138
024
THS

THESIS
1
2004

This is to certify that the
thesis entitled

RADIO FREQUENCY IDENTIFICATION TRANSPONDER
PERFORMANCE ON REFRIGERATED AND FROZEN BEEF
LOIN MUSCLE PACKAGES

presented by

JOHN CHRISTIAN ONDERKO

has been accepted towards fulfillment
of the requirements for the

M.S. degree in PACKAGING

Robt Clarke

Major Professor's Signature

May 11, 2004

Date

MSU is an Affirmative Action/Equal Opportunity Institution

LIBRARY
Michigan State
University

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE
APR 0 6 2005		
JUL 02 2008 6		

6/01 c:/CIRC/DateDue.p65-p.15

RADIO FREQUENCY IDENTIFICATION TRANSPONDER PERFORMANCE ON REFRIGERATED AND FROZEN BEEF LOIN MUSCLE PACKAGES

By

John Christian Onderko

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

School of Packaging

2004

ABSTRACT

RADIO FREQUENCY IDENTIFICATION TRANSPONDER PERFORMANCE ON REFRIGERATED AND FROZEN BEEF LOIN MUSCLE PACKAGES

By

John Christian Onderko

Radio Frequency Identification (RFID) is a technology that is quickly becoming an integrated tool in the field of Supply Chain Management. This research investigated the potential use of RFID as a cold-chain management tool for fresh meat packaging. Current RFID technology can penetrate many materials, but the retail food supply chain presents many challenges. Beef muscle presents a challenge due to the storage environment and moisture content of the product.

The objective of this research was to evaluate the effects of different storage temperatures of beef muscle on the data communication performance of an RFID system. Two RFID systems were utilized to evaluate performance differences between frequencies. Beef packages were tested individually and in stacked configurations to simulate item and shelf level tracking. Packages were frozen and refrigerated to simulate different storage conditions.

This research found that RFID systems operating in the 13.56 MHz frequency range should experience no loss of data when transmitting through a package of refrigerated or frozen beef. RFID systems operating in the 915 MHz frequency range should communicate through frozen packages, but may experience a loss of data when communicating through a refrigerated package.

Copyright by
JOHN CHRISTIAN ONDERKO
2004

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

AIDC	Automatic Identification & Data Collection
AMI	American Meat Institute
BSE	Bovine Spongiform Encephalopathy
DC	Distribution Center
EAN	European Article Numbering International
EEPROM	Electronically Erasable Programmable Read Only Memory
EPC	Electronic Product Code
EPS	Expanded Polystyrene
F	Fahrenheit
FIFO	First In, First Out
FMD	Foot and Mouth Disease
GHz	Gigahertz
ISO	International Organization for Standardization
kHz	Kilohertz
MHz	Megahertz
PVC	Polyvinyl Chloride
RAM	Random Access Memory
RF	Radio Frequency
RFID	Radio Frequency Identification
ROM	Read Only Memory
R/W	Read/Write
TI	Texas Instruments

KEY TO ABBREVIATIONS

UCC	Uniform Code Council
UHF	Ultra High Frequency
USAIP	United States Animal Identification Plan
USDA	United States Department of Agriculture
WORM	Write Once Read Many

INTRODUCTION

Radio Frequency Identification, or RFID, is a wireless data transmission technology that is quickly becoming an integrated tool in the field of supply chain management. RFID can be used within a company's supply chain for the tracking of raw materials to finished goods. These systems can operate in many different configurations and frequencies, depending on the application and material through which the signals must pass. Choosing the proper frequency is crucial to retaining visibility throughout the life of the product. While this technology has existed for many years, little research has been conducted on the potential and limitations of utilizing it with certain packaged products.

A typical RFID system is composed of four components: the host computer, interrogator, antenna and transponder. The transponder, or tag, is the wireless device that is attached to the case, item or package. This device communicates with the system's antenna to transmit data stored in its memory. This data can be used to locate, track and record information associated with the item it is attached to.

RFID systems have many benefits compared to other automatic identification and data collection (AIDC) technologies, such as bar codes. Bar codes require a line-of-sight between the laser and bar code. RFID systems are not constrained by this requirement, as radio frequencies can penetrate certain mediums, allowing items within a pallet to be recognized. Other benefits include the ability to recognize numerous transponders at the same time, capability to write dynamic information to the transponder, longer read ranges, and the ability to track moving objects, just to name a few. Despite these benefits, RFID does have its limitations. The use of RFID has been restricted by its inability to transmit data without interference from certain materials (Albano & Engels, 2002). The largest challenge is the ability of the transponder to communicate its data to the antenna without loss of resolution or information. Systems operating in the ultra-high frequency (UHF) bandwidth are known to have interference issues with moisture and metallic objects.

Current RFID technology can penetrate many different mediums, but the retail food supply chain presents many challenges. The transmission frequency of an RFID system must travel through differing mediums, along with varying environmental conditions. Beef muscle presents a challenge due to the moisture and tissue content of the product. Prior research focused on meat packaging has led to the development of a material testing protocol for choosing transponders based on properties of modified atmosphere and controlled atmosphere packages (Vorst, 2003). Vorst also evaluated the effects of transponders on the bloom time of beef loin muscle. His research reported that there was no appreciable consumer or product aversion in utilizing RFID transponders as a supply chain management tool on fresh meat packaging.

Within the last year, some of the world's largest retailers have announced aggressive plans that detail how RFID technology will be integrated into their supply chains. In the United States, Wal-Mart, Albertson's and Target stores have instituted plans that require their top suppliers to apply RFID transponders to case and palletized goods beginning in 2005. European grocers have also announced their own plans that will require their top suppliers to integrate RFID transponders into shipments of cased goods. These implementation plans forecast the application of RFID transponders to the item level within the next 4-6 years (Wal-Mart (I), 2004).

As retailers and grocers begin to receive items that are individually tagged, they must understand the technological and material properties that these items present. When fresh meat packages contain transponders, the storage environments of these products can present many challenges to the operations of RFID systems. The affect of colder temperatures on the performance of packages containing RFID transponders has not been studied. A recent study found the average retail fresh meat case operates at 41° Fahrenheit (F) (AMIR, 2004). Frozen storage conditions may also be utilized during transportation and storage of fresh meats. These storage environments, coupled with the moisture found in fresh meats could potentially lead to a loss of data during the data transmission cycle.

This study will evaluate the use of RFID as a cold-chain tool by measuring the affects of different storage temperatures of fresh meat packages on the data transmission ability of two systems, operating at different frequencies. The goals of this study were to understand how beef muscle interacts with data transmission when conditioned in these operational environments. The first goal was to understand what effects refrigerated and frozen temperatures had on the data transmission of systems operating at 13.56 MHz and 915 MHz. RFID systems from Texas Instruments (TI) and Matrics Inc. were evaluated. The TI system operated at a frequency of 13.56 MHz, and the Matrics system operated at a frequency of 915 MHz. The second goal of this study was to measure what effect these temperatures had on the data transmission performance of packages in a stacked configuration.

The author hypothesizes that RFID systems operating in the 13.56 MHz bandwidth will experience zero loss of data communication between a transponder and interrogator while operating at both refrigerated and frozen temperatures. It is hypothesized that systems operating in the 915 MHz bandwidth will experience a total loss of data communication between the transponder and interrogator at both refrigerated and frozen temperatures.

LITERATURE REVIEW

RFID Technology

Radio Frequency Identification is an AIDC technology that utilizes radio frequency (RF) energy for the wireless transmission of data. RFID systems are comprised of four major components, a host computer, a transponder (tag), an interrogator (reader), and an antenna. Transponders have imbedded memory chips to record and retrieve data from. Antennas transmit and receive the data that is carried on the transponder and relay that information to the interrogator so that it may be interpreted and decoded. These components can have many different configurations, depending on the application and frequency that the system operates at. The frequency that is used to transmit data from the tag to the reader can very from a few hundred kilohertz (kHz), to tens of gigahertz (GHz). Most RFID systems used for supply chain applications utilize the 13.56 MHz or 915 MHz band. These are utilized because of the cost and read range characteristics they display (AIM, 2001).

RFID systems are classified into two main categories, active or passive. The distinguishing factor is how the transponder receives its power to communicate data. Transponders used in active systems carry an internal power source such as a battery or cell to power the communication circuitry. This type of transponder actively transmits its data and can be read at distances up to many miles. Active transponders vary in sizes from a matchbox to a shoebox, usually dependent on the size of the battery. Due to the size of active tags, they are generally utilized in long-distance, capitol asset tracking scenarios.

Examples include monitoring railroad cars within switching yards, and automatic toll collection systems.

Passive RFID systems do not have an internal source of power to energize the transponder. The data transmission cycle of a passive system begins when the reader's antenna transmits an interrogation signal. As a transponder enters this RF field, its communication circuitry is energized. The antenna then recognizes the transponder's signal, and the interrogator decodes the data. The orientation between the transponder and the antenna can influence performance of these systems, as RF fields can fluctuate. Read ranges for passive systems vary from a few centimeters to many feet, depending on the system/antenna/tag configuration (Kipp, 2003).

The data that are stored on transponders resides in a memory chip that forms part of its communication circuitry. Memory "may comprise read-only memory (ROM), random access memory (RAM) and non-volatile programmable memory for data storage depending upon the type and sophistication of the device (AIM, 2001)." ROM memory contains the transponder operating instructions that allow it to properly transmit its data. Temporary data storage during transponder field interrogation is held in RAM. Data stored on write-once, read-many (WORM) or re-writeable (R/W) transponders is held in non-volatile programmable memory, usually electrically erasable programmable read only memory, or EEPROM (Clarke, 2001). Transponder manufacturers allocate memory in many different configurations. Some transponders contain only ROM memory, while others combine a section of RAM and a section of R/W on the same circuit.

Data Protocol Specifications

Global standards groups such as International Organization for Standardization (ISO) and EPCglobal, inc. have published standards for RFID communications. These standards classify the data format and air interface protocols for systems that operate across all bandwidths. The purpose of these standards is to allow a commonality to exist between manufacturers and users of RFID equipment. This allows transponders manufactured by Company A to be read by an interrogator manufactured by Company B. The standards also define the format that the data will be encoded in. This allows a transponder encoded with data from User A to be decoded and recognized by User B.

In the United States, RFID standards for interrogator to transponder communication are being led by EPCglobal. EPCglobal is an international organization that was formed between the Uniform Code Council (UCC) and the European Article Numbering International (EAN) bodies. The goal is to drive global adoption of its standards for the identification of individual items within the world's supply chains. The group has defined a new identification system that incorporates a company's UCC product code with new information to form the Electronic Product Code, or EPC (EPCglobal, 2004). The EPC is a number that uniquely identifies an object and may be communicated using any of the defined EPCglobal standards. Currently, these standards are being utilized by early adopters such as Wal-Mart and Target stores for their RFID implementation plans (Wal-Mart Stores, 2004).

The data communication standards defined by EPCglobal for passive transponders are divided into two classes. Class 0 transponders are read-only, factory programmed and must have the following characteristics:

- Being factory programmed with EPC, and optionally other data,
- Being read be the reader
- Being selected as part of a related group of transponders, and
- Being individually destroyed (Auto-ID Center (I), 2003)

Class 1 transponders utilize WORM memory, are factory or user programmable, and must adhere to the following characteristics:

- Being programmed with EPC and possibly other data
- Being read by the interrogator
- Being selected as part of a related group of labels, and
- Being individually destroyed (Auto-ID Center (II), 2003)

Newer standards are currently being developed through EPCglobal to support the increasing memory capacity of newer generations of transponders. The new Class 1.2, or C1V2, standard is currently being written with input from both manufacturers and users of RFID equipment. This standard defines how "data is encoded on the EPC tag itself," and defines new numbering rules for specific values within the EPC to increase interrogator efficiency (EPCglobal, 2004). Wal-Mart expects "to move to C1V2 protocol tags when they become available (Wal-Mart Stores, 2004)."

Application to the Supply Chain

A company's supply chain may see multiple benefits when RFID technology is incorporated into its products. These benefits begin with the raw materials and continue through to the point of retail sale of the finished goods. "Clearly, different companies will benefit from different applications – some may find a significant improvement in sales through improving on-shelf availability while others may find cost savings from reducing shrinkage (Agarwal, 2001)." Agarwal's assessment of the benefits that RFID brings to the consumer goods industry has identified over 8 specific benefit cases for its use. While some do not directly apply to fresh meats, all have a strong retail application that will benefit the supplier, retailer or consumer at some level.

Agarwal's benefits are based on two requirements:

- The tagging of individual items
- The infrastructure to support multiple read points in the supply chain.

An evaluation of Agarwal's benefits and their application to fresh meat packaging shows many benefits. Suppliers will benefit from the ability to automate proof of delivery. As goods reach the retailer, automated scanning of the packages reduce human error in counting, while automatically sending confirmation of receipt to the supplier. Retailers will benefit from an improvement in on-shelf availability of products through a reduction in out-of-stock inventories. As shelf inventory levels hit their reorder point, that data may be automatically sent to the warehouse or stock room to replenish the shelf with product. This also has the built-in benefit of eliminating stock verification by automating the process. Retailers will also benefit from the incorporation of shelf-life dating to their product so that stores can utilize first-in-first-out (FIFO) stock rules with perishable products. "Goods with expiration dates can be better managed (moved more quickly when code dates are near), reducing the need for write-offs due to spoilage. This benefit is particularly important for perishable and date-specific products (A.T. Kearney, 2004)." RFID will also allow for increased security of high margin products by allowing for real time locating within the store, and conversely, signaling when a product has left the store.

Retailer Implementation of RFID Technology

Many retailers of consumer goods will soon realize the potential that RFID brings and the benefits that may be incorporated to their existing supply chains. Wal-Mart Stores of Bentonville, Arkansas, has recently instituted an implementation plan that requests their top one hundred suppliers to apply transponders at the case and pallet level. Wal-Mart expects to receive these items beginning January, 2005 at one Regional Distribution Center (DC), one Grocery DC and one SAM'S Club cross-dock DC. Their implementation strategy requests all of their domestic U.S. business suppliers to apply transponders by the end of 2006.

Wal-Mart has categorized the benefits of RFID into three areas of influence: supplier, collaborative and internal. "With respect to the collaborative benefits we are focusing on providing you [supplier] with additional visibility into our supply chain to improve Store/Club in-stock and potentially improve the freight claims process (Wal-Mart Stores, 2004)." Each supplier is thus required to understand and implement RFID technology into their own organization, and provide solutions to individual issues that may arise from packaging/product material interactions.

As of March 2004, many other national and international retailers have announced plans to incorporate RFID into their organizations that mirror the Wal-Mart announcement. Target Inc. has announced a pilot that requires their top vendors to apply transponders to cased goods beginning in 2005. European based grocers Tesco, Marks & Spencer and Metro AG have also announced similar pilot trials that will commence in late 2004. All of these companies have identified the use of UHF systems adhering to the EPCglobal Class 0 & 1 protocols to be acceptable solutions. Class 1.2 will be implemented when equipment becomes available.

Animal Agriculture Tracking

The United States Animal Identification Plan (USAIP) is a recent industry-state-federal partnership that has been formed to protect American consumers by safeguarding and improving the security of the animals that comprise the national herd. The USAIP "defines the standards and framework for implementing a phased-in national animal identification plan (USAIP, 2003)." The USAIP has been formed with the help of the United States Department of Agriculture (USDA) and the National Institute for Animal Agriculture. Its purpose is to create a plan that will "identify individual animals or groups, the premises where they are located, and the date of entry to that premises (USAIP, 2003)."

The USAIP is divided into three phases for implementation:

- Phase 1 – premises identification
- Phase 2 – individual or group identification for interstate and intrastate commerce
- Phase 3 – retrofitting remaining processing plants and markets and other industry segments with appropriate technology that will allow for the tracking of animals throughout the livestock marketing chain.

The USAIP notes that "the goal of 48-hour traceback, most likely, will require the integration of RFID technology to automate the recording of animal movements (USAIP, 2003)." By utilizing the memory capacity of the transponders, the necessary data may be carried on a transponder attached to the animal. In the event of a disease outbreak which necessitates a quarantine of specific animals, RFID will provide visibility in the supply chain to allow for the safe removal of those animals from stock.

Cattle and Food Borne Pathogens

Bovine Spongiform Encephalopathy, or BSE, is a degenerative disease that affects the nervous system of cattle. This disease can be spread to other cattle through feed contaminated with meal made from BSE-infected animals. The disease can also spread to humans who eat meat from a diseased animal (Reagan, 2002). To prevent an outbreak in the United States, the USDA has instituted three firewalls to combat its entry. The first firewall bans the import of animals and their products from countries with confirmed cases of BSE. The second firewall involves a "surveillance program that focused on testing high-risk cattle for BSE"; the third firewall bans "at-risk animal protein in cattle feed (Reagan, 2002)." Despite these precautions, the first known case within the United States was discovered in a cow in Washington state in December, 2003 (Associated Press, 2004).

Escherichia coli O157:H7 is a foodborne bacterial pathogen that can cause severe sickness or death in humans who consume food contaminated with it. "Between 1993 and 1998, most (72%) of the E. coli O157:H7 outbreaks were foodborne and of the foods implicated in the outbreaks, beef was responsible for 45% of the cases and 90% of the time the beef product was ground (Sofos et al., 2003)"

Foot and Mouth Disease, or FMD, is a highly contagious viral disease that can be rapidly transmitted though a population of animals. The disease primarily affects cloven-hoofed animals, and can be harbored by certain species, such as cattle, for over 2.5 years. Animals can become infected "through direct contact with an infected animal or indirect contact through contaminated equipment, facilities, people, feedstuffs and other materials (Bruning-Fann, 2002)." In the event of an outbreak, Bruning-Fann states that "with a highly contagious, rapidly disseminating disease, it is critical to know the livestock inventory and location of all farms." RFID can provide this visibility into the livestock and fresh meat supply chains to help quarantine animals, equipment or products that may be carriers of these pathogens.

Tray-Packed & Case-Ready Meats

Fresh meats have traditionally been cut, packaged and labeled in the store butchery before being placed on the retail shelf. According to the American Meat Institute (AMI), "prior to the 1960s, carcasses were shipped to retailers for breaking and cutting. In the 1960s, packing plants created 'boxed beef or boxed meats,' which provided smaller pieces called primals and sub-primals that could be further cut and wrapped at the retail store (AMI, 2004)." The traditional form of packaging fresh meats involved placing the cut on an expanded polystyrene (EPS) tray, and wrapping the package with polyvinyl chloride (PVC) film (Brody, 2002).

Newer meat-packing technologies have ushered in the "case-ready" package to the grocery retailer's shelves. A package is deemed case-ready when its "objective is to deliver prepackaged red meat with several days of shelf life to the retailers ready for the (display) case (Brody, 2002)." Case-ready meats are gaining favor with retailers due to the inherent benefits associated with the labor, packaging and distribution that the unit has to offer (AMI, 2004). With the centralization of meat plants, retailers may see a reduction in labor costs by eliminating the need for an in store butchery and associated personnel. Due to their engineered atmospheres, they allow for longer shelf and product lives. Case-ready meats will also reduce out of stocks by allowing the store to purchase specific cuts of meat. The AMI reports that 1.2 billion packages of case-ready meats were sold in the U.S. in 2000, with the potential to sell 9 billion packages in the future (Mandigo, 2002).

Data Integration

The ultimate goal of RFID is to create the "perfect purchase order": assurance that the correct product, in the correct quantity, is delivered from product suppliers to distribution centers to stores on schedule, with no mistakes. RFID tracking capabilities combined with the computer database enable accurate knowledge of product information, such as product location, quantity, and value at all stages of the supply chain. Gaining better control over inventory would contribute to improvement in processes, products and services, design, methodology, and supplier relations (Clarke, 2002).

As the USAIP and retailers begin to implement RFID into their business operations, the marriage of data from these two plans may be incorporated. The seamless transmission of data from livestock to the retail shelf will allow the two sources of data to be combined into a single source of storage: the RFID transponder. The operational potential of such a data system requires the knowledge of how the properties of fresh meats interact with RF transmissions. This research will focus on how two RFID systems, operating at different frequencies, affect the transmission ability of the data stored on the transponders.

Radio frequency transponders are rapidly becoming a viable technology for tracking of perishable food items through the grocery supply chain. However, the effects of package environment on radio frequency transponders are not well known; the impact of colder environments on transponder performance has not been studied. Little research has been conducted on the effects of extreme operational environments to the performance capabilities of RFID transponders. Recently completed research has focused on the mapping of the read-range field during normal laboratory conditioning: 72°F, 50% relative humidity (Kipp, 2003). These results have shown distinct field patterns that correlate to the type of antennae used, and at what operational frequency. Another study in the field has focused on the effects of transponders on bloom time of beef loin muscle (Vorst, 2002). This study has shown that transponders do not adversely affect the coloring or bloom time of the muscle with the application of the transponder to the polyvinyl chloride (PVC) overwrap film.

MATERIALS AND METHODS

This study will involve packaging individual beef loin steaks typically seen in butcher shops and retail meat cases. Transponders will be placed on the face of the package, located on the outer surface of the overwrap film. The packages will be conditioned at the average retail case refrigerated temperature of 41° F. Packages will then be placed within the read field of each system's antenna, and read-cycled to test if a transponder's data will be recognized. A read-cycle will consist of one transmission of data from a transponder to the host computer. Packages will then be stacked directly on top of another within the system's read field. The system will again be read-cycled to determine if all of the packages read. If all of the packages record a read, the test will be repeated with the addition of one package to the stack. The test will end when the system does not record a read from at least one package in the stack. Both test procedures will be repeated after conditioning the packages at a frozen temperature. For consistency between experiments, all tests were conducted with the antenna parallel to the transponder. This configuration is recommended by the manufacturers for optimal performance.

RFID System – Texas Instruments (Plano, TX)

A Texas Instruments S6350 RFID reader system was obtained for purposes of testing. The system operates at a frequency of 13.56 MHz, and houses the interrogator and antenna in a single unit (8"x 5"x 1"). See Appendix 1, Figure 1. The communication protocol for the system is proprietary to TI, designated Tag-it™. The interrogator was managed with S6350 Reader Utility software that was installed on a Dell Inspiron 2500 laptop computer. The computer was connected to the interrogator through a serial port connection. The operational read range for the system was determined to be approximately five inches from the top panel on the unit. The system was installed on a laboratory bench in a conditioned laboratory at 72° F and 50% relative humidity. See Appendix 1, Figure 1.

RFID System – Matrics Incorporated (Columbia, MD)

A Matrics EKT-001 RFID reader system that operates at a frequency of 915 MHz was obtained for testing. The interrogator unit was model RDR-001, attached to an ANT-001 antenna via coaxial cable. The Matrics system operates on the EPC Class 0 data protocol. The interrogator was controlled by Matrics Tag Tracker 3.0.1 software that was installed on the aforementioned laptop. The computer was connected to the interrogator through a serial port connection. The operational read range for the system was determined to be approximately twenty feet from the face of the antenna. The system was also installed in the conditioned laboratory at 72° F and 50% relative humidity. The antenna (29"x 13"x 2") was mounted on a wood frame, with the interrogator was positioned 10 feet to the rear. This location was recommended by the manufacturer so that the interrogator was not in the antenna's RF field. See Appendix 1, Figure 2.

Transponder Preparation

Texas Instruments RI-I01-112A 13.56MHz Tag-it™ transponders were obtained from Texas Instruments. Transponders were received on roll stock and were then individually cut to a uniform dimension of 2" by 2". Transponders were then individually placed within the read range of the unit. The system was read-cycled once to record a positive read from the transponder. Once operational status was confirmed for a transponder, they were affixed to the adhesive side of an Avery 5163 paper label. This simulates a typical adhesive pricing label that is applied directly to a meat package. The front of the label was sequentially marked with a numeral starting from 1 and ending at 50. The numbers aided in data collection and indicated the order in which the samples were tested.

Matrics DDS-001 adhesive label transponders were obtained for testing. Transponders were received individually separated and packaged in stacks of 50. Tags were individually placed within the read range of the antenna. The system was read-cycled once to record a positive read from the transponder. Once operational status was confirmed, they were also sequentially numbered to aid in data collection.

Preparation and Packaging of Tray-Packed Beef Loin Muscles

The preparation and packaging of beef loin muscle in this study was replicated using the method developed by Vorst. For the unique purposes of this study, certain omissions from his procedure occurred. The exact time from slaughter to simulated distribution was not recorded, as the color of the meat was not being measured. The use of high oxygen barrier nylon pouches were also omitted because the prevention of oxygen permeation into the package was not required (Vorst, 2003).

Two USDA Select strip loin muscles were obtained from a Lansing, Michigan distributor. Vorst utilized this cut due to the absence of connective tissue, and the uniformity provided between cuts. The strip loin muscles were labeled, vacuum packaged and weighed 15lbs and 18.85lbs whole, respectively. The muscles were then unpackaged and drained of all purged fluids. The individual beef muscles were sliced to a thickness of ½ inch through the lateral direction of the muscle. See Appendix 1, Figure 3.

Adams 4S trays (R.L. Adams Plastics Inc., Wyoming, MI) were used for this study to simulate common retail packages. Trays were constructed of expanded polystyrene (EPS) and measured 23.5cm x 18.4cm x 0.53cm in length, width and thickness. Sealed Air Corporation's Dri-Loc™ AC-25 absorbent pads were placed on top of the trays and directly under the steak. The pad is constructed of virgin fluff pulp, enveloped in polyethylene film. The pad measured 10.16cm x 17.8cm and has an advertised fluid absorbency of 40-50 grams. The pad is used for the absorption of excess blood and purging from the beef muscle. Plasticized PVC, 0.5 mil thick, was used as the overwrap film. The low barrier film was manufactured by Cryovac. This tray/pad/film combination is commonly found in retail meat applications.

Sample packages containing one steak were constructed and hand packed. The packaging process involved placing an absorbent pad centered in the EPS tray. An individual steak was then placed centered on top of the pad. A pre-cut piece of overwrap film was then centered over the tray, and wrapped around the edges to form the "face" side of the package. The excess film was wrapped and secured to itself on the underside, or "bottom" of the tray. This produced a package with zero headspace. Packages were uniform in appearance to typical retail meat packaging as described by Brody (Brody, 2002). The placement of the absorbent pad, steak and overwrap film were uniform for each sample produced. After statistical consultation, a total of 50 samples were constructed and found to be a statistically significant population size (CANR, 2003). See Appendix 1, Figure 4.

Test Procedure

The test procedure was divided into 4 consecutive experiments.

- Experiment 1 – Refrigerated samples tested with TI system
- Experiment 2 – Refrigerated samples tested with Matrics system
- Experiment 3 – Frozen samples tested with Matrics system
- Experiment 4 – Frozen samples tested with TI system

The test procedure used for these experiments was constructed to provide consistency between them while utilizing a perishable product. The procedure allowed the samples to maintain a refrigerated temperature during and between each experiment. After refrigerated testing was complete, the samples were frozen once for the remainder of the experiments. Samples were tested with one transponder attached and conditioned for each experiment. Transponders were able to be securely attached to the film and safely removed for later use. Although the TI and Matrics systems operate at different frequencies, transponders were never tested concurrently. This reduced the risk of false negatives being recorded due to interference from the other transponder.

Experiment 1 – Refrigerated Samples Tested With TI System

Step 1 – Attach Transponders

A TI transponder was attached to the overwrap film on the "face" of a sample package. The transponder was attached with the adhesive label on the left side of the package. This positioning replicated the label location of a typical retail meat package. This procedure was repeated for all 50 samples. See Appendix 1, Figure 5.

Step 2 – Condition

Samples were conditioned at 41° F for 48 hours to equilibrate both the package and transponder. Samples were placed in refrigeration with nothing stacked on top of them. This eliminated the chance of a transponder failing due to compressive forces.

Step 3 – Test Scenario

A sample was individually removed from refrigeration and placed above the S6350 unit. The S6350's antenna is located near the surface of the unit. The sample was orientated with the "face" of the package parallel and facing toward the top of the unit. The sample was located approximately five inches away from the S6350. This orientation allowed for an unimpeded communication path for the data, as only an air interface existed. The unit was read-cycled once and a read/no read was recorded as determined by the Reader Utility software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 7.

Step 4 – Test Scenario

A sample was individually removed from refrigeration and placed above the S6350 unit. The sample was orientated with the "bottom" of the package parallel and facing toward the top of the unit. The sample was located approximately five inches away from the S6350. This orientation allowed for the meat to act as a substrate and provide a barrier for the data. The unit was read-cycled and a read/no read was recorded as determined by the Reader Utility software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 8.

Step 5 – Test Scenario

A sample was individually removed from refrigeration and placed with the "bottom" of the package on the lab bench. Another random sample was removed from refrigeration and placed directly on top of the first sample in the same orientation. This procedure replicates typical retail meat displays where packages are stacked in a column. The S6350 was placed above the samples and read-cycled. A read/no read was determined for each sample. If both samples were recognized, another sample was removed from refrigeration and placed in the same orientation on the stack. The S6350 was read-cycled and a read/no read was determined for each sample. This procedure was repeated until a loss of one or more transponders was reported with the Reader Utility software. The number of successful packages in a stacked configuration to be read without loss was recorded. This test procedure was replicated 10 times using random samples. See Appendix 1, Figure 9.

Step 6 – Remove Transponders

TI transponder labels were removed from the sample packages without damaging the label or overwrap film. This was accomplished because the refrigerated temperature of the package reduced the aggressiveness of the label's adhesive. Transponder labels were placed in refrigeration to retain the same conditioning as the sample packages.

Experiment 2 – Refrigerated Samples Tested With Matrics System

Step 1 – Attach Transponders

A Matrics transponder was attached to the overwrap film on the "face" of a sample package. The transponder was attached with the adhesive label on the left side of the package. This positioning replicated the label location of a typical retail meat package. This procedure was repeated for all 50 samples. See Appendix 1, Figure 6.

Step 2 – Condition

Samples were conditioned at 41° F for 48 hours to equilibrate both the package and transponder. Samples were placed in refrigeration with nothing stacked on top of them. This reduced the chance of a transponder failing due to compressive forces.

Step 3 – Test Scenario

A sample was individually removed from refrigeration and placed in front of the ANT-001 antenna. The sample was orientated with the "face" of the package parallel and facing toward the front of the antenna. The sample was located approximately five inches away from the antenna. This orientation allowed for an unimpeded communication path for the data, as only an air interface existed. The RDR-001 interrogator was read-cycled once and a read/no read was recorded as determined by the Tag Tracker software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 10.

Step 4 – Test Scenario

A sample was individually removed from refrigeration and placed in front of the ANT-001 antenna. The sample was orientated with the "bottom" of the package parallel and facing toward the front of the antenna. The sample was located approximately five inches away from the antenna. This orientation allowed for the meat to act as a substrate and provide a tortuous communication path for the data. The RDR-001 interrogator was read-cycled and a read/no read was recorded as determined by the Tag Tracker software. This procedure was repeated for all 50 samples.

Step 5 – Test Scenario

A sample was individually removed from refrigeration and placed with the "bottom" of the package on the lab bench. Another random sample was removed from refrigeration and placed directly on top of the first sample in the same orientation. This procedure replicates typical retail meat displays where packages are stacked in a column. The ANT-001 antenna was placed above the samples and read-cycled. A read/no read was determined for each sample. If both samples were recognized, another sample was removed from refrigeration and placed in the same orientation on the stack. The RDR-001 interrogator was read-cycled and a read/no read was determined for each sample. This procedure was repeated until a loss of one or more transponders was reported with the Tag Tracker software. The number of successful packages in a stacked configuration to be read without loss was recorded. This test procedure was replicated 10 times using random samples. See Appendix 1, Figure 11.

Experiment 3 – Frozen Samples Tested With Matrics System

Step 1 – Condition

Samples were conditioned at 0° F for 48 hours to equilibrate both the package and transponder. Samples were placed in a freezer with nothing stacked on top of them. This eliminated the chance of a transponder failing due to compressive forces.

Step 2 – Test Scenario

A sample was individually removed from the freezer and placed in front of the ANT-001 antenna. The sample was orientated with the "face" of the package parallel and facing toward the front of the antenna. The sample was located approximately five inches away from the antenna. This orientation allowed for an unimpeded communication path for the data, as only an air interface existed. The RDR-001 interrogator was read-cycled once and a read/no read was recorded as determined by the Tag Tracker software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 10.

Step 3 – Test Scenario

A sample was individually removed from the freezer and placed in front of the ANT-001 antenna. The sample was orientated with the "bottom" of the package parallel and facing toward the front of the antenna. The sample was located approximately five inches away from the antenna. This orientation allowed for the meat to act as a substrate and provide a tortuous communication path for the data. The RDR-001 interrogator was read-cycled and a read/no read was recorded as determined by the Tag Tracker software. This procedure was repeated for all 50 samples.

Step 4 – Test Scenario

A sample was individually removed from the freezer and placed with the "bottom" of the package on the lab bench. Another random sample was removed from the freezer and placed directly on top of the first sample in the same orientation. This procedure replicates typical retail meat displays where packages are stacked in a column. The ANT-001 antenna was placed above the samples and read-cycled. A read/no read was determined for each sample. If both samples were recognized, another sample was removed from the freezer and placed in the same orientation on the stack. The RDR-001 interrogator was read-cycled and a read/no read was determined for each sample. This procedure was repeated until a loss of one or more transponders was reported with the Tag Tracker software. The number of successful packages in a stacked configuration to be read without loss was recorded. This test procedure was replicated 10 times using random samples. See Appendix 1, Figure 11.

Step 5 – Remove Transponders

Matrics transponder labels were removed from the sample packages without damaging the label or overwrap film. This was accomplished because the frozen temperature of the package reduced the aggressiveness of the label's adhesive.

Experiment 4 – Frozen Samples Tested With TI System

Step 1 – Attach Transponders

A TI transponder label was then removed from refrigeration and reattached to the overwrap film on the "face" of a sample package. The transponder was positioned in the same location as it was during Step 1. This procedure was repeated for all 50 samples.

Step 2 – Condition

Samples were conditioned at 0° F for 48 hours to equilibrate both the package and transponder. Samples were placed in a freezer with nothing stacked on top of them. This eliminated the chance of a transponder failing due to compressive forces.

Step 3 – Test Scenario

A sample was individually removed from the freezer and placed above the S6350 unit. The sample was orientated with the "face" of the package parallel and toward the top of the unit. The sample was located approximately five inches away from the S6350. This orientation allowed for an unimpeded communication path for the data, as only an air interface existed. The unit was read-cycled once and a read/no read was recorded as determined by the Reader Utility software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 7.

Step 4 – Test Scenario

A sample was individually removed from the freezer and placed above the ANT-001 antenna. The sample was orientated with the "bottom" of the package parallel and facing toward the top of the unit. The sample was located approximately five inches away from the S6350. This orientation allowed for the meat to act as a substrate and provide a tortuous communication path for the data. The S6350 was read-cycled and a read/no read was recorded as determined by the Utility software. This procedure was repeated for all 50 samples. See Appendix 1, Figure 8.

Step 5 – Test Scenario

A sample was individually removed from the freezer and placed with the "bottom" of the package on the lab bench. Another random sample was removed from refrigeration and placed directly on top of the first sample in the same orientation. This procedure replicates typical retail meat displays where packages are stacked in a column. The S6350 was placed above the samples and read-cycled. A read/no read was determined for each sample. If both samples were recognized, another sample was removed from the freezer and placed in the same orientation on the stack. The S6350 was read-cycled and a read/no read was determined for each sample. This procedure was repeated until a loss of one or more transponders was reported with the Reader Utility software. The number of successful packages in a stacked configuration to be read without loss was recorded. This test procedure was replicated 10 times using random samples. See Appendix 1, Figure 9.

RESULTS AND DISCUSSION

The results of these experiments found that the orientation of the package can influence the communication ability of a transponder's data. These experiments tested whether a transponder can communicate its data when the package is at a refrigerated and frozen temperature. These experiments also tested whether data could be communicated when a beef loin steak was directly between the antenna and transponder. The test procedure measured how many packages deep a transponder could transmit data through in a stacked configuration.

All refrigerated and frozen samples containing a TI transponder were able to communicate data when the transponder was facing toward and away from the antenna. The TI system was able to communicate data when samples were placed in a stacked configuration at both refrigerated and frozen temperatures. The maximum number of packages was found to be four during each replication. The maximum number of samples read can be attributed to the limited read range of the S6350 system, which was found to be six inches. The test results were consistent for each test scenario replication.

Refrigerated samples containing a Matrics transponder were able to communicate data when the transponder was facing toward the antenna. When the sample was facing away from the antenna, zero transponders communicated data. All frozen samples were read facing toward and away from the antenna. Refrigerated samples in a stacked configuration could only communicate a single transponder. The sample located on the top of the stack was the only one to communicate during each replication. Frozen samples in a stacked configuration communicated a maximum of 9 transponders. The addition of a tenth sample to the stack consistently saw the loss of communication for one or more transponders. This result was consistent for each test scenario replication.

Table 1. Refrigerated Read Percentages

	Refrigerated	
	Toward	Away
TI	100%	100%
Matrics	100%	0%

Table 2. Frozen Read Percentages

	Frozen	
	Toward	Away
TI	100%	100%
Matrics	100%	100%

Table 3. Depth of Reads

	Refrigerated	Frozen
TI	4 packages	4 packages
Matrics	1 package	9 packages

Results of this experiment show that the Matrics system could not communicate data through a beef loin steak in common retail packaging. The transponder could communicate when facing toward the antenna, but not away. The stacked configuration prevented any transponders from communicating when placed under another sample. The system was able to communicate when samples were conditioned at a frozen temperature. This suggests that fresh meat at a refrigerated temperature can impede the transmission of data for RFID systems operating at 915 MHz.

CONCLUSIONS

The results of this experiment suggest that a loss of communication could occur in Class 0 RFID systems operating at 915 MHz when utilized on packages of refrigerated beef. Grocery retailers who have announced RFID deployment strategies that adhere to UHF and EPCglobal standards need to evaluate the potential impact this may cause to their supply chains. The loss of visibility of a single package could nullify the advantages that have been identified by Agarwal. This could present a potential issue for retailers that plan to implement RFID systems into their organizations and expect to create a competitive advantage based on efficient supply chain management.

The loss of data communication would erase all of the benefits Agarwal has identified. Automated proof of delivery would produce erroneous results due to incorrect product inventories. This could lead to delays in restocking, incomplete stock verifications and a loss of virtual inventory. The ability of Wal-Mart's suppliers to have visibility into their supply chain could lead to incorrect order quantities and superfluous freight claims based on these inaccuracies. As suppliers conduct remote inventory polling, these inaccuracies will lead to incorrect reorder quantities and shipment times.

The loss of communication leads to data that is not transmitted and shared with the proper databases. As the USAIP is implemented, dynamic amounts of data will be routinely added to the memory of transponders and databases. As this data progresses down the fresh meat supply chain, a sudden loss of visibility could lead to the inability to recall packages of potentially contaminated meat.

The goals of this study were to understand how beef muscle interacts with transponder communications when conditioned in refrigerated and frozen environments. After completing the experiment, these goals have been achieved. The knowledge that refrigerated temperatures adversely affect the performance of fresh meat packages containing an RFID transponder operating at 915 MHz has been learned. The use of RFID systems operating at 13.56 MHz do not appear to be affected by these temperatures. This frequency may provide a better solution for products containing moisture in cold-chain applications.

FUTURE RESEARCH

As retailers such as Wal-Mart see their RFID implementation plans come to fruition, suppliers of cold-case goods will need to understand the impact that their products have on the transmission of data in the UHF bandwidth. The performance of RFID transponders in cold-chain applications extends beyond their use on fresh meat packaging. Items such as ice creams, frozen dinners, pickled foods, cheeses, yogurt, dough, vegetables, creams, milks and beverages are just a few of the products that contain moisture and require cold storage environments. The extent to which these products and their packaging materials inhibit or allow data communication remains to be studied.

Future research may be divided into three areas:

- Packaging material analysis
- Product analysis
- RF bandwidth analysis

These areas represent aspects of the packaging system that may be investigated to understand specific variables and how they impact RFID operations. By identifying variables that prohibit or prevent RF transmission, packaging engineers can be proactive in their approach to package design. Innovative packaging solutions will then allow for the seamless integration of RFID into the package system. These are areas that need to be investigated to overcome the limitations that have been identified in this experiment.

APPENDIX

Appendix 1. Photos and Graphics of Materials and Equipment

Figure 1. Texas Instruments S6350 system and Dell Inspiron 2500 computer

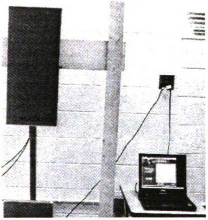

Figure 2. Matrics ANT-001 Antenna and Dell Inspiron 2500 computer

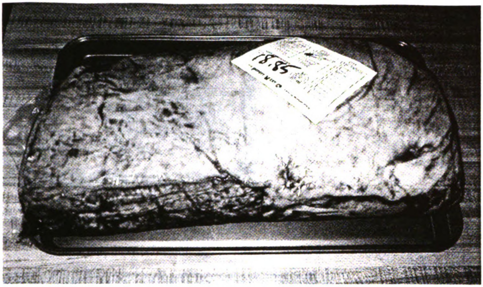

Figure 3. Vacuum packaged USDA Select strip loin muscle

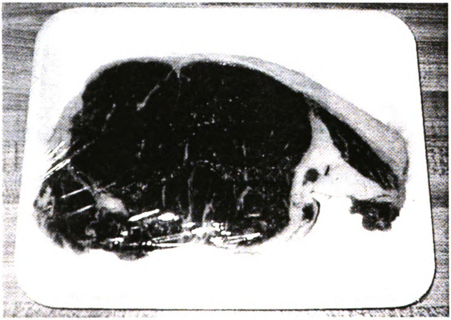

Figure 4. Face of tray packed sample

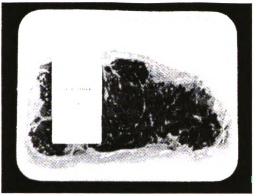

Figure 5. Sample with TI transponder label attached

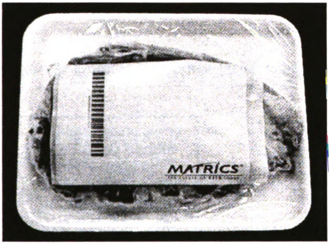

Figure 6. Sample with Matrics transponder label attached

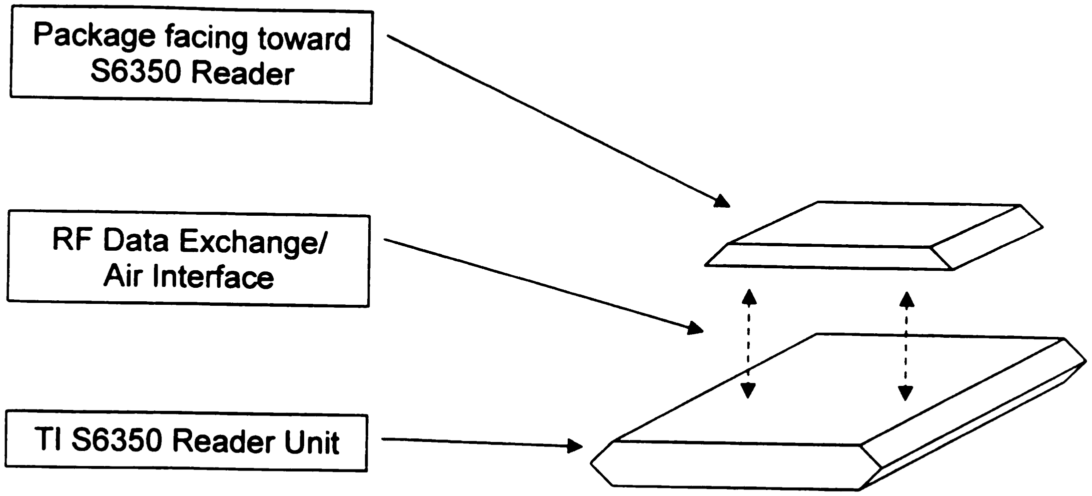

Figure 7. Graphic of package facing toward S6350 Reader

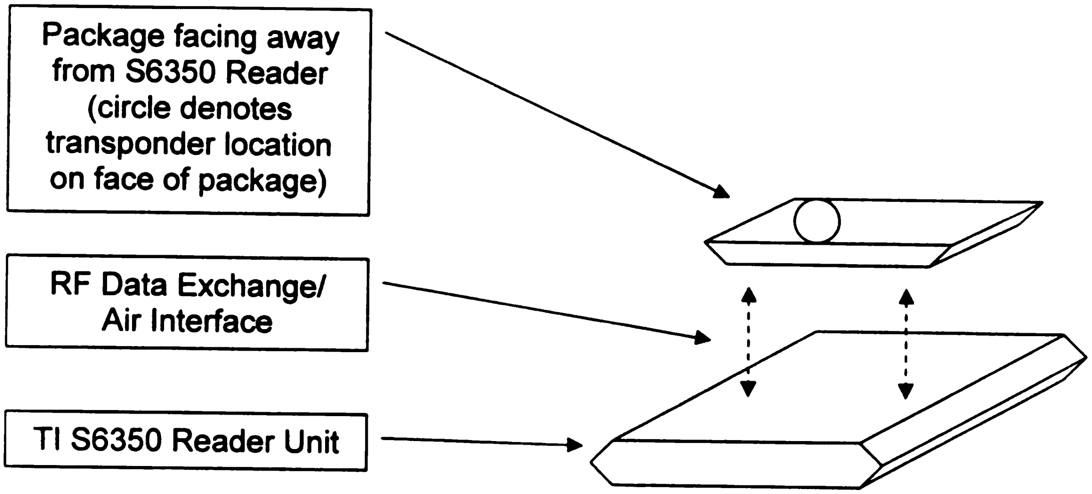

Figure 8. Graphic of package facing away from S6350 Reader

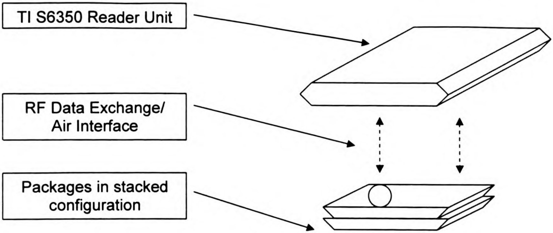

Figure 9. Graphic of packages in a stacked configuration

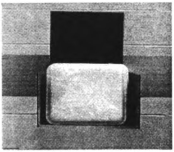

Figure 10. Picture of single package facing toward Matrics ANT-001 antenna

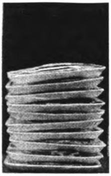

Figure 11. Samples in a stacked configuration

REFERENCES

Agarwal, V. 2001, September 1. Assessing the Benefits of Auto-ID Technology in the Consumer Goods Industry. Auto-ID Center, Massachusetts Institute of Technology, [On-line]. Available: http://archive.epcglobalinc.org/publishedresearch/CAM-WH-003.pdf.

AIM, Inc. 2001, August 23. Radio Frequency Identification RFID A Basic Primer. Automatic Identification Manufacturers, [On-line]. Available: http://www.aimglobal.org/technologies/rfid/resources/RFIDprimer.pdf.

Albano, S. and Engels, D.W. 2002, June 1. Auto-ID Center Field Trial: Phase I Summary. Auto-ID Center, Massachusetts Institute of Technology, [On-line]. Available: http://archive.epcglobalinc.org/publishedresearch/MIT-AUTOID-TR-006.pdf.

AMI. 2004, March. Case Ready Meats. American Meat Institute, [On-line]. Available: http://www.amif.org/FactsandFigures/FactSheetCaseReadyMeat.pdf.

AMIF. 1999. 1999 U.S. Cold Temperature Evaluation. American Meat Institute Foundation (AMIF), [On-line]. Available: http://www.amif.org/pdf/cold%20temp%20final.pdf.

Associated Press. 2004, March 24. U.S. Pressures Partners Over Beef Ban. MSNBC.com, [On-line]. Available: http://www.msnbc.com/id/4611358/

A.T. Kearney. 2004. RFID/EPC: Managing the Transition (2004-2007). A.T. Kearney, [On-line]. Available: http://www.atkearney.com/shared_res/pdf/RFID-EPC_s.pdf.

Auto-ID Center (I). 2003, February 23. Draft Protocol Specification for a 900 MHz Class 0 Radio Frequency Identification Tag. Auto-ID Center, Massachusetts Institute of Technology, [On-line]. Available: http://www.epcglobalinc.org/standards_technology/Secure/v1.0/UHF-class0.pdf.

Auto-ID Center (II). 2003, February 1. 13.56 MHz ISM Band Class 1 Radio Frequency Identification Tag Interface Specification: Candidate Recommendation, Version 1.0.0. Auto-ID Center, Massachusetts Institute of Technology, [On-line]. Available: http://www.epcglobaline.org/standards_technology/Secure/v1.0/HF-Class1.pdf.

Brody, A.L. 2002. Case-Ready Fresh Meat: Is It Here or Not? Food Technology 56:77-78

Bruning-Fann, C.S. 2002. Lessons Learned From the Foot and Mouth Disease Outbreak in the United Kingdom and Our National Plan in the Event of Such an Outbreak. *Proceedings of the 55th Annual Reciprocal Meat Conference*, American Meat Science Association, Savoy, IL. pp. 7-9.

CANR. 2003. Statictical consulatation.

Clarke, R. 2001. Radio Frequency Identification: Smart or Intelligent Packaging? Journal of Packaging Science and Technology 10:233-247

Clarke, R. 2002. Radio Frequency Identification: Will It Work In Your Supply Chain? *Worldpak 2002*, CRC Press, Boca Raton, FL. pp. 654-662.

EPCglobal. 2004. EPC Tag Data Standards, Version 1.1 Rev. 1.22. EPCglobal, [On-line]. Available: http://www.epcglobalinc.org/standards_technology/EPCTagDataSpecification11rev122.pdf.

Kipp, A. 2003. A Proposed Standard for Evaluating the Performance of Radio Frequency Identification Antennas, Tags and Readers. Master's Thesis, Michigan State University.

Mandigo, R.W. 2002. Ingredient Opportunities for Case-Ready Meats. Food Product Design. February 2002.

Reagan, J. 2002. The Beef Industry Plan: Keep America Free of Bovine Spongiform Encephalopathy. *Proceedings of the 55th Annual Reciprocal Meat Conference*, American Meat Science Association, Savoy, IL.

Ryan, M. 2002. A Model for the Implementation of A Radio Frequency Identification System Into A Warehouse Environment. Master's Thesis, Michigan State University.

Sofos, J.N., Skandamis, P., Stopforth, J., and Bacon, T. 2003. Current Issues Related to Meatborne Pathogenic Bacteria. *Proceedings of the 56th Annual Reciprocal Meat Conference*, American Meat Science Association, Savoy, IL. pp. 33-37.

USAIP. 2003, September 29. Draft Documentation for 2003 USAHA Presentation/Discussion, Version 4.0. United States Animal Identification Plan, [On-line]. Available: http://usaip.info/US_AIP_Plan _Draft_092903_Ver_4_0_Master_.pdf.

Vorst, K.L. 2002. Development of a Material Testing Protocol for Evaluation of Radio Frequency Transponder Effect on Bloom Time of Beef Loin Muscle. Master's Thesis, Michigan State University.

Vorst, K.L., Clarke, R.H., Allison, C.P., and Booren, A.M. 2003. A Research Note on Radio Frequency Identification Transponder Effects on Bloom of Beef Muscle. Meat Science 67:179-182

Wal-Mart Stores and Sam's Club. 2004. RFID Guidelines and Requirements, Document Version: 1.4.6656297.

Wal-Mart (I). 2004. Letter to author.

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 02497 6858