

## 1 Background Information

### 1.1 Acknowledgements

The RFID Solutions Center would like to express our thanks to The Boeing Company, The Center for Automatic Identification, Ohio University, and the Department of Quantitative Analysis and Operations Management College of Business, University of Cincinnati that made this report possible.

We would like to thank these organizations and acknowledge their significant efforts in providing support for this report.

### 1.2 Contract Information

Offering Department: U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate ("AFRL/MLM")

Recipient: Wright Brothers Institute

Vehicle: Memorandum of Understanding / Partnership Intermediary Agreement ("MOU" / "PIA")  
FA8650-06-3-9000

Contract: Collaborative Purchase Order ("CPO") FA8650-06-3-9021

Title: RFID Rapid Adoption Collaboration Initiative ("RRACI")

The objective of the program is for the recipient to stimulate the rapid transition of radio frequency identification (RFID) technologies by developing an RFID solutions center. The RFID solutions center shall provide an effective way to collaborate with government end users, contractors, and defense industry suppliers. The solutions center shall provide education, training, and application of specific system design capabilities to transition RFID technologies to meet military needs. The RFID solutions center shall provide the capabilities and services that shall assist the government in streamlining both internal and external supply chain challenges to support the war fighter.

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Project Summary Report:

## **Use of Passive RFID Technology to Track Items in Extreme Cold Storage: Results of The Boeing Company Study**

### **STATEMENT OF LIABILITY**

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## Use of Passive RFID Technology to Track Items in Extreme Cold Storage: Results of The Boeing Company Study

### 2 EXECUTIVE SUMMARY

In October of 2007, the RFID Solutions Center (RSC) completed an RFID study to prove the feasibility of using UHF Passive RFID to track items while in extreme cold storage setting to better track and manage assets.

Radio-frequency identification (RFID) is an automatic identification technology which combines inexpensive labels and radio infrastructure for tracking the identity and location of assets. Initiatives by large commercial entities like Wal\*Mart, The Boeing Company and Procter and Gamble, as well as government entities like the Department of Defense, have been using RFID to streamline supply chain processes, enhance asset visibility, and improve readiness. Closed loop systems are becoming increasingly interested in the use of this technology to improve service and reduce costs.

Throughout the radio frequency identification (RFID) industry practitioners are searching for the ever-elusive return-on-investment (ROI). One possible solution is to combine the relatively low cost of passive UHF RFID tags with high cost inventory or assets (Havens, 2006; Trebilcock, 2007). As one reads about RFID, a common discussion of late is the use of RFID in the cold chain. While not only referring to items kept at a cold temperature, the cold chain addresses items that must be temperature regulated. However, these articles mostly address items kept at temperatures that are within the standard ranges for most passive RFID equipment (see Table 1 for a sample of published specifications). If, however, a solution were presented that could work below the published temperatures, high-cost goods that had to be kept at extremely cold temperatures could potentially see a quick ROI.

**Table 1: Sampling of RFID Reader & Tag Minimum Specified Temperatures**

Reader/Tag	Minimum Operating Temperature	Minimum Storage Temperature
Mercury 5	0° C	-20° C
Alien 9800	-20° C	-20° C
Intermec IF5	-25° C	-30° C
Symbol XR-400	0° C	-20° C
Alien Squiggle	-25° C	-20° C
AD-222	-40° C	-40° C
TI Gen2 Chips	-40° C	-40° C

It is this specific scenario that was presented to Ohio University’s Center for Automatic Identification, housed within the Russ College of Engineering and Technology, University of Cincinnati’s Department of Quantitative Analysis and Operations management College of Business, and the RFID Solutions Center. The Boeing Company (Boeing) is currently using various pre-mixed epoxy-based sealants during the manufacturing process that have to be stored below -40° C. At \$3-\$6 per ounce, using new sealants while sealants getting ready to expire are nearby or having sealant expire in a freezer while new sealant is being ordered, can be costly propositions considering the shelf life of the sealants is often between 20 and 40 days. The challenges to this project were to track hundreds of sealant containers that are subjected to a quick freeze via a liquid nitrogen bath (-196° C) prior to being stored at -73° C.

The goals of this study were to determine how to define benefits of using RFID with cold chain applications as well as to prove the readability of tagged containers of sealant while subjected to extreme cold temperatures in a freezer.



## **Use of Passive RFID Technology to Track Items in Extreme Cold Storage: Results of The Boeing Company Study**

Using RFID to address common business problems can help firms reduce inventory and scrap due to expiration of product. These common business problems include:

- › Shrinkage of assets
- › Underutilized assets
- › High volume of scrap
- › High inventory levels

The study, conducted with the help of the University of Cincinnati and Ohio University, was limited in scope and did not include an operational analysis of productivity gains or other potential improvements in the management of extreme cold storage resources; instead, a number of RFID tags were tested to ensure readability throughout the deep freezing and thawing processes. Fifteen different Passive UHF RFID tags were selected across five different vendors. The study was intended as a proof-of-concept for three hypotheses:

1. Are passive RFID tags rated to no colder than -40 degrees Celsius still able to be read consistently while in a freezer with a temperature of -73 degrees Celsius?
2. Will passive RFID tags rated to no colder than -40 degrees Celsius still operate consistently after being subjected to temperatures as low as -196 degrees Celsius?
3. Is there a Return on Investment potential for passive RFID in the extreme cold storage supply chain?

The study successfully demonstrated that RFID is capable of significantly enhancing the ability to track items in an extreme cold storage supply chain. The study shows that current RFID hardware and tags can accurately track items being subjected to temperatures as low as -196 degrees Celsius and stored at temperatures as low as -73 degrees Celsius, improving asset availability and utilization.

The prime contractor for this activity was the Wright Brother's Institute, the program was sponsored by the Air Force Research Laboratory, and the program manager was the RFID Solutions Center.

### **3 Introduction**

This chapter defines the passive RFID technology tested in the study. It also lists a benefits analysis of RFID in extreme cold storage applications, the project team, and the overall layout of this final report.

#### **3.1 About Passive RFID**

Radio-frequency identification (RFID) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. Utilizing radio frequency waves, an RFID tag can be applied to or incorporated into a product for the purpose of location and identification. UHF Passive RFID can be read from several meters away and beyond the line of sight of the reader. Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, modulating and demodulating a (RF) signal and can also be used for other specialized functions. The second is an antenna for receiving and transmitting the signal.

RFID technology is in increasing use in enterprise supply chain management, improving the efficiency of inventory tracking and management. The Department of Defense, along with major commercial companies such as Wal-Mart, is implementing systems to test the ability of this technology to improve asset visibility, product integrity and readiness throughout the supply chain.



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The use of RFID in the DoD supply chain has the potential to provide real benefits in inventory management, asset visibility, and interoperability in an end-to-end integrated environment. RFID encapsulates the data accuracy advantages inherent in all types of automatic identification technology (AIT). Additionally, RFID is a totally non-intrusive methodology for data capture (requires no human intervention), is non-line of sight technology, and is a technology that possesses both read and write options within the same equipment item.

RFID addresses a key challenge that has been noted at every node within the DoD supply chain – lack of visibility of item data. As an integral aspect of the overarching suite of AIT capabilities, RFID will become a key technology enabler for the DoD logistics business transformation and will support long-term integration of the Unique Identification (UID) into the DoD end-to-end supply chain. RFID (both active and passive) is required by DoD to:

- › Provide near-real time in-transit visibility for all classes of supplies and materiel
- › Provide “in the box” content level detail for all classes of supplies and materiel
- › Provide quality, non-intrusive identification and data collection that enables enhanced inventory management
- › Provide enhanced item level visibility

Recent research has indicated that the potential for passive RFID applications in the extreme cold storage environment is significant, and successful trials have been conducted in the aerospace industry.

### **3.2 Benefit Analysis**

This benefit assessment is based on interviews with Boeing personnel and examination of the existing literature. The Table below summarizes the expected benefits from RFID implementation for the tracking of items in extreme cold storage applications. The first column of the Table lists the perceived benefit. The second column defines the supply chain management process affected by this benefit. These processes include “Plan,” “Source,” “Make,” “Deliver” and “Returns.” Note that a single benefit may affect multiple supply chain processes. This column is based on the well-known Supply-Chain Operations Reference (SCOR) Model used to describe, measure, and evaluate supply chain activities. Here we have adapted the typical SCOR methodology to apply to RFID implementations. The third column describes the metric most affected by the perceived benefit. The possible values in column three are “Speed,” “Efficiency,” “Reliability” and “Information Visibility.” The fourth column provides comments that give more details on how RFID is expected to lead to the defined benefit. The final column lists the qualitative impact assessment relative to the other perceived benefits. This column corresponds to potential benefits to be achieved by Boeing but also shared with other members of the supply chain. Ideally, these values would be replaced with actual dollar values, but this is not possible at the current time without extensive input from Boeing personnel.



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**Table 2: Expected Benefit Analysis from RFID Implementation**

Benefits	Supply Chain Process	Metric	Comments	Impact Assessment
Improved Forecasting	Plan	Information		
Visibility	Better demand tracking by separating usage into scrap and true demand	Low		
Inventory Reduction	Source	Information		
Visibility	Storage visibility through reduction in duplicate inventory location	Medium		
Cycle Time Reduction	Make	Speed	Quicker inventory retrieval	Medium
	Source	Speed	Faster receiving through simultaneous tag reads	Low
Reduced Scrap	Plan	Efficiency	Better match supply and demand	High
	Source	Efficiency	Dwell time reduction	High
Labor Cost Savings	Source	Efficiency	Improved receiving efficiency	Low
	Make	Information		
Visibility	Reduced cost of inventory tracking	High		
Enhanced Product Integrity	Returns	Reliability	Fewer failures due to better control over expiration date	Low
Potential for Consignment	Source	Reliability	Better data reliability	Medium
Reduced Expediting	Make	Speed, Reliability, Efficiency	Better match supply and demand	Medium

Implementing RFID within a facility can mitigate each of these business problems and result in a substantial return on investment. More importantly, the return on investment for RFID cascades for every additional problem addressed. The resulting return on investment grows even more rapidly as each new application is brought on-line.

The recent introduction of affordable RFID will have an immediate impact on extreme cold storage applications: reducing operational costs, reducing scrap, increasing inventory accuracy and improving forecasting. RFID addresses the following functions for assets:



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- › Locating in real time
- › Usage Tracking or producing an audit trail
- › Decreased stock outs
- › Checking inventory instantaneously
- › FIFO Compliance

An additional impact from RFID implementation is related to supply chain risk. On-time completion of projects in the aerospace industry is a very important metric. Boeing's current backlog of booked orders approaches \$250 billion (Cassidy 2007). Most contract orders in the aircraft industry include delivery timelines and often penalties for delayed shipments. Delayed deliveries of Airbus' A380 super jet have been linked to some \$7 billion in cost overruns at the company (Clark 2006). RFID provides a mean to better control supply chain processes in order to mitigate risk due to delayed order deliveries. Because aircraft deliveries are determined by contracts that often include monetary penalties for late and missed deliveries, such risk mitigation can provide substantial benefits.

### **Investment**

The implementation of a RFID system contains two cost components: a fixed cost consisting of the antennas and readers and a variable cost consisting of the "tags" that identify an asset or an individual.

RFID's substantial return on investment is due to its flexible nature. That is, once the fixed cost components are installed, they may be used for a variety of applications. Each new application addresses a business problem, which in turn increases the return on investment.

- › Potential Benefits Defined
- › Reduced Scrap: Better Match Supply and Demand
- › Labor Cost Savings: Reduced Cost of Inventory Tracking
- › Inventory Reduction: Storage Visibility through Reduction in Duplicate Inventory location
- › Cycle Time Reduction: Quicker Inventory Retrieval
- › Reduced Expediting: Better Match Supply and Demand

### **3.3 Project Team**

This project was conducted by a team of passive RFID and Academia professionals and supported by The Boeing Company. The project team was comprised of The Boeing Company, the Wright Brother's Institute, Alien Technology, University of Cincinnati, and Ohio University. The team roles are described below.

#### *The Boeing Company*

Boeing is the world's leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft combined. Additionally, Boeing designs and manufactures rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. As a major service provider to NASA, Boeing operates the Space Shuttle and International Space Station. The company also provides numerous military and commercial airline support services. Boeing has customers in more than 90 countries around the world and is one of the largest U.S. exporters in terms of sales.



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Boeing has a long tradition of aerospace leadership and innovation. We continue to expand our product line and services to meet emerging customer needs. Our broad range of capabilities includes creating new, more efficient members of our commercial airplane family; integrating military platforms, defense systems and the war fighter through network-centric operations; creating advanced technology solutions that reach across business units; e-enabling airplanes and providing connectivity on moving platforms; and arranging financing solutions for our customers.

Headquartered in Chicago, Boeing employs more than 150,000 people across the United States and in 70 countries. This represents one of the most diverse, talented and innovative workforces anywhere. More than 83,800 of our people hold college degrees—including nearly 29,000 advanced degrees—in virtually every business and technical field from approximately 2,800 colleges and universities worldwide. Our enterprise also leverages the talents of hundreds of thousands more skilled people working for Boeing suppliers worldwide.

### *Wright Brothers Institute*

The Wright Brothers Institute was the recipient of the grant and is the prime contractor for this contract.

### *Alien Technology Corporation*

Alien Technology Corporation (ATC) was the sole subrecipient of the grant and provided overall program management as well as significant support through the RFID Solution Center (RSC) for training, integration facility support, and RFID solution engineering support. Alien Technology provides UHF Radio Frequency Identification (RFID) products and services to customers in retail, consumer goods, manufacturing, defense, transportation and logistics, pharmaceuticals and other industries. The RFID Solutions Center, a division of ATC, is the most advanced facility devoted entirely to the application of RFID technology. Open to enterprises, government agencies and their partners, the Center comprises 23,000 square feet of educational, R&D and real-world implementation resources designed to enable the global RFID community to tap the potential of RFID technology.

### *Center for Automatic Identification, Ohio University*

Ohio University performed the technical study for this document.

### *Department of Quantitative Analysis and Operations management College of Business, University of Cincinnati*

University of Cincinnati developed the Business Case Study for this document.

## **3.4 Report Layout**

The remainder of this report describes the study design, findings, conclusions, and recommendations. The following section describes the findings with regard to the three proof-of-concept areas, while the final section provides an overall conclusion and recommendations for a permanent roll-out of a passive RFID to track items in an extreme cold storage application.

## **4 Methodology**

This chapter describes the study and its phases. The selection of the study tags and placement of tags on actual product are described, as well as the physical layout of the readers within the test freezers.

### **4.1 Study Information**

This study, conducted with the full support of Boeing, tested the feasibility of using passive RFID to track time and temperature critical sealants in an extreme cold storage application. This study, planned and conducted



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from September of 2006 through September of 2007, tested the ability of passive RFID technology to be used in an extreme cold storage environment, using commercially-available standards-based RFID components over a 7-week period.

The primary goal of the study was to assess the effects of extreme cold on passive RFID tags. The study was limited in scope and did not include an operational analysis of productivity gains or other potential improvements in the management of supply chains; these benefits could be more adequately measured with a larger project now that the proof-of-concept has been completed.

The trial was intended as a proof-of-concept for testing whether passive RFID can successfully track items within an extreme cold storage application, testing three hypotheses:

- › Will passive RFID tags continue to read successfully at temperatures far below listed temperature specifications in an extreme cold storage application to as low as -73 degrees Celsius.
- › Will passive RFID tags continue to read successfully after being immersed in baths of liquid nitrogen to a temperature of -196 degrees Celsius, indicating that the current technology for passive RFID tags is able to withstand temperatures far outside of the specified limits?
- › Is there an achievable ROI for passive RFID when utilized in extreme cold storage applications?

### **4.2 Passive RFID Tag Selection**

To determine what RFID tags would work, samples of fifteen different RFID tag types were selected across five different vendors (see Table 3). Two sample tags were chosen from each batch and qualified using an Alien 9800 with circular polarized antennas to record their read rates during a one minute period at three feet from the antennas in free space. The tags were then placed in the freezer at -73° C for 24 hours. The tags were removed and tested again. Finally, the tags were placed in the freezer for 36 hours where they were successfully read on a continuous basis. Since all of the tags read before, during and after exposure to the freezer without a significant decrease in performance, the tags were further sorted by performance and size. Since the size of the sealant containers would play a significant role in tag selection, all of the larger omni-directional tags were eliminated, leaving the AD-222, Alien Squiggle, Alien 2x2, Omron Ninja, Rafsec Short Dipole, Rafsec Dog Bone, Rafsec Web and the Symbol Dipole. Of these, the AD-222, the Alien Squiggle, the Alien 2x2 and the Rafsec Web had the most favorable size and read rates, resulting in their selection for the next phase of the testing. The remaining tests were conducted with these four tags. It should be noted that while the Omron Ninja had the most favorable form factor, the limited range of this tag precluded it from selection since a read range of up to three feet, through an RF translucent material, was required.

Having selected the potential tags, a roll of each tag type was obtained (1,000 tags for the AD-222 and the Rafsec Web; 500 tags for the Alien Squiggle; 200 tags for the Alien 2x2). The rolls were incrementally encoded, validated and then placed in the freezer at -73° C for 43 hours to ensure that the tags were brought to temperature. The tags were then removed from the freezer and left for 24 hours to ensure that the tags had a chance to dry out prior to retesting. In all four instances, all of the tags that were read prior to exposure to the freezer were still readable afterwards. While additional testing with larger numbers of tags should be conducted, these results do imply that the current tag technology is robust enough for production.



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**Table 3: RFID Tags Selected for this Study**

Selected Passive RFID Tags	
AD-222	Alien 2x2
AD-420	Omron Ninja
AD-612	Rafsec Dog Bone
AD-812	Rafsec Frog Dual Dipole
AD-820	Rafsec Short Dipole
Alien Omni-directional	Rafsec Web
Alien Squiggle (Higgs chip)	Symbol Dual Dipole
Alien 2x2 (Higgs chip)	Symbol Dipole

It is this specific scenario that was presented to Ohio University's Center for Automatic Identification, housed within the Russ College of Engineering and Technology, University of Cincinnati's Department of Quantitative Analysis and Operations management College of Business, and the RFID Solutions Center. The Boeing Company (Boeing) is currently using various pre-mixed epoxy-based sealants during the manufacturing process that have to be stored below -40° C. At \$3-\$6 per ounce, using new sealants while sealants getting ready to expire are nearby or having sealant expire in a freezer while new sealant is being ordered, can be costly propositions considering the shelf life of the sealants is often between 20 and 40 days. The challenges to this project were to track hundreds of sealant containers that are subjected to a quick freeze via a liquid nitrogen bath (-196° C) prior to being stored at -73° C.

The goals of this study were to determine how to define benefits of using RFID with cold chain applications as well as to prove the readability of tagged containers of sealant while subjected to extreme cold temperatures in a freezer.

Using RFID to address common business problems can help firms reduce inventory and scrap due to expiration of product. These common business problems include:

- › Shrinkage of assets
- › Underutilized assets
- › High volume of scrap
- › High inventory levels

The study, conducted with the help of the University of Cincinnati and Ohio University, was limited in scope and did not include an operational analysis of productivity gains or other potential improvements in the management of extreme cold storage resources; instead, a number of RFID tags were tested to ensure readability throughout the deep freezing and thawing processes. Fifteen different Passive UHF RFID tags were selected across five different vendors. The study was intended as a proof-of-concept for three hypotheses:

1. Are passive RFID tags rated to no colder than -40 degrees Celsius still able to be read consistently while in a freezer with a temperature of -73 degrees Celsius?
2. Will passive RFID tags rated to no colder than -40 degrees Celsius still operate consistently after being subjected to temperatures as low as -196 degrees Celsius?
3. Is there a Return on Investment potential for passive RFID in the extreme cold storage supply chain?



## Use of Passive RFID Technology to Track Items in Extreme Cold Storage: Results of The Boeing Company Study

The study successfully demonstrated that RFID is capable of significantly enhancing the ability to track items in an extreme cold storage supply chain. The study shows that current RFID hardware and tags can accurately track items being subjected to temperatures as low as -196 degrees Celsius and stored at temperatures as low as -73 degrees Celsius, improving asset availability and utilization.

The prime contractor for this activity was the Wright Brother's Institute, the program was sponsored by the Air Force Research Laboratory, and the program manager was the RFID Solutions Center.

### 4.3 Passive RFID Tag Placement

As indicated previously, the second phase of the testing was a determination of the ideal tag placement location. To aid in the evaluation, Integral RFID's Instant EPC Hotspot software was used. Representative samples of the sealant in two ounce and six ounce containers were provided by the manufacturer. The samples were tagged and evaluated for each of the four tags selected. Optimum tag placement on the sealant containers were then determined for each of the four tags utilizing the EPC Hotspot software. Figure 1, shows the suggested orientations for the Rafsec Web and the Alien 2x2. Due to their size, the selected dipole tags could only be placed horizontally around the smaller containers.

One issue that was brought up during the meetings was the desire to read the tags after they were placed in the dispensing guns. The reason for this is that some of the sealants qualify as hazardous materials and there was the desire to use the RFID system to also validate that all hazardous materials containers were disposed of correctly. A sample gun was obtained, an RFID label was placed over the existing label and the sealant was placed in the dispensing gun. After removing the sealant container, the label was read. This process was repeated three separate times. After each removal, the tag was still readable, implying that despite scuffing and some label tearing (see Figure 2), that the RFID tag was not significantly impacted by the tight fit of the dispensing gun.



Figure 1: Recommended Tag Orientations



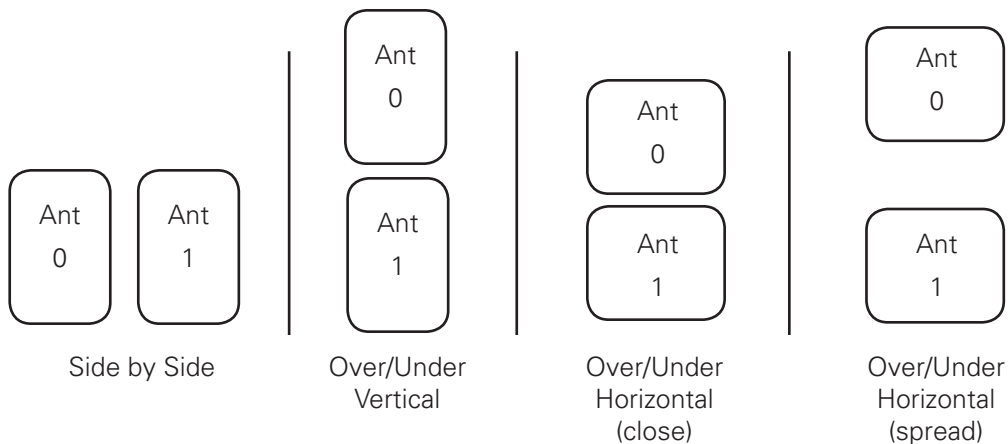
Figure 2: Scuffed Tag from Sealant Dispensing Gun



#### 4.4 Freezer Testing

The third phase of the project was an evaluation of the tags on the sealant containers, in the freezer. 193 containers of sealant were consecutively tagged with each of the four selected RFID tags. The sealant was then placed in boxes that held between 20 and 48 sealant containers. The sealant was placed in the boxes in even rows, but without regard to the rotational orientation of the RFID tag. The boxes were then placed in the freezer, which was at room temperature, and tested for 100% readability. All four tags were able to achieve 100% read rates when the antennas were placed within 20 inches of each other (which is the approximate distance needed for three sets of readers in the freezer). Quite often, all of the tags could be read regardless of where in the freezer the samples were. There seemed to be a certain amount of location issue with where the boxes were to get the 100% read rates, but for those locations where 100% was not achieved, the rates were usually in the 98-99% range. These results indicate that the tag orientations and locations were effectively selected and that the incomplete reads were probably due to antenna placement and reader configuration. At the same time, the 100% rates do indicate that the antenna configuration and reader settings were close.

To address the issue of antenna placement and configuration, four antenna configurations were tested with the samples. The initial layout was to place each of the paired antennas (the Alien 9800 used for these tests was a bi-static system and antennas must be paired) next to each other on either side of the samples. Other combinations of antenna placements were investigated (see Figure 3), but the physical size of the freezer that was used for these tests limited the options. The orientation selected was antennas mounted horizontally and spread as far apart vertically as the freezer would allow.



**Figure 3: Antenna Orientations Inside the Freezer**



#### 4.5 System Components

RFID equipment for the study included:

- Alien Technology ALR-9800 Readers
- Alien Technology ALR-9610-BC Antennas



### 5 Results

This chapter provides the results against the three proof-of-concept areas for the study described in the first chapter.

The testing conducted shows that standard EPC Class 1, Gen 2, RFID tags are able to withstand extremely cold temperatures as well as outperform the published specifications in a repeatable manner. This demonstrates the ability to leverage the commodity level pricing against the need to easily track high value, consumable materials in a manufacturing environment. The results from this initial round of testing are significant, positive and encouraging for this project and for the technology in general. As stated at the outset, the hardware and tag manufacturers will only guarantee their products to, at best, -40° C. However, as shown in this project, over 2,200 tags have been successfully tested down to -73° C. Additionally, approximately 800 tags have proven to continuously function, within the distances tested, at almost double the stated minimums. As companies attempt to find ways to achieve an acceptable ROI with RFID, closed loop solutions such as this may be the answer.

For those industries that use products that need to be kept between -40° and -73° C, this project shows that the technology is to a point where it can perform adequately. Furthermore, there is evidence that the tags will survive exposure to -196° C, possibly allowing for their use in cryogenics and other deep freeze applications. While additional testing will need to be done to further optimize the antenna placement and reader settings within the production freezers, the testing done here has shown that such testing is worthwhile.

#### 5.1 Passive RFID Tags Operating at -73 Degrees Celsius

The first proof-of-concept requirement of the study was to determine whether the passive RFID tags will consistently read while in a -73 degree Celsius environment when only rated to -40 degrees Celsius.

The consistently high tag read rate at -73 degrees Celsius of this study indicates that current passive RFID tag technology can indeed operate successfully while in a -73 degree Celsius environment and that passive RFID systems can be used to greatly assist users in tracking and locating stock items in an extreme cold storage application.

#### 5.2 Passive RFID Tags Subjected to Temperatures of -96 Degrees Celsius

The second proof-of-concept requirement of the study was to determine whether the passive RFID tags will continue to read after being subjected to temperatures as cold as -196 degrees Celsius for extended periods of time when only rated to -40 degrees Celsius.

The fact that the tags tested in this study continued to read after being immersed in baths of liquid nitrogen to a temperature of -196 degrees Celsius of this study indicates that the current technology for passive RFID tags is able to withstand temperatures far outside of the specified limits.



### **5.3 Extreme Cold Storage ROI**

Although this study did not collect actual ROI data, the successful demonstration of passive RFID tags reading at extremely cold temperatures along with the high cost and time sensitivity of the items to be tracked offer substantial opportunities to realize the benefits listed in section 3.2.

## **6 Conclusions**

This final chapter provides the overall conclusion of the trial as well as next step recommendations to include implementing a passive RFID system within extreme cold storage applications.

### **6.1 Feasibility**

The study successfully demonstrated that a relatively inexpensive passive RFID system can significantly enhance the ability achieve ROI in the areas discussed in section 3.2.

### **6.2 Summary of Results**

The nature of this study was limited, and utilized a limited number of tests and time spans that do not necessarily reflect all applications. The study was intended to provide proof-of-concept for three key concepts. It was determined through this study that the passive RFID tags and readers can:

- › Be used to greatly assist users in tracking and locating stock items in an extreme cold storage application to as low as -73 degrees Celsius.
- › Continue to successfully read after being immersed in baths of liquid nitrogen to a temperature of -196 degrees Celsius indicating that the current technology for passive RFID tags is able to withstand temperatures far outside of the specified limits.
- › Offer ROI in a number of areas that can cascade down to numerous other applications.

While full inventory impacts were not able to be accurately projected through the limited nature of the study, it has been shown that current passive RFID technology is capable of tracking items at extreme cold temperatures for sustained periods of time.

### **6.3 Next Steps**

Preliminary analysis has identified potential benefit areas and cost areas. Next steps include the development of a pilot project that would 1) quantify cost reductions and revenue enhancements made possible by RFID implementation; 2) evaluate RFID implementation strategy under alternative operating conditions. This pilot is expected to involve small scale practical tests to determine the parameters of an RFID implementation. The full RFID system implementation and testing alternative configurations would then be modeled using simulation. Simulation is the use of computers to “imitate, or simulate, the operations of various kinds of real-world facilities or processes” (Law and Kelton 2000). Simulation models allow for performance evaluation of complex operating systems under many different conditions in a timely and cost-effective manner. The proposed pilot investigation would involve the following steps:



# Use of Passive RFID Technology to Track Items in Extreme Cold Storage: Results of The Boeing Company Study

## 7 APPENDICES

### 7.1 Appendix A: Reference Documentation

The following documentation was developed or referenced to complete this activity:

ID	Document Name
1	Havens, J. (2006, November 16). <i>The Real Benefits of Asset Tracking and RFID: Mike Braatz of PanGo</i> . Retrieved July 1, 2007, from AIM Global: <a href="http://www.aimglobal.org/members/news/templates/podcast.asp?articleid=1894&amp;zoneid=42">http://www.aimglobal.org/members/news/templates/podcast.asp?articleid=1894&amp;zoneid=42</a> .
2	Schuman, E. (2007, May 30). <i>Report: RFID Still Struggling</i> . Retrieved June 17, 2007, from eWeek.com: <a href="http://www.eweek.com/article2/0,1759,2138480,00.asp">http://www.eweek.com/article2/0,1759,2138480,00.asp</a>
3	Trebilcock, B. (2007, February 22). <i>Passive RFID for asset management</i> . Retrieved July 1, 2007 from Modern Materials Handling: <a href="http://www.mmh.com/article/CA6418371.html">http://www.mmh.com/article/CA6418371.html</a> .
4	Cassidy, Padraic. "Boeing Net More Than Doubles on Airplane Orders," Marketwatch. January 31, 2007.
5	Clark, Nicola. "Airbus Forecasts a Loss for 2006," International Herald Tribune. January 17, 2007.
6	Clark, Nicola. "Next Delay for A380: A Decade Before Break Even," International Herald Tribune. October 19, 2006.
7	Law, Averill M. and W. David Kelton. <i>Simulation Modeling and Analysis</i> , 3rd Edition, McGraw Hill, New York, NY. 2000.
8	Moradpour, Shahram. "Solving the RFID Cost-Benefit Equation," RFID Product News. Issue 1, Volume 2, 2005.
9	Nurminen, Timo. "The End of RFID Middleware?" RFID Journal. January 16, 2006.
10	Radishofski, Amy. "Boeing Estimates \$2.8 Trillion Market for Commercial Planes," Manufacturing.net. June 13, 2007.



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