

High Volume, Low Cost Production of RFID Tags Operating at 900 MHz.

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Abstract— This paper describes a strategic approach to the high volume production of low cost RFID tags operating in the 900 MHz band for multiple applications such as transport tracking, retailing inventory, and security access.

WaveZero's core technology resides in the capability to deposit thin layer of metal on plastic film rolls by means of vacuum deposition. Joined with their many years of expertise in the design of Radio Frequency equipment for wireless commercial applications, WaveZero has in the recent past applied this technology to the realization of EMI shielding for the electronic industry.

With this premise, the design and development of an industrial process for the manufacturing of RFID tags using vacuum deposition has been natural for WaveZero. Thanks to the inherent capability of vacuum technology to deposit aluminum in its purest form, WaveZero has been capable of developing cost effective antennas with performance comparable or superior to products realized with different technologies. Furthermore, the use of aluminum makes WaveZero antennas completely recyclable and thus compliant to the WEEE and ROHS normative.

As further demonstrated by the article, the production of low cost antennas has become strategic to the goal of achieving low cost RFID tags. WaveZero, thanks to core technology and the most effective way of depositing metal on plastic film, is acquiring a leadership position in the race to reach the ambitious goal of the 5¢ price tag.

I. BACKGROUND

The use of Radio Frequency Identification (RFID) in commercial applications has been around for 20 years, although the technology is over 50 years old. It has been used in toll collection, to track rail cars, as anti-theft tags on clothing in retail stores, in building security, library systems, as anti-theft devices in your car keys, and even to track livestock, pets, and purebred dogs when implanted under the skin of the animal. The Exxon/Mobil Speedpass system for purchasing of gasoline is a good example of an RFID consumer application.

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Market analysts like Frost and Sullivan¹ and ARC Advisory Group² expect the use of passive UHF RFID in manufacturing supply chain applications to achieve phenomenal growth over the next five years. At that time, the combination of maturing customer mandates and available interoperable standard products will combine to create a burst of growth in the marketplace.

Researchers predict that RFID will be a \$20 billion market by 2013³. Starting from 1999, research has been undertaken to use RFID technology as the next generation of bar codes to enable companies to track the movement not only of cases and pallets but also of individual items in a box. However, only recently, have retail chains and all those along the supply chain been implementing or considering the implementation of RFID technology into their distribution chains systems as the price of the tags has dropped.

About several hundred million tags have already been produced for use in RFID systems. Large corrugated customers are following Wal-Mart's lead. Nestle, Purina Petcare Company, the U.S. Department of Defense, Proctor and Gamble, and Unilever, among others. Wal-Mart has committed to requiring its top 100 vendors to use EPC technology at the case and pallet level by 2005⁴. These top 100 suppliers represent 1.3 billion cases annually⁵.

II. RFID OPERATING MODE DESCRIPTION

RFID system protocol and network architecture mainly consists of two interacting components, the RFID reader and a battery-less (e.g., passive) RFID tag.

Each consumer product would have one of these passive RFID tags (transponder) either on the product itself or on its packaging. The tag typically consists of a bi-dimensional antenna built on polymeric substrate and a microchip the size of a grain of sand electrically connected with the antenna. Each chip contains in its memory a unique

¹ www.frost.com/prod/servlet/report-brochure.pag?id=A196-100-00-0.

² www.arcweb.com/research/ent/rfid.asp

³ *RFID: Just the Facts*, page 4.

⁴ *Board Converting News*, v. 19, no. 42, Oct. 20, 2003, p. 1.

⁵ *Official Board Markets*, v. 79, no. 42, Oct. 18, 2003, p. 4.

Electronic Product Code (EPC), the unique number that identifies a specific item in the supply chain. The products are then packaged into corrugated containers that also have their own RFID tags and then onto pallets with their own tags.

As the pallets leave the consumer product company, contract packager, or corrugated box manufacturer, an RFID reader positioned above the loading dock door scans the RFID tags with radio waves. The tag then converts the radio signal into DC power necessary to start broadcasting the tag's EPC code back to the reader via the digital modulation of the backscattering signal. The recent introduction of Generation 2 EPC components has made the connection between the reader and the tag more robust in the environment and with superior privacy.

Throughout distribution, the location of the product is continually monitored by its RFID tag. When the product arrives at the retail distributor and at its final destination (retail store), it goes through RFID readers in the unloading area. There is no need to open the boxes to check the shipment for identification purposes. Stores would have their own readers at their docks and even on their shelves to monitor inventory levels. Eventually, the consumer could leave the store without having to stop by a cashier -- the readers at the store's exit would recognize all the items. The customer would swipe his credit or debit card and payment would be made⁶.

RFID will use available and usually unlicensed bands of radio waves for transmission of data, either HF or UHF. The higher the frequency, the greater will be the distance in the ability to read the tags. This paper focuses on the solutions for manufacturing products operating in the 900 MHz band.

III. RFID BENEFITS

The major benefits for retailers can be summarized in the following list:

1. Better inventory management,
2. Reduced administrative errors,
3. Reduced cost of direct labor in receiving and goods check-in,
4. Reduced attrition,
5. Higher product availability leading to higher sales,
6. Reduced loading time and faster check-out⁷.

⁶http://archive.epcglobalinc.org/aboutthetech_idiotsguide.asp. EPCglobal (www.epcglobalinc.org), a joint venture between EAN International and the Uniform Code Council, is a not-for-profit organization entrusted by the auto-ID industry to establish and support the EPC Network as the global standard for auto-identification of any item in the supply chain. 113 S. West Street, P.O. Box 25708, Alexandria, VA 22313 (877) 836-2422, f (703) 836-2795, info@aiccbox.org

⁷ *Strategies for Deriving Value Beyond RFID Compliance*, Christian Hanebeck, GlobeRanger Corporation White Paper, November 2003, p. 6.. GlobeRanger Corporation

To economically quantify the advantages of RFID implementation for retailers, it is enough to say that the deployment of \$90,000 RFID network at a store with 50,000 items of which only 30% are tagged, would feature a 180% return of investment (ROI) within a year⁸.

However, if strong advantages are evident for retailers, suppliers, carriers and manufacturers are not reaping the same benefits from the deployment of RFID while they are being asked to pay the price. The problem clearly focuses on the cost of the single tag, currently still not competitive enough to guarantee suppliers a ready return on investment from the deployment of the technology⁸.

This White Paper focuses on the technological approach to the tag cost problem that hinders the expansion of the industry. However, before moving into the details of this solution and its advantages in the manufacturing of high volume RFID tags at low costs, it is necessary to analyze the state of the art today.

IV. STATE OF THE ART IN RFID TAGS MANUFACTURING

The major processes involved in the manufacturing of RFID tags are listed in the following table:

- Antenna production process
- Chip assembly

Both of these activities have gone through heavy development in the last few years with the purpose of increasing the throughput and reducing the final cost of the tag. This paper separately analyzes the current solutions adopted in the market today.

Antenna Production Process

The most popular processes currently on the market for the production of bi-dimensional antennas are:

- Chemical etching
- Conductive ink printing

Chemical Etching is an established technology used for the realization of printed electronic circuit boards. In order to reach the necessary volume requirement, the technology has been modified adopting a roll to roll process where copper tape roll typically 20-40 micron thick is glued to a polymeric roll substrate, typically PET. The copper film is then masked with a photo-resist mask and inserted in a chemical bath where the exposed copper is chemically attacked and removed, thereby creating the desired pattern. The photo-resist mask is then be removed with standard process.

(www.globeranger.com) is a provider of RFID systems and software.

⁸ <http://www.silicon.com/hardware/storage/0,39024649,39119661,00.htm>.

The strongest advantage of this process, originally invented for the development of flexible circuits, is its availability and well known manufacturing cost parameters. The currently estimated cost for copper etching is \$10 per square meter of produced material that, for 600 antennas per square meter, is equivalent to 1.6 cents per antenna.

Conductive ink printing is certainly the most approachable process on the market. Based on flexographic equipment, the antennas can be printed on a polymer roll in a single step with no need for masking. The major drawback for this technology is the inherent cost of the material used in the process, usually a conductive ink loaded with 30% [80%!!!] silver flake particles, and the higher surface resistivity of the conductive layer, a feature inversely proportional to the final performance of the antenna.

Perhaps of even greater concern is the inherent environmental impact of using silver. As RFID tags are used and disposed of, their increasing density within landfills around the world will eventually jeopardize ground water supplies thus leading to requirements for recycling as is presently done for electronics (e.g., the European Union's WEEE Directive).

Chip Assembly

The major challenge in assembling the active component onto the antenna circuit is represented by the small size of the chip itself, the need for low temperature attachment and the required throughput capacity.

Chips for passive RFID tags had their size reduced to sub millimeter dimensions in order to optimize the cost of the component thus increasing the number of chips per wafer. This of course creates technical problems when the chip, whose pads are now below the 100 micron size, needs to be connected to the antenna at high speed.

In order to overcome this problem, pick and place (PnP) equipment manufacturers have developed innovative technology enabling the attachment of the chip to the antenna roll using standard flip chip technology and dispensing fast curing conductive adhesive at high speed. The process is quite simple and is capable of attaching about 10,000 components per hour, equivalent to about 70 million tags per year at a cost per equipment of less than \$1 million⁹.

Some tag manufacturers have approached the problem from a different point of view, focusing their attention on the production capacity and thus purposefully adopting another process, the "strap" attach. In this solution, the chip is attached to a polymeric carrier film in roll form at high density and high velocity using roll-to-roll equipment. This polymeric carrier has previously been prepared with small caves on the surface to receive the chip which corresponds to large conductive pads. Proper geometry of the cave and chip die guarantees the proper positioning of the chip on the

film¹⁰. Once this step is completed, it is possible to couple the roll containing the straps with the roll containing the antennas and accomplish the final assembly by using dispensed adhesive. Of course, due to the different density and location of the chip on the strap carrier, each strap needs to be singulated before attachment. The advantage of this process, as stated by its major supporters, is the possibility to assemble chips at a very high velocity. The disadvantage is that the process consists of two-step phases and that the singulation of the strap causes in some way a reduction in the speed of the process. While it is possible to load the straps at incredible speed, the final assembly of the strap on the antenna is still a process regulated in its throughput by the curing of the adhesive used for attachment.

V. WAVEZERO STRATEGIC APPROACH

WaveZero believes that the technical ownership of the manufacturing processes involved in the production of RFID tags can sustain a continuous cost optimization associated with superior quality of the final product and thus guarantee a leadership position in the market.

To this purpose WaveZero has been working to perfect the antenna design, antenna manufacturing and the chip assembly processes and integrate them in a single highly automated production line. This will differentiate WaveZero from all the other players in the RFID arena that, for one reason or the other, have only invested in a particular aspect of the production process underestimating, for example, the cost impact of the antenna in the whole process.

In light of these comments, the preferred process consists of:

- Antenna design
- Antenna production process
- Chip assembly

Antenna Design

The cost of antenna manufacturing strongly depends on the geometry of the antenna itself. With current designs, typically about 600 antennas per square meters can be produced. If the process used for producing antennas costs \$10 per square meter it is easy to understand how the single antenna can cost about 1.5 cents each causing a sales price of about 3 cents a piece.

It becomes therefore very important to control the geometrical parameters of the antenna design in order to be able to have the densest packaging of antennas per square meter. These parameters are:

- Frequency
- Active component impedance characteristics

WaveZero, with its many years of experience in wireless design, has all the technical capabilities in house to design and develop an antenna optimized for both performance and

⁹ <http://www.muehlbauer.de/>

¹⁰ http://www.alientechnology.com/technology/fsa_manufacturing.php

cost by adequately controlling the geometry of antennas and thus packaging more antennas per square meter. However, as explained in this paragraph, this alone would not be sufficient if not supported by the further control of the manufacturing processes parameters used for producing the final tags. The integration of a design capability with the manufacturing processes used to produce RFID tags is the key to the cost optimization of the product which is so necessary to succeed in this market.

Antenna Production Process

WaveZero's intellectual property¹¹ resides in its capability to deposit a thin film of metal on polymeric substrates using a vacuum metallization process like sputtering and/or thermal evaporation.

Vacuum deposition is an established technology that has been historically used in the packaging industry for taste preservation of snack food. The reason for adopting such methodology, of course, resides in the lowest cost per square meter of RFID antenna achieved by vacuum deposition when a thin layer of metal is deposited on plastic.

WaveZero has been applying vacuum deposition in the use of electromagnetic interference (EMI) shielding which is manufactured by depositing a film of metal on a plastic substrate within a vacuum chamber. WaveZero has adapted this process to bi-dimensional RFID antennas. This development has placed WaveZero in the position to produce RFID antennas at the lowest possible costs available in the market today.

Beyond the lowest cost per square meter of plastic roll dispensed, vacuum deposition features other advantages like:

- Simple process all accomplished within a chamber
- Highly automated controls (minimum labor)
- Multiple metals and layering possible
- Exceptionally low surface resistivity
- Antenna tag performance achieved with minimum coating thickness and thus minimum material usage
- Compliant with EU RoHS and WEEE Directives
- Entirely green process

Of particular interest are the advantages achieved by using aluminum as the metal of choice. In this case, together with the cost optimization, the product complies with all ROHS requirements regarding hazardous materials. Indeed, aluminum is perhaps the most non-toxic metal known with no deleterious affects on humans, animals, or the environment. From a recycling point of view, and in recognition of the impact the European Union's WEEE Directive is having, the aluminum and polymer film are conveniently and economically recycled through any number of approaches. The fact that the aluminum layer is measured in only microns of material makes the recycling

effort all the easier because the amount of material is minute¹².

Due to the excellent volume resistivity of the metal layer deposited with vacuum deposition, WaveZero has been able to comply with RFID tag requirements by depositing only a few microns of metal, much less than any other technology available on the market today.

The production process developed by WaveZero is based on highly automatic vacuum deposition equipment depositing a thin film of metal on polymeric rolls. The rolls of plastic are placed within the hermetic chamber where a vacuum is created within a few minutes. At that point no human intervention is necessary to perform the metallization process. In theory one technician can easily attend to multiple vacuum deposition units, making this process highly effective and repetitive with a low labor cost. The equipment can be designed for different volume requirements, from a few million antennas up to 100 million antennas per year, so that upfront investment is matched to the throughput capacity.

Chip Assembly

WaveZero's production process is implemented in the form of multiple manufacturing cells each with a production capacity of about 50 million to 100 million antennas per year, depending upon the precise size and configuration of the cell components. Each cell will consist, in general, of one or more vacuum deposition chambers and one chip assembly machine. This configuration will allow WaveZero to duplicate this configuration many times assuring excellent scalability of the process which will keep up with the market demand.

Chip assembly performed by PnP machines fit this strategy better than strap attachment thanks to its inherent process simplicity. The reason is that, if strap attachment technology is excellent in placing the chip on the straps, it still has problems in transferring the strap to the antenna. Today, the attachment rate of straps to antennas is in the range of 10,000 units to 20,000 units per hour per piece of equipment compared to 10,000 units per hour with one PnP machine. Due to the superior scalability of the PnP approach, this process features a lower total cost of ownership per unit produced.

VI CONCLUSION

The WaveZero production process consists of metallization of the antenna rolls and then chip attachment to the same roll. No other processes will be required to complete the production of the tags and the chip will not require any special etching process as is used for the strap process. The

¹¹ Numerous patents and patents in process both in the U.S. and internationally protect WaveZero's technological underpinnings involving the vacuum deposition of thin functional films.

¹² As an illustration of how effective a small amount of vapor deposited metal can be, the 120 inch reflective mirror located at Lick Observatory, Mount Hamilton, San Jose, California was metalized with less than one (1) ounce of aluminum.

wafers can therefore be processed without any additional process other than standard cutting.

Vacuum deposition of metal on plastic film is the core technology of WaveZero. Supported by internal design capability, the production of antennas in house is central to WaveZero's position in the RFID market.

The manufacturing process can be finalized with an in-line radio test of each antenna on a one by one basis. Each failed tag is marked for disposition. This approach to tag production guarantees a 99.7% first pass yield reducing the overall production cost per tag. Due to WaveZero's intellectual property in the production of bi-dimensional flexible antennas on plastic film and the strategic decision to integrate this capability with low cost high efficiency chip assembly, the lowest RFID tag costs can be obtained.

Since every player in the industry has equal access to all of the active components available on the market, antennas represent the strategic cost element in the rush to achieve the lowest cost tag. In this regard, WaveZero has established and maintains a worldwide technological leadership position that minimizes the production costs of RFID tags.

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