 & 915	Partial
Protocol Standards	Fragmented	ISO15693	ISO18000	ANSI
Cost (Billions)	> 50¢	< 15¢	< 15¢	< 15¢
Range w/ Mobiles	< 8"	< 8"	> 10 feet	> 2 feet
Data Transfer Rate	10 kbps	30 kbps	256 kbps	256 kbps
Adhesive Labels	✘	✔	✔	✔
Proximity Limitation	Metals	Metals	Liquids	Liquids
Interference	Motors	-	Cell Phones	WLAN

Emerging Market Dominance

Electronic Product Code Generation 2 (EPC Gen 2). The structure of EPC is similar to the existing UPC barcode (though there are differences). The similarity stems from the fact the EPC is based on the Global Trade Item Number (GTIN) which is an umbrella group monitoring the current UPC system. The EPC basically consists of one header and three sets of data. The header identifies the EPC version number (so that different versions can be used in future). The first data set indicates the EPC manager i.e. the manufacturer of the product. The second data set is called the Object Class which refers to the type of product being tracked (usually called the Stock Keeping Unit). The third data set is actual serial number which will indicate when and where the product was made (Atock, 2003). The difference between UPC and EPC is that EPC has a unique code for each item while UPC does not. Furthermore, standardization of data storage on tags will bring down the costs and help in mass deployment of the technology. The EPC already has the support of the Uniform Code Council and EAN International, which are the two main bodies regulating the present international barcode standards.

III. Applications:

It is estimated that up to seven percent of the global drug supply is counterfeit. Also, on an average the pharmaceutical industry spends U.S. $2 billion annually on overstocked or outdated products (Hartman, 2004). These are just examples of one industry sector that will benefit from RFID application. It is outside the scope of this paper to completely capture the applications and implications of RFID technology across all the industries. There will be however, significant impact on the pharmaceutical, food, beverage and electronics packaging industries. This is not only due to the volumes associated with these industries but also due to implicit security issues, especially in the pharmaceutical and food industries. FDA has already recommended RFID deployment to the pharmaceutical industry at an item level (FDA, 2004). This in turn may impact the way in which the pharmaceutical packaging industry works. Not only will there be changes to the packaging materials (e.g. substrates) and packaging processes but probably also to the associated packaging machineries as well (once the high speed integrated model is used).

Overall the RFID application spectrum can be characterized as:

- Security and Anti-Counterfeiting Applications: In a recent pilot study conducted by a host of companies in the United Kingdom (including Merck Pharmaceuticals, British Telecom and Schering Healthcare) RFID was tested for effectiveness in checking for security and authenticity of drugs(Labels & Labeling, 2004). The unique factor in this study was that it bypassed the supply chain and used testing only at the point of manufacture and the point of sale. This 'authentication at the point of dispensing' study provided real time data to doctors and chemists, and prevented dispensing of illegal, expired or counterfeit drugs.
- Logistical Applications: Companies like Wal-Mart, Target and DoD have realized that RFID might be the solution to the supply chain problems that occur to due to an array of suppliers and the associated vendors . Real time tracking of goods is the biggest market for RFID tags. In the United States alone the pharmaceutical market offers a potential of 12 billion tags annually at the item level (ARC, 2004). Logistical differentiation is what helps retailers like Wal-Mart keep the prices low by reducing the number of lost, spoilt and broken products. Since RFID has become part of the strategic outlook of these organizations, the demand for these tags and hence their impact on the product and packaging suppliers (and their respective supply chains) is expected to be huge. Data analysis and consolidation, product tracking, customer preference tracking, automatic reorder processing and vertical and horizontal system integration are just a few of the logistical roles RFID is expected to play.
- Monitoring and Detection Applications: Monitoring of food and pharmaceutical products with RFID is already underway in the industry. Manufacturers are using RFID technology in products to indicate temperature abuse (Want, 2004). Since the risk of contamination (e.g. Salmonella in chicken) is greatly enhanced during elongated exposure of food products to warm temperatures, it is critical to know about the quality of food at the point of purchase. Moreover, the reader can easily detect all the spoilt food in the grocery store without any human involvement and indicate the exact position and

condition of the food item to the operator. RFID is also being used by electronic packagers for impact data. Since there is a threshold value for the amount of stress that the packaging can take before transferring the impact to the product itself (e.g. computers) there is a business case for RFID deployment. The RFID tags automatically record stress values, acceleration and any damage incurred. Further, it relays this information to the reader when the items are being loaded for transportation and also when the retailer receives the shipment, hence obviating the need to check individual units. Another critical application has been in tamper proofing of the food and pharmaceutical packaging. RFID allows remote sensing of any tampering and loss of integrity of packaging, irrespective of the volumes (as long as it is within range). Nestle is using RFID enabled reusable trays for confectionary processing that send real-time data on the cleanliness of trays and hygiene of the product (Shutzberg, 2004).

IV. Challenges

As is the case with any new technology, RFID brings to the table new opportunities and challenges. The challenges posed by RFID can be broadly divided into three categories:

- Technological Challenges: The lack of uniformity of technology , lack of standardization of EPC data exchange protocols, need for integration with the existing Enterprise Resource Management (ERP) Systems and synchronization of data correction mechanisms in the supply chain are only some of the technological challenges. Even after a decade long intensive development, different countries allow the use of different frequency bands for RFID. Table 2 (Bridgelall, 2004) gives a quick snapshot of the global RFID frequency allocations. This will create obstacles because RFID tags made in one country might have problems exchanging information with readers in another. Furthermore the integration of RFID into the existing ERP systems will pose another challenge. The importance of middleware has already been discussed in section II (a). The stability of middleware along with its capability to smoothly integrate with existing organizational information systems such as SAP and PeopleSoft will be critical to any measurable success of RFID. Apart from the software challenges there are certain obstacles in hardware as well. One of the biggest problems is the loss or weakening of RFID signal emanating from antenna in the tag. This phenomenon is known as Return Loss (%age of the original antenna signal strength that is lost during transaction with the reader). There is a significant reduction in RFID signal if the packaging has excessive amounts of metals (i.e. cans) or plastics and also if the food has high moisture content.

Table 2. Global RFID frequency allocation

Frequency	Un-licensed Operation
125 kHz	World-Wide Allocation
13.56 MHz	World-Wide Allocation
458 MHz	Singapore, U.K., Hong Kong (500 mW/45 kHz)
865 MHz to 869 MHz	**Under Development for SRDs in Europe CEPT/ERC/REC 70-03 E** (500 mW/250 kHz now – 2W request for 866.6 MHz under review.)
902 MHz to 928 MHz	North and South America, Taiwan (1 watt spread spectrum)
918 MHz to 926 MHz	Australia, New Zealand, South Africa, China (~1 watt/varying bandwidth)
2.45 GHz	World-Wide Allocation

Return loss will be the biggest concern in case of omnidirectional antennas, such as dipoles. In a recent study (Foster & Burberry, 1999) it was observed that a can of tomatoes caused a return loss of 20% while a regular plastic beverage bottle resulted in a return loss of 16%. Furthermore, dielectric products can cause a change in the resonance frequency of the system.

- Security Challenges: Some privacy concerns have already been raised with respect to the use of RFID technology. The whole debate centers around the possibility that if the tags were to remain active (intentionally or unintentionally) even after the customer had made the purchase, it could be used to track customers (Alfonsi, 2004). Also, there is a similar concern as is to the use of credit cards with the monitoring of buying patterns.

- Financial Challenges: The biggest of all challenges will be to bring down the cost of RFID tags. The cost of tags itself is a huge concern because it is a repetitive cost. However, with the increase in volumes this has been reducing, with various industry estimates for EPC tags being as low as a nickel per tag (Ward, 2003). There will be however; other substantial costs as well – costs of tag readers, tag printers, technology infrastructure needed to support RFID, and cost of services for creation, maintenance and upgradation of the system. Since most of these are recurring costs, RFID will require absolute commitment from the organization, which has been difficult to come by until now.

V. Implications and Future

Many industry reports (Costlow, 2004), white papers (Shutzberg, 2004) and government reports (FDA, 2004) have all indicated their preference for the technology. The fact that government (United States DoD, FDA) and industry (Wal-Mart, Target, Merck Pharmaceuticals) are simultaneously pushing for the adoption of RFID makes it all the more promising. Researchers at MIT’s Lemelsen Center ranked RFID as one of the top ten innovative technologies (competing with internet, personal computers, cell phones etc.) in the last 25 years (CNN,2004). There seems to be a consensus in the industry that the charge (for RFID adoption) will be led by the pharmaceutical sector, closely followed by the food, beverage and electronics industries because of the high stakes and volumes, and better margins involved in the respective businesses. From manufactures such as Nestle, International Paper, Philips, Unilever, and Procter & Gamble to retailers like Wal-Mart, Safeway and Target, have all initiated their RFID feasibility programs. As mentioned in earlier sections, there will be significant challenges. The biggest challenges will come for the information technology and packaging industry when the manufacturers and retailers will mandate the use of RFID. Whether the packaging is done at the production facility or at a co-packer, RFID will demand more flexible processing systems which will have a direct impact on the operational efficiency and profitability of the packaging industry.

It is possible that the RFID technology will be married to an existing long range tracking technology such as the Global Positioning System of the United States (Rice, 2005) or the (upcoming) European Union’s Galileo global navigation system. This will enable real time tracking of shipments of materials and goods. So if the shipment starts from China and travels to New York, not only can the shipment’s location be tracked but the condition of each individual item can be known instantaneously. RFID will take some more time to solidify as a pervasive reality, and this has given precious time to the manufacturing and packaging world to evolve.

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