Low Cost and Reliable RFID Tags for All Frequencies

Kevin Chung, Ph.D.
Avante International Technology, Inc.
70 Washington Road, Princeton Junction, NJ 08550
Web: www.avantetech.com Email: avante@aitechnology.com

Introduction

The realization of commercial savings with the use of RFID technology have been notably acknowledged with the endorsement of major companies such as Gillette, AstraZeneca, Gap, and particularly Wal-Mart [1]. Major milestones of adoptions are currently scheduled for 2004-2005 timeline.

Attentions have been rightly placed in the cost of RFID chips. The possibility of the Alien's "Fluidic-Self-Assembly, FSA" process and any other process that can increase yield per wafer will certainly help to further the roadmap for the paradigm shift from barcode to RFID in the future. This paper hopes to include other aspects of the RFID story that must be studied carefully to avoid a false start and failure in the field.

Besides the cost of chips, the following are the other success factors that must also be included to ensure successful deployment of RFID technology for the expected retail and other commercial uses:

- Inlay reliability and cost
- Reliable contact from chip to inlay or to "jumper-strap"
- Reliable interconnection from "jumper-strap" to inlay
- Antenna arrays and scanners for different application environment
- Prevention of tampering and documentation of changes of encoded data in an open ISO environment

All of the five other aspects of cost and reliability have not been studied either academically or commercially. The technologies and infrastructures required for fulfilling these requirements and producing reliable low cost RFID tags have been left to the manufacturers to ponder. In this paper, we will examine them in detail.

We will also examine in detailed all of the factors that affect the reliability of smart tag being made. We believe this aspect of RFID technology deserves much more studies and attention before enthusiastic pioneering companies are disappointed and discouraged.

Form-Factors of Inlays Determine their Applications

There are three radio frequency ranges that are currently driving the smart tag markets for different applications. Higher frequency of operation typically yield longer read distance but is also balanced with the much more sensitivity to the substrate and contents that the RFID tags are attaching to.

The first major frequency is 13.56 MHz that is internationally accepted and operating under the ISO standard: 14442 A & B (short range), 15693 (long range).

The second major frequency for RFID that has received a lot of attention is the 915 MHz range that operates in the frequency range commonly used for the analog cellular mobile phone operation. The longer free-air read distance attracted more potential users in United States today for smart tag application.

The third frequency range is the 2450 MHz (2.45 GHz) range. This is close to the commonly used frequency for digital cellular mobile phone. They are currently in testing for airline baggage tracking in United States.

One of the more significant implications of the different frequencies of operation is that the smart tags are in different form-factors in terms of shape and size of conductive traces on the inlay. The shape and size is critical for the 2450 MHz and slightly less so for the 915 MHz tags.

There is only one single shape and size that will be functional for the 2.45 GHz smart tag as typified by those that are currently sold by SCS (Figure 1). Similarly, the smart tags for 915 MHz are also limited to one size and shape with slight variations as typified by tags sold by ALIEN and MATRICS (Figure 2)

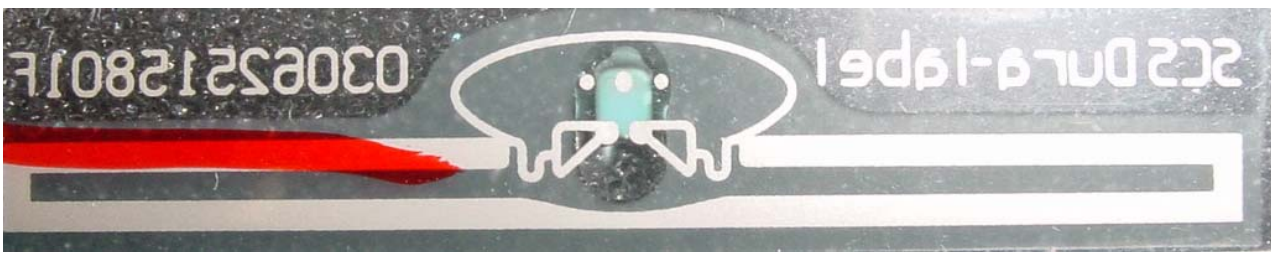


Figure 1: Picture of Size (1.8"x0.3", typical for SCS tag) and Shape of Smart Tag Operating @ 2.45 GHz

Figure 2: Picture of Size (3.5"x1.2" typical from Alien Technology Corp.) and Shape of Smart Tag Operating @ 915 MHz

level of supply chain management. Item-level tracking requires smart tags that can fit into all sizes and shapes from syringes to CDs to boxed items.

In the same survey, 51% of the potential users want to use smart tag technology to help track assets of all size and forms. Assets tracking application of smart tags have similar requirements to that of the item-level tracking.

In the same survey, more than 46% want to track works-in-progress. Works-in-progress tend to be more controllable and are typically placed in larger totes suitable for such manufacturing. Thus, work-in-progress may be able to use large tags if that is required.

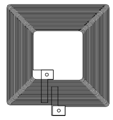
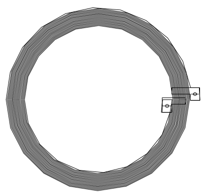
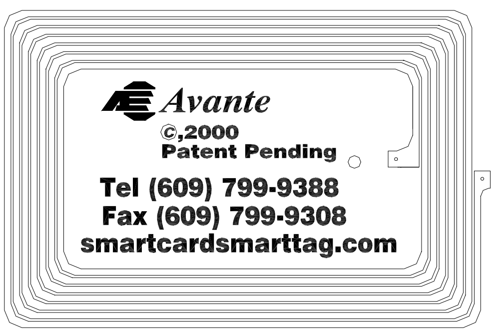
In a recent report by Accenture on the supply chain management with the use of RFID includes: 50-80% improvements in productivity for the ability to track receiving and product check-in, 5-10% gain for put-away and replenishment, picking and packing operation in the pallet and tray level also see marked enhancement. "The value of RFID increases as you go from tagging pallets to cases to individual units." Theft in warehouse (10-15% of total inventory shrinkage) can also be reduced if RFID is used on individual units." [2]

The smaller RFID form-factor smart tags are suitable for both packaging items of smaller and odd sizes as well as larger packaging and pallets. The larger size tags can only be used for larger packaging of boxes and pallets.

That is, the small size of the 2.45 GHz tag may be applied readily on items of all sizes. However, the undesirable effect of attenuation and absorption by water, liquids, and thus substrates that may contain excessive amount moisture all but eliminates this range of frequency for use in item level packaging and tracking. It may be used for items placed in totes. RFID tags by SCS have been in testing for use in airline baggage tracking for a while. However, because of the moisture-sensitivity, rain and snow will post issues when bags are being transported outside the controlled terminal areas.

The larger size tag of 3.5 inch by 1.2 inch for the 915 frequency placed some limitation for its used in item level tracking. However, it is small enough for some of the unit level applications and almost all of the box and pallet-level tracking. While they are still sensitive to liquid and moisture, they maintain better than 80% of its usefulness. One of the major advantages of 915 MHz is that they have sufficient read range of 3-4 feet in most cases at 4 watts power level. The real trade-off of substrate sensitivity and effective read distance will become more obvious with more deployments.

The frequency range of 13.56 MHz is more established and more commonly accepted by all countries of the world and thus making it immediately more useful for item or unit level tracking. The near-field effect used for reading and encoding the smart tags allow the size and shape of the inlays to be made in almost any size and shapes. Figure 3 is a typical representation of some of the smart tags size and shapes that have been optimized by Avante International Technology, Inc.

<table>
<tr><th>No.</th><th>DIAGRAM</th><th>APPLI-
CATIONS</th><th>SIZE</th><th>READ
DIST.</th></tr>
<tr><td>1</td><td></td><td>Articles
Labels</td><td>0.6"X0.6"</td><td>>8"</td></tr>
<tr><td>2</td><td></td><td>Syringes</td><td>1.3"x0.4"</td><td>>8"</td></tr>
<tr><td>3</td><td></td><td>CD</td><td>1.15" OD</td><td>>13.5"</td></tr>
<tr><td>4</td><td>
</td><td>Cards</td><td>2"X3"</td><td>>36"</td></tr>
<tr><td>5</td><td>

SCALE: 1=2</td><td>Baggage</td><td>5"x2"</td><td>>40"</td></tr>
<tr><td>6</td><td>

SCALE: 1=3</td><td>Pallets
Totes</td><td>10.8"x3.1"</td><td>>60"</td></tr>
</table>

Figure 3: Schematic Representation of Smart Tags FORM-FACTORS for Different Level of Item and Unit Tracking from Syringe to CD to Human and Pallet

Some people believe that operating at the same 4 watt level @13.56 MHz means leads to dramatically shorter in read-write distance. While it is true that for similar size smart tag of 3 inch by 2 inch can only be read at approximately 3 feet, this slightly lesser read distance may be easily compensated with suitable antenna array to double its read distance. More importantly, large tags of 10 inch by 3 inch can be read-write at a distance of up to 5 feet.

The combination of such versatility in different sizes and shapes and its immunity to water and moisture make them better suited for item level labeling and tracking. The availability of different antenna arrays [3] for baggage tracking, work-in-progress tracking, and receiving and shipping tracking at up to 8 feet/second conveying speed with full orientation independence help compensate its short coming of a slightly lesser read distance of operating at lower frequency of 13.56 MHz.

Table 1 below is a comparison of the smart tags applications for the three major frequencies at 13.56 MHz, 915 MHz and 2.45 GHz.

Table 1: The Different in Sizes and Shapes of Inlays @ Different Operation Frequencies

OPERATING FREQUENCY	***13.56 MHz***	***915 MHz***	***2450 MHz*** ***(2.45 GHz)***
Typical # of Loops @ 2 inch x 3 inch	<10	1 (3.8"x1.5")	1 (0.3"x1.5")
Thickness Implication	Can easily fit into a single layer.	Can easily fit into a single layer.	Can easily fit into a single layer.
Width and Length	Largest can be ♦ 10"x6" Smallest can be ♦ 0.6"x0.6" ♦ 0.2"x3.0"	Limited flexibility ♦ 3.5"x1.2" ♦ 3.9"x0.4" ♦ 2.2"x1.2"	No flexibility
Shape	Round to square to rectangular	One basic shape only	One shape only
Applications	♦ Larger tag of 2"x10"for pallet ♦ 2"x3" for card size ♦ 3"x4" for badge ♦ 0.6"x0.6"for smaller articles ♦ 0. 2"x1.8" for smallest syringes ♦ 1.2" circular shape for CD ♦ Any size and shapes in between ♦ Can be placed on any article for article-level tagging of any size and shape	♦ Can be placed in articles larger than the sizes of 2.2"x1.2" flat surfaces. ♦ May be limited by the substrate (water and liquids sensitive) ♦ May be subject to health concern when too close to operators or users at several times higher power level than cell phone ♦ Article level tagging is more difficult for smaller objects	♦ Can be placed in almost all articles ♦ May be limited by the substrate (water and liquids sensitive) ♦ May be subject to health concern when too close to operators or users at several times higher power level than cell phone ♦ Article level for most articles other than those smaller than the one-size tag

Form-Factor Affects the Read Distance and Read Rate

As illustrated in Figure 3, smart tags of all sizes can be made for 13.56 MHz operating frequency. Each shape and size affects the read distance because of its ability to "extract" electromagnetic energy from the scanning field.

The one-size-only nature of 2450 and 915 MHz smart tags also means the same read and write distance for all of its tags as far as "free-space" measurements are concern. Table 2 is a summary of the read distances of smart tags operating at different frequencies.

Table 2: Size of Smart Tags and Read Distances at Different Frequencies

OPERATING FREQUENCY	***13.56 MHz***	***915 MHz***	***2450 MHz*** *(2.45 GHz)*
Wavelength	♦ In the FM frequency band ♦ 68 ft, near field	♦ Similar to the analog cell phone frequency ♦ 1.0 ft, plane wave	♦ Similar to the digital cell phone frequency ♦ 0.4 ft, plane wave
Typical FREE SPACE Read Distance	♦ 5 feet max. ♦ 8-60 inches depending on size of tag	♦ Up to 17 feet ♦ 7 feet average ♦ 3-4 feet typical	♦ >17 feet max. ♦ >7 feet average
0.6"x0.6"	♦ >8 inches	♦ NA	♦ NA
1.3"x0.4"	♦ **>8 inches**	♦ NA	♦ **>10 feet**
1.15" OD Circular	♦ >13.5 inches	♦ NA	♦ NA
2"x3"	♦ **>36 inches**	♦ **>10 feet**	♦ NA
5"x2"	♦ >40 inches	♦ NA	♦ NA
10.8"x3.1"	♦ **>60 inches**	♦ NA	♦ NA

It is obvious from Table 2 that the versatility of sizes and shapes of RFID tags operating at 13.56 MHz is not matched by the higher frequencies of operation. It should also be obvious that there are differences in read distances for different sizes of inlays.

Suitable use of each size and shape must be matched by the use of suitable antenna arrays. A well-engineered antenna arrays for specific applications not enhance the read distance by a factor of two. A well-designed antenna arrays can also be used to ensure 100% read rate when multiple items with RFID tags placed in all different orientation.

Form-Factor Determines the Costs of Inlays

Making reliable smart tag is technically easy. By simply soldering all interconnections from the chip level to the inlay level easily ensure the read distance and read rate of smart tags. However, the task of making reliable RFID smart tags at useful prices of $0.05-0.50 becomes exponentially more difficult.

There are three basic factors that affect the pricing and reliability of RFID smart tags:

- Cost of chip
  ($500/12,500 chips yield per chip price at $0.02; $500/125,000 chips yield per chip price at $0.002)
- Cost of inlay
  (Determined by the price of substrate with metallization and the size of the tag. High temperature substrate such as polyimide may cost as much as $100 per pound while polyester with copper may be close to $10 per pound. This means that the cost of inlays may be as high as $0.10 to as low as $0.02 for PET @ 3.5"x1.2" tag.)
- Cost of Assembly
  (Typically $0.02 per tag at the industrial standard of $0.01 per I/O)

Table 3 below is a summary of the cost for the current RFID smart tags that are being made.

Table 3: Estimated Price of Inlays for Smart Tags Based on Different Substrate/Metallization for Different Frequencies

OPERATING FREQUENCY	***13.56 MHz***	***915 MHz***	***2450 MHz (2.45 GHz)***
Typical # of Loops @ 2 inch x 3 inch	<10	1 (3.5"x1.2")	1 (0.3"x1.5")
Thickness Implication	Can easily fit into a single layer.	Can easily fit into a single layer.	Can easily fit into a single layer.
Width and Length	Largest can be ♦ 10"x6" Smallest can be ♦ 0.6"x0.6" ♦ 0.2"x3.0"	Limited flexibility ♦ 3.5"x1.2" ♦ 3.9"x0.4" ♦ 2.2"x1.2"	No flexibility
Shape	Round to square to rectangular	One basic shape only	One shape only
Inlay Cost **Copper Etching**	♦ $0.02/0.2 (On Polyimide) ♦ $0.01/0.16 (On PET) ♦ **$0.01/$0.16** (On Solderable ESP7450 by AVANTE)	♦ $0.15 (On Polyimide) ♦ $0.12 (On PET) ♦ **$0.12** (On Solderable ESP7450 by AVANTE)	♦ $0.03 (On Polyimide) ♦ $0.02 (On PET) ♦ **$0.02** (On Solderable ESP7450 by AVANTE)
Inlay Cost **Thin Film Aluminum Deposition**	♦ $0.02/0.2 (On Polyimide) ♦ $0.01/0.16 (On PET) ♦ **$0.01/$0.16** (On Solderable ESP7450 by AVANTE)	♦ $0.15 (On Polyimide) ♦ $0.12 (On PET) ♦ **$0.12** (On Solderable ESP7450 by AVANTE)	♦ $0.03 (On Polyimide) ♦ $0.02 (On PET) ♦ **$0.02** (On Solderable ESP7450 by AVANTE)
Inlay Cost **Thick Film Silver Inks or Deposition**	♦ $0.03/0.3 (On Polyimide) ♦ $0.02/0.20 (On PET) ♦ **$0.02/$0.20** (On Solderable ESP7450 by AVANTE)	♦ $0.25 (On Polyimide) ♦ $0.18 (On PET) ♦ **$0.18** (On Solderable ESP7450 by AVANTE)	♦ $0.05 (On Polyimide) ♦ $0.04 (On PET) ♦ **$0.04** (On Solderable ESP7450 by AVANTE)

From the Table 3 summary, it is clear that etched copper inlays on special solderable substrate ESP7450 available from AI Technology, Inc. in Princeton, New Jersey represents one of the lowest cost with the highest reliability as any other means of manufacturing such smart tags.

For the same "theoretical" cost of RFID smart tags may be in the range of $0.12 for inlay +$0.04 for chip +$0.02 for processing =$0.18 for 915 MHz size.

The same "theoretical" cost of RFID tags for the 2.45 GHz application, the price of the tag is approximately $0.02 for inlay +$0.04 for chip +$0.02 for processing =$0.08.

The price of smart tags for 13.56 MHz may ranges dramatically depending on the sizes even as in the "theoretical" sense. For the smallest tags, the cost includes $0.01 for inlay + $0.04 for chip + $0.02 for processing =$0.07. For the largest tags, the cost may includes $0.16 for inlay +$0.04 for chip + $0.02 for processing =$0.22.

Table 4 is a summary of cost estimations based on the cost of chip that may depend on the process, etc., cost of inlay that depends on size and substrate, and cost of assembly that are fixed. The cost of chips is estimated based on the estimated price of $500 for a wafer that produces 12,500 chips using traditional process and 125,000 chips for the Alien FSA and similar processes. The pricing is obviously hypothetical.

Table 4: Estimated Cost of Smart Tags Based on Different Substrate/Metallization for Different Frequencies

OPERATING FREQUENCY	*13.56 MHz*	*915 MHz*	*2450 MHz (2.45 GHz)*
Cost of Chip	♦ $0.04 (Traditional) ♦ $0.004 ("Alien")	♦ $0.04 (Traditional) ♦ $0.004 ("Alien")	♦ $0.04 (Traditional) ♦ $0.004 ("Alien")
Cost of Inlay	♦ $0.01 (Smallest) ♦ $0.16 (Largest)	♦ $0.12	♦ $0.02
Cost of Assembly	♦ $0.02	♦ $0.02	♦ $0.02
Smart Tag Cost ($500/8" traditional wafer)	♦ **$0.07 (Smallest)** ♦ **$0.22 (Largest)**	♦ **$0.18**	♦ **$0.08**
Smart Tag Cost ($500/8" Alien's wafer)	♦ ***$0.04 (Smallest)*** ♦ ***$0.18 (Largest)***	♦ ***$0.15***	♦ ***$0.05***
Smart Tag Cost ($1000/8" traditional wafer)	♦ **$0.11 (Smallest)** ♦ **$0.26 (Largest)**	♦ **$0.22**	♦ **$0.12**
Smart Tag Cost ($1000/8" Alien's wafer)	♦ ***$0.07 (Smallest)*** ♦ ***$0.22 (Largest)***	♦ ***$0.15***	♦ ***$0.09***

The cost estimation is optimistic based on the chip manufacturers' willingness to offer their wafer at $500 eventually. At this point, the pricing is at least 2 times of this possibility. If the Alien's FSA method of dicing wafer into chips is proven to work efficiently in production, the price of chips can drop as much as to 10% of the estimated cost for chip. That is, the price of the chip can be ignored. The overall cost will be determined by the inlay and assembly costs.

Interconnection Method Determines the Reliability of RFID Tag

There are many assembly methods for connecting the RFID chip to inlay with good reliability. In the first glance, direct attachment of the die to the inlay with conductive adhesive bonding would be ideal and low temperature process and low cost. However, when oxidation of contact pads for the copper or aluminum traces made by chemical etching or thin-film deposition methods quickly degrades the reliability of such interconnection. To prevent oxidation, the contact pads on the inlay must be plated over with nickel-gold, nickel-palladium or nickel-silver in case of copper or aluminum [4], just like the contact bumps on the chip for flip-chip attachment. The costs of such operations make them expensive to produce.

Alternatively, the inlay traces may be printed or otherwise deposited with precious metal ink using the traditional thick-film process. One of the drawbacks of this approach is that the use of thick film printing tends to be costly.

Another drawback is the variation in conductivity when longer traces are printed. Variation of conductivity also induces variation in read-write distance and capability. The third drawback is the difficulty in producing very fine line reproducibly for item-level tracking. Thus, thick film process tends to be used only for the 2.45 GHz and the 915 MHz RFID tags that have simpler geometry and wider spaced traces.

Figures 4a, 4b, 4c, 4d below are pictures and representation of the various interconnection methods used in attaching chip to inlay. RFID tags for 13.56 MHz invariably involved “cross-over” from the end to the beginning of the conductive trace. The most intriguing cost effective method is the use of “chip-jumper” or “chip-strap” where the chip is first prepared into manageable “tab” with ends that are directly solder-able or conductive adhesive attached to the contact pads on the inlay traces [4].

Figure 4a:
Direct flip-chip attachment onto inlay for 2.45 GHz using conductive polymer thick film and adhesive. The key for reliability is to ensure that the polymer thick film ink can be printed with consistent conductivity as to provide the same read distance every time. Because of the relative small size of the chip, placement accuracy must also be sufficient. As size of chip decreases, the placement may need to be handled by special flip-chip bonding equipment rather than the standard surface mounting equipment. Flip-chip bonding systems tend to be slower and more expensive.

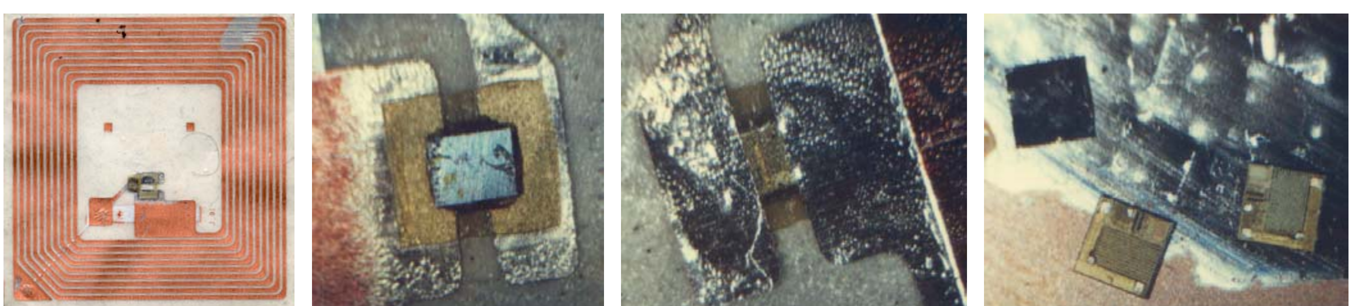


Figure 4b:
Direct compression flip-chip attachment onto inlay for 13.56 MHz made of thin film aluminum. Thin film aluminum can be a very low cost solution. The only concern is the known phenomenon of oxidation of aluminum over time. The contact resistance will continuously increase and at faster rate degradation at higher temperatures.

Reliability will be improved if the contact pads on the aluminum traces are passivated from oxidation with suitable precious metal barrier such as nickel-gold, nickel-silver, etc.

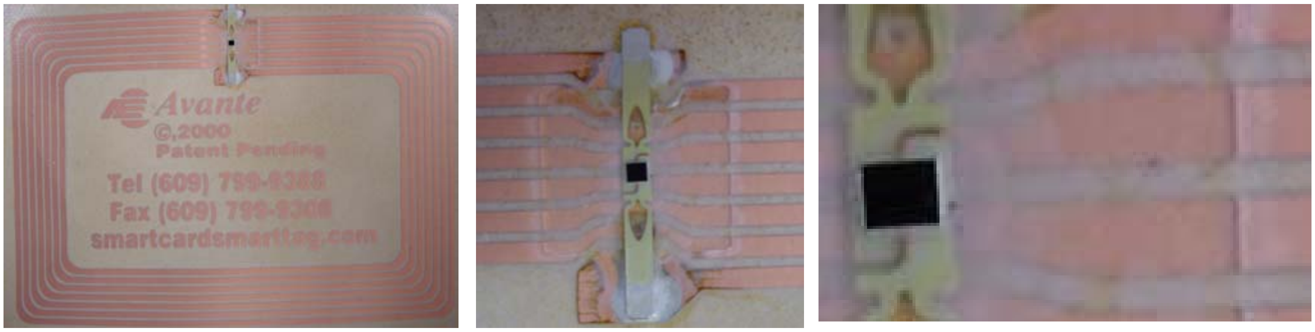


Figure 4C:
Soldering attachment of “chip-jumper” to etched copper for 13.56 MHz inlays made by AVANTE. The “chip-jumper” serves as “cross-over” as well as easily surface mounting pick-and-place device. The connection between “chip-jumper” is soldered onto inlay on substrate with etched copper. Etched copper has an advantage of consistent conductivity and precision in dimension. The proprietary substrate has the performance at high temperature similar to that of polyimide but at the cost similar to PET polyester.

The use of “chip-jumper” interconnection for RFID smart tags and the applications thereof is a patent-pending technology of AVANTE [4]. It has been proven to provide outstanding production yield of over 98% and long-term reliability at temperature as high as 150°C.

This card size tag enable reading at approximately 3 feet and have been used extensively for AVANTE tradeshow leads capturing and retrieval applications that also included walk-through portals.

Figure 4dws:
Conductive adhesive bonding of “chip-jumper” inlay for 915 MHz made of polymer thick film silver. Because of the smaller chip size @ 150 micron, the patented process of FSA is critical in the handling. The “chip-jumper” or “chip-strap” is used to extend the device into size suitable to be handled by traditional bonding equipment. In this particular case, silver conductive ink is used to form the inlay. As long as the conductive traces that are much longer than that of 2450 MHz RFID can maintain consistent conductivity, the performance can be maintained.

The same tag can be produced with etched copper antenna on high temperature substrate such as ESP7450 used for SMART-BADGE made by AVANTE. Etching copper traces will provide 100% yield in terms of consistent electrical performance. If the “chip-jumper” is produced on carrier that can tolerate soldering, the reliability of the soldered joints on the RFID inlay will also be improved for both high and low temperature applications.

The combination of the FSA process and soldering on etched copper are ideal for the reliability and yield as well as the overall cost in the manufacturing of RFID tags.

Table 5: Comparative Reliability of Various Methods of Interconnections for RFID Smart Tags Manufacturing

Chip Bumps to Contact Pads on "Jumper"	**SOLDERING**	**CONDUCTIVE ADHESIVE INTERCONNECT**	**MECHANICAL "COMPRESSION" JOINTS**
	♦ Currently not used ♦ Soldering will be most reliable	♦ Contact pads must finish with precious metal for long term reliability ♦ Used on thick film inlays	♦ **Contact pads must finish with precious metal for reliability** ♦ **Used by most manufacturers**
Interconnection Between "Jumper" & Inlay	**COPPER INLAY (Etched or Thin Film Deposition)**	**THICK-FILM INLAY (Printed Silver Ink on Plastic Substrates)**	**THIN-FILM INLAY (Aluminum)**
	♦ Copper traces are highly conductive & reproducible. ♦ Soldering interconnections are the most reliable ♦ Soldering is a high temperature process that requires high temperature substrates	♦ Contact pads on inlays and chips are precious metal ♦ Used by many manufacturers for 915 and 2450 MHz tags ♦ Longer traces of antenna degrade performance and are more costly	♦ Contact pads on inlays are not precious metal ♦ Used by many for 13.56 MHz tags ♦ Mechanical compression joints are the only one seen on market that will not be reliable
Soldering Interconnection From "Jumper" to Inlay	♦ **Soldering of "jumper" to proprietary AVANTE substrate inlay is a patent-pending technology**	♦ Soldering is not needed ♦ Not seen	♦ Soldering cannot be done easily on aluminum ♦ Not seen
Mechanical Compression Contact Interconnection	♦ Mechanical compression method is sometimes seen ♦ Reliability of copper contacts without Ni-Au is poor	♦ Mechanical compression method can be used with reliability ♦ Not seen often	♦ **Compression contact is used by many for 13.56 MHz tags** ♦ **Long-term reliability and performance is highly questionable**
Conductive Adhesive Connecting "Jumper" to Inlay	♦ Conductive adhesive contact method is sometimes seen ♦ Reliability of copper contacts without Ni-Au is not poor	♦ **Conductive adhesive is a low temperature process** ♦ **Used by many manufacturers for 915 & 2450 MHz tags**	♦ Conductive adhesive has not been used ♦ Aluminum contacts without Ni-Au finish cannot be done
Direct Attach of Chip to Inlay	**COPPER INLAY (Etched or Thin Film Deposition)**	**THICK-FILM INLAY (Printed Silver Ink on Plastic Substrates)**	**THIN-FILM INLAY (Aluminum)**
Soldering of "Jumper" to Inlay	♦ Possible and reliable ♦ Not seen. Would need special substrate	♦ Soldering is not needed ♦ Not seen	♦ Soldering cannot be done on aluminum. ♦ Not seen
Mechanical Compression	♦ Compression method is sometimes seen ♦ Reliability of copper contacts without Ni-Au is poor	♦ Compression method can be used with reliability ♦ Not seen often	♦ **Compression contact is used by many for 13.56 MHz tags** ♦ **Long-term reliability is highly questionable**
Adhesive Bonding of "Jumper" to Inlay	♦ Conductive adhesive is sometimes seen used with poor reliability when copper contacts without Ni-Au is poor	♦ **Conductive adhesive is a low temperature process used by many manufacturers for 915 & 2450 MHz tags**	♦ Conductive adhesive has not been used ♦ Aluminum contacts without Ni-Au finish is not feasible

Performance at Higher Frequency is Affected by Inlay Substrate and Content that are Being Labeled and Tracked

The wavelength of electromagnetic wave at approximately 68 feet means that the reading of the RFID tags will be a near field effect. While the wavelength of 915 MHz and 2.45 GHz is short (1.0 ft and 0.4 ft respectively) it thus interacts with the passive smart tags primarily on the far field effect. The proximity to the microwave regime at 2.45 GHz means that the read distance will be affected by water. The dielectric heating and absorption typically deteriorate the read distance when the RFID tags are placed close to such contents. The longer wavelength at 13.56 MHz is immune to the water and liquid environment.

Table 6: Higher Frequency and Shorter Wavelength Has Different Interaction that is Affected by Substrates and Contents Being Tracked

OPERATING FREQUENCY	**13.56 MHz**	**915 MHz**	**2450 MHz** (2.45 GHz)
Wavelength	♦ In the FM frequency band ♦ 68 ft, near field effect	♦ Similar to the analog cell phone frequency ♦ 1.0 ft, plane wave	♦ Similar to the digital cell phone frequency ♦ 0.4 ft, plane wave
Tag to Reader Field Interaction	♦ Near field effect ♦ Waves circumvent around conductive substrate unless it is several meters wide and length	♦ Far field effect ♦ Waves "bounce" around conductive substrates in most substrates	♦ Far field effect ♦ Waves "bounce" around conductive substrates in all most all substrates
Water and Liquid Sensitivity	♦ Insensitive to water, snow and other liquids even when immersed.	♦ Read distance greatly affected by water, snow, and other liquid either in front or behind the tag.	♦ Read distance is dramatically affected by water, snow, and other liquid.
Reflection vs Absorption	♦ Transmit through surfaces and substrate that contain moisture and water ♦ Circumvent small conductive subject ♦ Reflection from conductive surfaces larger than wavelength	♦ Absorption on surfaces that contain moisture and water ♦ Reflection and bounces back from conductive surfaces that are invariably larger than wavelength	♦ Absorption on surfaces that contain moisture and water ♦ Reflection and bounces back from conductive surfaces that are invariably larger than wavelength
Applications	♦ Can place directly on containers that contain water ♦ Not subject to attenuation and thus read rate reduction when placed under substrates that contains moisture ♦ Cannot be placed on metal surfaces ♦ Longer read distance of several feet only for larger tags	♦ Cannot place directly on containers that contain water ♦ May be subject to attenuation and thus read rate reduction when placed under substrates that contains moisture ♦ Cannot be placed on metal surfaces ♦ Longer read distance of several feet	♦ Cannot place directly on containers that contain water ♦ May be subject to attenuation and thus read rate reduction when placed under substrates that contains moisture ♦ Cannot be placed on metal surfaces ♦ Longer read distance of several feet

Combination Tags are Useful for Some Applications

There are several application environments where dual frequency tags are not only possible but make sense. The additional capability of adding one or two additional chips for a combination of 13.56, 915 and 2450 MHz will only add to the marginal cost [5]. This type of "universal RFID" tags are useful for some specific applications. The following are some of the scenarios:

1. Intercontinental and international baggage handling system:

   It may become a reality that United States Airlines may adopt one frequency such as 2.45 GHz or 915 MHz system for their baggage tracking system. It is also quite clear that the rest of the world is leaning toward the 13.56 MHz system. It will quite difficult to automate the transfer flights with totally different tags and readers being used.

   It would make perfect sense to place two different tags on the same baggage tag. With the use of a solderable supporting substrate film such as ESP7450 with etched copper antenna traces etched on the same basic area with a smaller higher frequency tag included inside or side by side. Both chip-jumpers can be placed and soldered in single surface-mounting pass.

   The not so apparent advantage of this approach is that the marginal cost for adding another chip is nominal. For an baggage tag for 13.56 MHz, the inside can readily accept another trace of antenna for the 2.45 GHz. The only additional cost is the chip that may cost less than $0.01 if the highly touted Alien Technology's FSA process is successfully used.

   Reader-encoders can be built with switching or simultaneous mechanism without interference. The wide apart frequency ranges and the substantial distance between the closest antenna traces in the RFID tag of all three frequencies make the co-existence without interference possible.

2. Unit items within packaging box and containers:

   Because of the form-factors and the potential absorption and other deleterious effect due to the higher frequency, one type of RFID tags may not be able to meet all of the requirements. For example, individual vials or syringes may be best labeled with 13.56 MHz RFID tags such as those illustrated in form-factor 1 of Figure 3.

   The overall box packaging may use the same frequency at the larger form-factor of style 6 of Figure 3. It may also be preferred to include another RFID chip such as those of 915 and 2450 MHz or both types of chip as illustrated in Figure 2. This may give either more cross-platform compatibility or the desired longer read range afforded by the higher frequency tag.

   A combination of any two or all three may be incorporated in the RFID tag in a single manufacturing step with a marginal increase in the cost of the chips.

Antenna Arrays and Scanners for Different Application Environments

There are also the issues of scanners and hardware systems for different commercial environments. As recently as June of 2003, Linda Dillman, Wal-Mart's CIO said, "Wal-Mart is still evaluating readers and is having problems finding antennas in all of the form factors it needs. [1]"

Based on the application requirements, the following is a summary of antenna array and reader configurations that must be addressed to provide a comprehensive solution in the supply chain management:

- Handheld scanner
  Most developed among all reader systems with multiple sources of suppliers.

- Checkout counter scanner
  This type of counter scanner should have different sizes for different items to be scanned. They are designed to simulate the barcode scanner counter in a conveyer like configuration. They must have ability to accommodate large and small articles in a conveyer configuration to be scanned for sales. We have yet to find such counter scanners for uses at 915 and 2450 MHz. The AVANTE SMART-TRAKKER™ counter scanner configuration as shown in Figure 5a has tested to provide a 100% read rate for multiple medications with different packaging shapes and sizes when placed on the counter or passing over the counter in simulation to actual counter dispensing. Please refer to Figure 5a for more details.

- Conveyer-based portal for large articles such as airline baggage and large items
  Must have ability to accommodate the conveyer size currently used for airport and larger. The standard airport conveyer has a 44-inch width without a limit for the height of items. Again, more antenna arrays and readers are available for 13.56 MHz than for 915 and 2450 MHz. AVANTE has tested a patent-pending antenna array with a 100% read rate for bags with random orientation and position as sponsored by the FAA. Smaller conveyer sizes are easier to engineer and make than larger systems. While higher frequency conveyer portal may have a longer read distance, the read rate may be less. Please refer to Figure 5a for details.

- Human walk through portals for access and asset tracking
  Must have ability to accommodate standard doorframe and preferable able to accommodate 6-feet wide double doors as well. Again, antenna arrays and readers are more abundant in 13.56 MHz than in 915 and 2450 MHz. AVANTE has used such SMART-PORTAL™ in tradeshow and event management in its patented allowed application. Please refers to www.leads-trakker.com and Figure 5b for details.

- Warehouse truck loading door scanner
  This lift-gate type doorway is typically 10 feet by 10 feet in size. It is much easier to cover this size doorway with either active or higher frequency tags. AVANTE has designed special antenna arrays that can cover such width for pallet type tag of approximately 10-inch by 3-inch tag for 13.56 MHz that can be read at a distance of 5 feet.

- Warehouse isle monitoring scanner
  Ideally, it should cover a width of up to 8 feet. Again, the larger tags must be used in this pallet-level tracking. With the 5 feet coverage for its larger tags at 13.56 MHz, antenna arrays

have been designed to cover this width easily for pallets passing through an isle way with RFID tags attached to pallets and boxes in all orientations and positions that are common for forklift transporting environment.

Figure 5a:
The patent-pending (allowed) antenna array portal on the left was designed to have an open top [3]. This design permits the large and taller articles to be tracked as long as the tag is placed at below 30-in height. It has been proven in official FAA test to track bags with tags in all position within the portal and random orientation at 8 feet/second.

This patent-pending (allowed) antenna array on the right is a "flat-bed" scanner designed to allow multiple tagged items to read either stationary or in motion with a 100% read rate [3].

Figure 5b:
The patent-pending (allowed) antenna array portal is mobile and has a taller height than all doorway, and is slightly wider than a standard 3 foot door [3]. Attendees wearing RFID badges are automatically scanned in non-intrusive manner. The portals provide demographic interests and management of access to special sessions and activities.

Multiple SMART-PORTAL™s can be placed along each other to provide doorway access and monitoring of double door of 6 feet and wider.

These patent-pending (allowed) walk through portals are also ideal for tracking assets which is of wide interests among RFID technology users.

Guaranteeing the Integrity of the Encoded Data in RFID Tags

Traditionally, data integrity encoded in smart tags are protected by encryption and by using some write-once only “locks” from tampering. These methods will continue to be used in those applications that are used in a closed environment.

In an open environment of commerce, such encryption will decrease the usefulness of RFID technology. Barcode must be readable by any and all users in the supply chain. The ability to document the processes and transits from work-in-progress, packaging for shipping, receiving, inspection, shelving, inventory, and sales in terms of date/time stamps and even including user IDs would be a very useful management tool as proposed by “Electronic Product Code” (EPC) as proposed. To achieve full “real-time” and “real-place” management, the system should allow the authorized users to write onto them and those that may not have the authority at least to read them and inspect them.

AVANTE has a patent-pending process and method to build a relational check code to tie the application specific data will the tampered-proof tag data. This technology maintains the ISO protocols of being able to be read by anyone along the supply chain. Authorized users are able to add to the data but unauthorized adding or changing will provide immediate indication of such tampering. This relational check code approach as applied to RFID and its applications ensures the integrity of the encoded data. This check code is achieve without special encryption that will prevent ISO-based reader to read and write onto the tags as they see fit. However, there is a indicator for the authorized users to know that the data has been changed by unauthorized users. The change in relational check codes after authorized changes also helps to document who along the supply chain has made that particular change. For more details on how this “relational-check-code” technology, please read the published pending patent [6].

The potential important applications including the tracking and matching of medications to patient to eliminate human errors in dispensing medical care is illustrated in Figure 6 below.

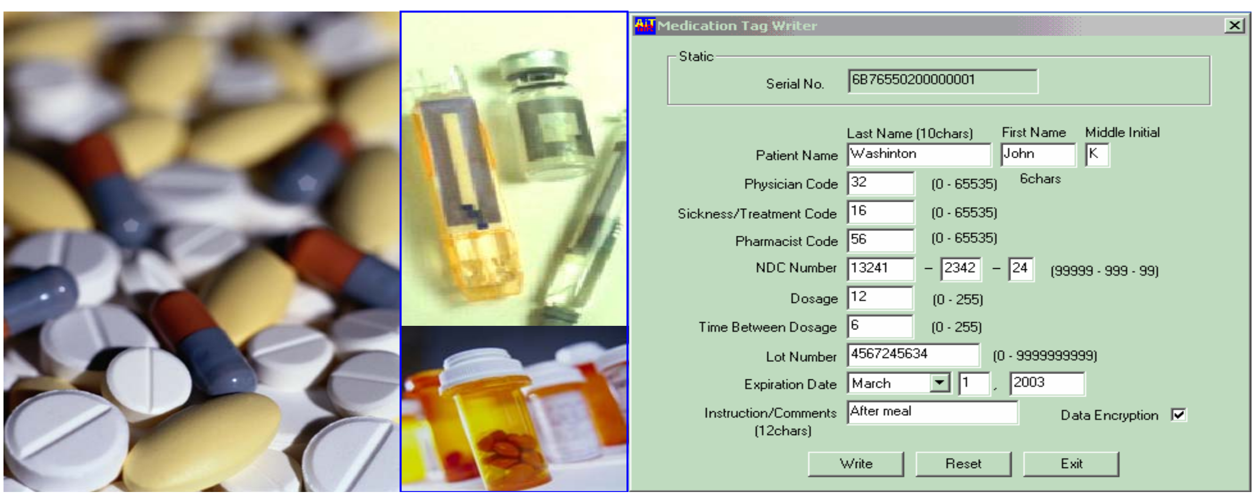


Figure 6:
All prescribed mediations including smallest vials and syringes have been successful tagged with 13.56 MHz RFID tags identifying the NDC number, lot/date, dosage, special instructions, the intended patient’s name, the physician and the pharmacist, etc. (www.hipa-trakker.com)

For these mission critical applications, the use of relational check code to ensure integrity of the encoded data is of highest value [6].

SUMMARY

The benefits of RFID in reducing the costs of supply chain management has been documented and proven in a variety of applications. The cost of the recurring costs of the disposable RFID tags with reliable performance have been determining how fast and how far this technology are being adopted.

The cost-effective performance of RFID tag is a result of the following factors:

- Cost of chips
- Inlay reliability and cost
- Reliable contact from chip to "chip-jumper" (or directly to inlay)
- Reliable interconnection from "chip-jumper" to inlay

In addition to the cost and performance of tags, the infrastructure like the following must also be available and cost-effective to ensure timely adoption:

- Antenna arrays and scanners for different applications
- Prevention of tampering of encoded data in an open ISO environment

This paper attempted to put all of these six factors in perspective.

The cost of making reliable RFID smart tags will be the lowest with the use of the more traditional and industry standard manufacturing techniques such as etching and thin film deposition to form inlays and soldering for interconnections.

The drive for smaller size chips to reduce the cost, the "chip-jumper" approach makes it both necessary and cost effective. AVANTE has developed a patent-pending (allowed) approach of soldering such "chip-jumper" onto the etched copper inlay. This soldering capability is afforded by the proprietary low cost flexible substrate (ESP7450) proven to work well in soldering and longer term higher temperatures.

To ensure the infrastructures are available to handle a variety of tasks and tracking of the whole supply chain, the development and engineering for antenna-arrays with different form-factors has become critical. In this paper, we demonstrated for the first time many applications for large baggage and human access with patent-pending antenna arrays for the 13.56 MHz.

Even though 13.56 MHz has a shorter read distance, its flexibility of RFID inlay sizes from large to small enables such RFID tags to be used in all levels of tracking. The immunity of such tags to be read in rain and snow also makes them ideal for uses that required outdoor exposure.

The tracking of the full supply chain must include cost-effective item-level tracking. Integrating unit-level to pallet- and eventually to container-level tracking may need a combination of RFID technologies. The possibility and advantages of RFID tags enabled with chips for two or more frequencies for specific applications have been illustrated.

Consistent performance and reliability in RFID tags are the keys to large-scale uses of RFID technology. RFID tags of all three operating frequency ranges can benefit with the more reliable soldered interconnections. More specifically, the application of "chip-jumper" and direct soldering to low cost solderable inlays is an ideal combination for cost-effective manufacturing.

References:

[1]. "RFID's Momentous Week", Reported by Mark Roberti, mroberti@rfidjournal.com, http://216.121.131.129/article/articleprint/464/-1/2/

"Wal-Mart's vote for RFID tags may give Everett firm a boost: Merchandise tracking system expected to take off at retailer's urging", Bill Virgin, Seattle Post-Intelligencier Reporter, June 7, 2003

[2]. "The Intelligent Warehouse", a report made by Mitchell and Tobolski of Accenture and reported by Bob Violino, bviolino@rfidjournal.com, http://216.121.129/articleprint/459/-1/81/

"Integration Impeding Use of RFID", a survey by Allied Business Intelligence, by Ed Rerisi and reported by RFID Journal, http://216.121.131.129/article/articleprint/453/-1/1/

[3]. "Antenna array for smart RFID tags", by Kevin Chung, US Patent Application # 20020044096 A1 (Published April 18, 2002)

"Medical assistance and tracking system and method employing smart tags", by Kevin Chung, US Patent Application #20030052788 A1 (Published March 20, 2003)

"Tracking system and method employing plural smart tags", by Kevin Chung, US Patent Application # WO 02/031629 A3 (Published April 18, 2002)

"Tracking method and system as for an exhibition", by Kevin Chung, US Patent Application #09/975,370 (Allowed and being issued)

"Tracking method and system as for an exhibition", by Kevin Chung, US Patent Application #10/365,803

"Antenna arrangement for RFID smart tags", by Kevin Chung, US Patent Application # 10/246,990 (Allowed)

"Article tracking system and method", by Kevin Chung, US Patent Application # and PCT # WO 02/33511 A2 (Published April 25, 2002)

[4]. "Electronic circuit construction, as for a wireless RF tag", by Kevin Chung, US Patent Application #10/191,580 (Allowed)

"Tamper-resistant wireless article including an antenna", by Kevin Chung, US Patent # 6,421,012 B1 (Issued on July 16, 2002)

"Wireless article including a plural-turn loop antenna", by Kevin Chung, US Patent # 6,353,420 B1 (Issued on March 5, 2002)

"High-Density Electronic Package, and Method for Making the same", by Kevin Chung, US Patent # 6,376,769 B1 (Issued on April 22, 2002)

[5]. "Low cost reliable RFID tags enabled with multiple frequency chips", US Patent Application by Kevin Chung, 2003.

[6]. "Smart tag data encoding method", by Kevin Chung, US Patent Application #20030006878 A1 (Published on January 9, 2003)