



Radio Frequency Identification Tagging: Applications for the Construction Industry

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CONTENTS

ACKNOWLEDGMENTS	ii
LIST OF FIGURES	viii
LIST OF TABLES	x
EXECUTIVE SUMMARY	xi
1.0 INTRODUCTION	1
1.1 Purpose of Research Project	2
1.2 Scope.....	2
1.3 Research Approach	2
1.4 Report Organization.....	3
2.0 DESCRIPTION OF RFID TECHNOLOGY	4
2.1 Components	4
2.1.1 Tag, or Transponder	4
2.1.2 Antenna	6
2.1.3 Scanner.....	8
2.1.4 Reader	8
2.2 How RFID Works	9
2.2.1 Overview	9
2.2.2 Operating Frequencies	10
2.2.3 Data Storage Capabilities.....	11
2.2.4 Data Communication Protocol	13
2.2.5 Batch Reading	16
2.3 Benefits	18
2.4 Costs	18
2.5 Limitations	20

2.6 Complementary Technologies.....	21
2.6.1 Radio Frequency Data Communication	21
2.6.2 Global Positioning Systems	22
2.6.3 On-Board Sensors	23
3.0 CURRENT RFID APPLICATIONS	24
3.1 Transportation	24
3.1.1 Rail Car Management.....	25
3.1.2 Traffic Management.....	25
3.1.3 Tolls and Fees	26
3.1.4 Fare Collection	26
3.1.5 Fleet Management.....	26
3.1.6 Vehicle Access.....	27
3.1.7 Solid Waste Hauling.....	28
3.1.8 Fuel Dispensing.....	28
3.2 Manufacturing.....	29
3.2.1 Automobiles.....	29
3.2.2 Computer Hard Disk Drives.....	29
3.2.3 Pharmaceutical Products.....	30
3.3 Security and Law Enforcement.....	30
3.4 Agriculture.....	32
3.4.1 Livestock/Animal Control	32
3.4.2 Food Distribution.....	33
3.4.3 Food Processing	34
3.5 Construction	35
3.5.1 Compressed Gas Cylinder Tracking	35
3.5.2 Small Tool Handling.....	35
3.5.3 Construction Equipment Monitoring	36
3.6 Athletics	36
3.6.1 Sports Event Timing.....	36
3.6.2 Golf Ball Identification.....	36

3.7	Miscellaneous Applications	36
3.7.1	Military Asset Tracking	36
3.7.2	Facility Management	37
3.7.3	Industrial Laundry	37
3.7.4	Underground Mining	38
3.7.5	Laboratory Monitoring	38
3.7.6	Forestry	39
3.7.7	Power Station Management	39
3.7.8	Automatic Guided Vehicle (AGV) Control	39
3.8	Applications in the Testing Phase	40
3.8.1	Postal Service	40
3.8.2	Smart Home Appliances	40
3.8.3	Airline Baggage	41
4.0	POTENTIAL CONSTRUCTION APPLICATIONS	42
4.1	Overview of Industry/RFID Supplier Workshop	42
4.2	Potential Applications	42
4.2.1	Engineering/Design	42
4.2.2	Material Management	43
4.2.3	Maintenance	44
4.2.4	Field Operations	45
5.0	RFID PILOT TESTS	47
5.1	Contractor Pilots Related to Material Receiving	47
5.1.1	Bechtel Red Hills Project	48
5.1.1.1	Description of Manual Receiving Approach	50
5.1.1.2	Description of RFID Receiving Approach	52
5.1.1.3	Results	54
5.1.1.4	Lessons Learned	57
5.1.1.5	Red Hills Pilot Summary	58
5.1.2	Bechtel Baytown Project	58
5.1.2.1	Baytown Pilot Test Procedure	59
5.1.2.2	Baytown Test Results	60

5.1.2.3 Lessons Learned.....	61
5.1.2.4 Baytown Pilot Summary.....	61
5.2 Owner Pilots	61
5.2.1 Smart Instrument Tracking for Rohm & Haas F4 Project	61
5.2.2 Pressure Relief Valve Maintenance on ExxonMobil Refinery.....	62
5.2.3 Operator Rounds and Mechanical Integrity Inspections	64
5.3 NIST Steel Component Tracking Application	65
6.0 RFID'S ROLE IN A FULLY INTEGRATED, AUTOMATED PROJECT PROCESS (FIAPP)	69
6.1 Construction	70
6.1.1 Personnel Accountability.....	70
6.1.2 Safety.....	70
6.1.3 Rigging Equipment	71
6.1.4 Preventive Maintenance	71
6.1.5 Fleet Management.....	71
6.1.6 Measuring and Testing Equipment	72
6.1.7 Quality	72
6.1.8 Material Control	73
6.2 Facility Management	74
7.0 SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS.....	76
7.1 Summary	76
7.2 Recommendations	78
7.3 Conclusions	78
REFERENCES	79
APPENDIX A. Glossary of Terminology.....	86
APPENDIX B. List of RFID Suppliers.....	101
APPENDIX C. List of Trade and Related Standards Organizations	109
APPENDIX D. Standardization Issues	113

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2.1: Assortment of RFID Tags	4
2.2: Examples of Fixed Antennas	7
2.3: Example of a Portable Antenna	7
2.4: Telxon Hand-held Reader	9
2.5: How RFID Works	9
2.6: Hughes Multiplexing System	10
2.7: Tag Memory Map	12
2.8: Tag Memory Map for Computer Example	13
2.9: Tag Memory Map for Selected Computer Configuration	13
2.10: Example of Frequency Shift Keying	14
2.11: Comparison of FDX, HDX, and SEQ Approaches	16
2.12: Schematic of Batch-Reading Issue	17
3.1: RFID Tag for Livestock Control	33
3.2: RFID Tag on a Sprinkler Control Valve	37
5.1: The Red Hills Generating Facility	48
5.2: Pipe Support in Lay down Area	49
5.3: Installed Pipe Support	49
5.4: Red Hills Lay down Area	50
5.5: Manual Receipt of Pipe Hangers and Supports	50
5.6: Flowchart Depicting the Manual Material Receipt Process	51
5.7: RFID Attached to Pipe Support	52
5.8: Worker Receiving Pipe Support using RFID Approach	53
5.9: Pallet of Bulk Pipe Supports for Baytown Project	59
5.10: Lay down Area for Baytown Project	59
5.11: Worker Scanning RFID Tag for Baytown Pilot Project	60
5.12: Dresser Pressure Relief Valve	63

LIST OF FIGURES (cont.)

<u>Figure</u>	<u>Page</u>
5.13: NIST Emission Control Project.....	66
5.14: Belt-wearable RFID Reader.....	67
6.1: Relationship Between RFID and FIAPP.....	69
6.2: Project Life Cycle Asset-Tracking Model.....	75

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2.1	Characteristics of Active versus Passive Tags	5
2.2	Characteristics of Read-Write Tags versus Read Only Tags	6
2.3	Frequency Bands and Applications	11
2.4	RFID Costs	19
5.1	Red Hills Pilot Test Time Measurements	55
5.2	Summary of Times for Manual and RFID Approaches	56
5.3	Estimated Time Required to Process 100 Pipe Supports/Hangers	57

EXECUTIVE SUMMARY

This report provides construction industry owners and contractors with current information about enhancing their operations using radio frequency identification (RFID) technology. Radio frequency identification involves the use of tags, or transponders, that collect data and manage it in a portable, changeable database; communicate routing instructions and other control requirements to equipment; and withstand harsh environments. It can be viewed as a sister technology to bar code labels which use light waves instead of radio waves to read a tag. An RFID system comprises tags, or transponders, and a reader that, depending on configuration, includes an antenna and scanner. The tag contains a small integrated circuit chip and an antenna that is encapsulated in a protective shell. The reader contains, at a minimum, an antenna and scanner and is used to communicate with the tag. Tags can be categorized as read only or have both read and write capabilities. Moreover, they are classified as active, which means they include a battery, or passive, which means they are powered by the reader's energy field. The memory capacity of the tags varies from 64 to 32,768 bytes (one byte equals eight bits of binary code). The technology, in existence for several years, is currently being used in several application areas such as vehicle access, personnel identification, asset tracking, livestock identification, and tolls and fees. Application development is currently underway in areas related to groceries, postage stamps, and baggage identification in airports.

The primary benefits of using RFID technology are its ability to store data and retrieve it at a later time. In addition, unlike bar code labels, it is more robust because RFID tags are not damaged as easily, can be read in direct sunlight, and survive harsh conditions. Limitations include higher tag costs compared to bar code labels; lack of standardization, which prohibits one manufacturer's reader from reading another manufacturer's tag; and potential interference from steel objects and other radio frequency signals.

The purpose of this research project was to disseminate information regarding RFID to owner and contractor organizations, enabling them to take advantage of this emerging technology as it becomes commercially available. The project report also

provides RFID manufacturers with relevant information regarding the needs of the construction industry so future RFID products better address the industry's needs.

The scope of this research project includes (1) providing Construction Industry Institute (CII) member companies with a better understanding of RFID tagging technology (what it is, how it works, benefits, costs, and current applications); (2) understanding CII member company needs in terms of what applications will best suit their needs, the type of data that should be stored on each tag, and barriers to implementation; (3) pilot-testing applications in the construction and owner facility operations environment; and (4) assessing how RF tagging technology can be incorporated into a fully integrated, automated project process (FIAPP).

A construction industry-RFID supplier workshop was held to disseminate information about this technology and to generate suitable application ideas for the industry. Thirty-one people attended the workshop, which included representation from both CII owner and contractor firms and four RFID suppliers (Brady RFID Systems, HID, Intermec-Amtec, and SAT Corporation). Potential application areas discussed by participants included material management and procurement (e.g., material receiving, installation, and startup and commissioning), field operations (e.g., personnel management, timekeeping, handling certification for mechanical machinery, and fleet management), and maintenance (e.g., inspection, repair history, operating data, and compliance records). Moreover, the following critical points were identified during the workshop:

1. RFID has its strengths and limitations.
2. There are few construction-related RFID suppliers.
3. RFID should be used with the larger company information system (FIAPP).
4. Bar code labels and RFID tags should be considered complementary technologies.

With the information gathered during the workshop, five application ideas were selected and pilot tests conducted to learn more about RFID and its applicability to the construction industry. One contractor application, related to receiving pipe supports on a jobsite, was explored. Three owner applications related to (1) tracking smart instruments, (2) maintenance of pressure relief valves, and (3) operator rounds and mechanical

integrity inspections were tested on existing plant facilities. The National Institute of Standards and Technology also conducted an experiment using RFID to track steel components on a job site. These tests involved the use of passive RFID technology in the 125-Khz frequency range.

Results from these pilot tests showed that RFID can potentially reduce costs for both owners and contractors. The contractor pilot showed that RFID tags reduced the time required to download data into a company's material tracking system and could "flag" an item so an entry was not repeated. When scanning the tags, sun glare was not a problem. Furthermore, it was perceived that there were lower rework costs, reduced inventory shrinkage, reduced start-up times, and positive material identification for the owner applications.

This report also investigates ways to integrate RFID technology throughout the project life cycle, improving productivity, cost, schedule, quality, and safety. The primary areas are related to construction (personnel accountability, safety, rigging equipment, fleet management, measuring and testing equipment, quality, and material control) and owner operations. From the owner's perspective, asset management would provide the greatest benefit. At the point of manufacture, RFID tags could be encoded with specific information by the manufacturer that the contractor would use upon receipt for inventory control at the site, including preventive maintenance requirements that would apply throughout the component's life and during the storage cycle of the project. When the asset was turned over to the owner, the information stored on the RFID tag could be used to track the asset's life during its maintenance and operation period.

Radio frequency identification is becoming more popular as a tagging and identification technology. In addition to its relatively large storage capacity, it is very reliable and extremely robust in harsh environments. This technology also has a high level of security because it is nearly impossible to replicate tag information. Several applications have already been successfully developed using this technology. As demonstrated by the contractor and owner pilot tests, RFID is a promising technology for enhancing construction operations related to material receiving and also possibly other operations related to maintenance and operations. Overall, this technology has

significant potential for enhancing several processes in the construction and facility operations environment.

1.0 INTRODUCTION

Radio frequency identification (RFID) refers to a branch of automatic identification technologies in which radio frequencies are used to capture and transmit data. The radio frequency identification technology involves the use of tags, or transponders, that can collect data and manage it in a portable, changeable database within the tag; communicate routing instructions and other control requirements to equipment; and withstand harsh environments. Specific RFID applications have already been developed in many areas including material identification, tool handling, automatic guided vehicle control, toll and fee collection, hazardous material identification, meter reading, equipment maintenance, personnel identification, asset location and tracking, animal tagging, and home and business security systems. A recent study projects annual sales revenue for RFID to increase approximately 300% from 1999 to 2004 (868 million to 3,622 million, respectively (Id Systems, 1999).

Owner and contractor organizations may want to become more familiar with RFID technology so they too can reap the benefits other industries have already experienced by applying this innovation. Under the guidance of Dr. Edward Jaselskis, a civil and construction engineering professor at Iowa State University, Ames, two graduate students conducted this research project, which investigates how RFID technology can enhance construction operations by reducing project cost and cycle time. Moreover, the project considers the possibility of incorporating RFID technology into a fully integrated, automated project process (FIAPP). Owner and contractor Construction Industry Institute (CII) member companies can benefit from this study because they will be able to make more informed decisions about the various RFID applications and how they can be combined with integrated, automated systems, improving operating efficiency.

This research project assists CII member companies in making more informed decisions regarding the RFID application at any phase within the project cycle where improved efficiency is desired and can be achieved. Some examples described in this report relate to (1) enhancing the material receiving process for engineered items,

(2) improving the installation process of smart instruments and steel components, and (3) improving maintenance operations during critical turnaround projects.

1.1 Purpose of Research Project

The purpose of this research project is to collect information regarding RFID technology and present it to CII member companies, enabling them take advantage of this emerging innovation. It also provides suppliers of this technology with important information about the needs of owner and contractor organizations, enabling the suppliers to tailor to the industry's needs.

1.2 Scope

The scope of this research project involves

- Providing CII member companies with detailed information about RFID tagging technology (e.g., description, current applications, benefits, costs, and limitations), promoting a better understanding and wider acceptance of the technology.
- Soliciting feedback from CII member companies in terms of their needs, what applications will best meet these needs, the type of data that should be stored on each tag, and barriers to implementation.
- Performing pilot tests from both owner and contractor perspectives to determine the technology's capabilities and potential for improving project life cycle costs.
- Assessing how radio frequency identification technology can be integrated into FIAPP.
- Summarizing and reporting the findings of this research.

1.3 Research Approach

The initial research approach involved developing a better understanding of the technology through an extensive literature review and interviews with several knowledgeable RFID specialists. The research team next sponsored an industry-RFID supplier workshop for owner and contractor representatives to introduce and promote the technology and to solicit ideas about potential applications. Based on recommendations from this workshop, several pilot applications were developed and tested from an owner

and contractor perspective. The results of these pilot tests are summarized and presented in this final report. The report also considers RFID's role in FIAPP. Finally, the report presents the research team's recommendations for implementing this technology in both owner and contractor organizations.

1.4 Report Organization

This report begins with a description of the technology, that is, considering its components, operating processes, benefits, current applications, costs, and limitations. A discussion of potential applications, the result of the industry-RFID supplier workshop, is then provided. After the pilot tests are described, including the results, RFID's role in a FIAPP is explored. Recommendations for successful implementation are presented in the following chapter, and the study conclusions end the report.

2.0 DESCRIPTION OF RFID TECHNOLOGY

This chapter provides a general description of the radio frequency identification (RFID) technology including its components, an overview of how the technology functions, its benefits, its costs, and its limitations. A comprehensive glossary of RFID terminology is presented in Appendix A. Furthermore, a complete list of RFID suppliers and trade organizations is included in Appendices B and C, respectively.

2.1 Components

Radio frequency identification systems consist of four basic components: (1) tag, or transponder, (2) antenna, (3) scanner, and (4) reader. In some industrial applications where equipment may be permanently fixed, each of these components is a separate item. In other applications where portability is required, some of the components may be combined into one hand-held configuration that includes, for example, the antenna, scanner, and reader. A description of each component follows.

2.1.1 Tag, or Transponder

The tag, also called a transponder, contains an antenna and integrated circuit chip that is encapsulated to protect against shock, fluids, dust, dirt, and other contaminants. Radio frequency tags can come in many shapes and sizes. Figure 2.1 shows a variety of tags manufactured by Texas Instruments. Note that some of the tags are in the shape of identification cards, disks, cylinders, and hermetically enclosed glass capsules (refer to lower right corner of the figure). A tag can range in size from the size of a small aspirin to approximately the size of a brick (Datalogic, 1996). Over 34 billion unique identification codes can be stored on the tags (Hughes Identification Devices, no date).



Figure 2.1: Assortment of RFID Tags

Tags are classified as active or passive and may have read-write or read only capability. Active tags contain a battery that powers the tag once the reader has activated it. They can be read or written to from greater distances because of the battery; however, active tags are generally more expensive than their passive counterparts and have a limited 3 to 10 year life. Some active tags are now being produced that use the incoming radio signal to recharge their internal battery, extending their life beyond 10 years (Moore, 1998). Passive tags, on the other hand, are powered solely by the magnetic field emanated by the reader or may contain batteries that are used to energize the internal circuitry but are not responsible for data transmission. Passive tags have an extremely long life and usually last longer than the object itself, making it suitable for use in hazardous waste material container tracking and identification (What is RFID?, 1996). Read and write ranges for passive tags are generally less than 6 feet; in most configurations, the read range is only 8 to 12 inches. Refer to Table 2.1 for a summary of this information.

Table 2.1: Characteristics of Active versus Passive Tags

	Active	Passive
Power Source	Battery	Powered by magnetic field
Read Range	5-100 ft.	Less than 6 ft (usually 1-6 inches)
Lifetime	3-10 yrs.	Unlimited lifetime

A read only tag is programmed either during manufacture or by the user once during its lifetime. The information programmed onto read only tags cannot be altered at a later time. Read only tags are generally used only for simple identification purposes, because they hold approximately 8 to 128 bits of memory. With read-write tags, as the name implies, the user can alter the information stored on the tag. There are also write-

once, read many (WORM) formatted cards and tags that are essentially read only; the user can program them one time.

The memory capacity of read-write tags varies anywhere from 64 to 32,768 bytes where one byte equals 8 bits of binary code (i.e., “0” or “1”); this represents several pages of text (Datalogic, 1996). The larger capacity tags are basically portable data files that can initiate action or be selectively read for specific information (Radio Frequency Identification, 1998). The precise amount of memory depends on the specific tag selected. For example, Balogh fixed code or read only tags are available with 1-byte, 2-byte or 7-byte capacities. Its read-write tags are available with 64-byte, 2-kilobyte, or 8-kilobyte memory capacities (Balogh, no date). Refer to Table 2.2 for a summary of read-write versus read only tag characteristics.

Table 2.2: Characteristics of Read-Write Tags versus Read Only Tags

	Read-Write	Read Only
Memory Capacity	64 -32,768 bits	8-128 bits
Information Content	User can alter	User can not alter
Data Transfer Speed	Approx. 3,000 bps	Approx. 8,000 bps

2.1.2 Antenna

The antenna transmits an electromagnetic field that activates the transponders when they come within range. When the transponder transmits its data, the information is, in turn, received by the antenna. To meet different mounting and orientation demands, they may be fixed or portable. Antennas are available in several configurations and vary in size and shape. They can be freestanding or imbedded in other structures such as in a concrete block wall to detect personnel badges or passersby. Antenna placement depends on factors such as the system’s operating frequency, the size of the tags and antenna in use, the nature of the surrounding materials, and the amount of free space

(Floyd, 1993). Figure 2.2 shows various antennas that are fixed in place including a portal antenna that would be found at store entrances. Figure 2.3 shows a portable antenna, which also houses the scanner electronics.

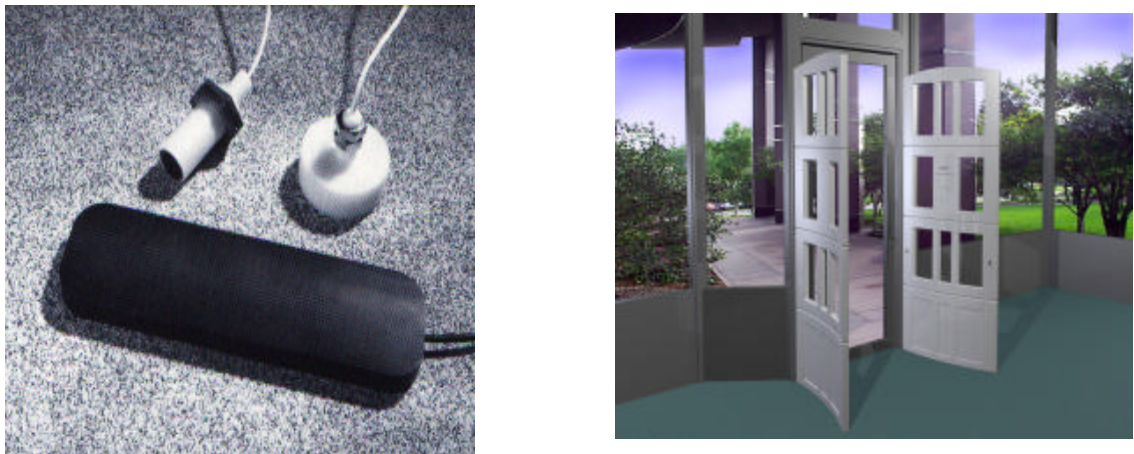


Figure 2.2: Examples of Fixed Antennas



Figure 2.3: Example of a Portable Antenna

2.1.3 Scanner

The scanner board is connected to the antenna and has the following two functions: it (1) generates the energizing signal transmitted from the antenna to the transponder and (2) filters and amplifies the incoming data signal. Certain scanners have an antenna integrated into the printed circuit board; others must be used with a separate antenna (Telsor, no date a). Upon receipt of the reader's enabling signal, the scanner initiates the magnetic field generated by the antenna, acts as a receiver for the return code from the transponder, and relays the signal back to the reader. Scanners are configured in models with external antennas, as well as with internally integrated antennas.

2.1.4 Reader

The reader communicates with the tag via the antenna, using an electromagnetic field. Readers convert the scanner's analog output into the digital format, which can then be used for data analysis, recording, and reports by the host computer. Reader interfaces also monitor incoming signals from the transponders to ensure valid tag data and virtually error-free operation (Telsor, no date b).

Readers come in either stationary or hand-held models. Stationary models typically have a greater read range because they can generate more energy than the battery-operated, hand-held models. Hand-held models are used where portability is desirable, such as warehouse management. These portable readers generally contain an antenna, scanner board, reader electronics (decoder, data converter, and computer interface), and a power supply (What is RFID?, 1996). Figure 2.4 shows a Telxon reader that includes an antenna and scanner. This portable unit is rated for operation in an explosive environment (Class I Division 2) and can withstand rough treatment (e.g., can be dropped approximately four ft on a solid surface and still function properly).



Figure 2.4: Telxon Hand-held Reader

2.2 How RFID Works

2.2.1 Overview

Figure 2.5 provides an overview of how this technology works. The reader (including an antenna and scanner) sends energy to the tag (refer to A in diagram), and the tag sends identification data back to the reader (refer to B in diagram). The reader decodes the data and transmits it to a computer for inclusion in the facility information system (refer to C in diagram).

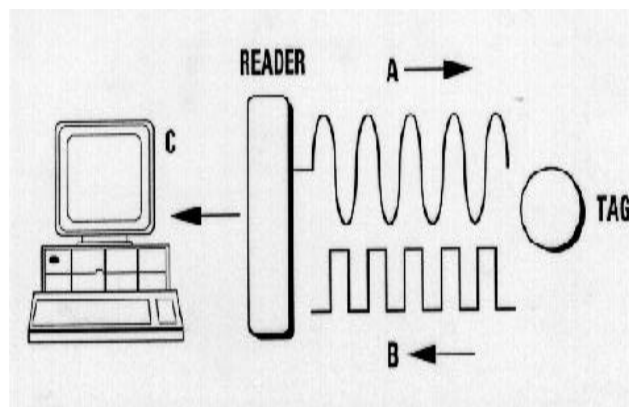


Figure 2.5: How RFID Works

In addition to the single channel system depicted in Figure 2.5, there are also multiplexing systems. Figure 2.6 shows the schematic of a Hughes IS52001 multiplexing system, a multiplexing reader that will support up to eight scanners. It is equipped to supply an enable signal to each scanner while inquiring for a transmitted ID. The multiplexing reader decodes the ID number, digitally formats it, and identifies the scanner number, sending the information to the host computer (Hughes, no date).

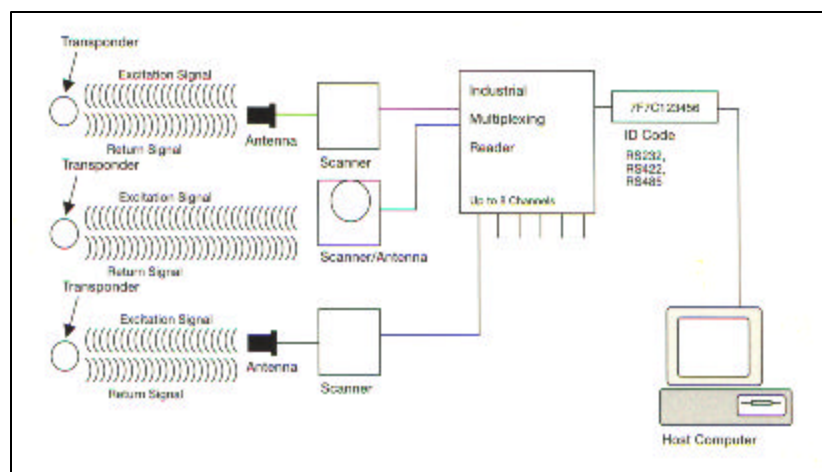


Figure 2.6: Hughes Multiplexing System (Hughes, no date)

2.2.2 Operating Frequencies

Radio frequency identification operates within three frequency ranges: high, intermediate, and low. Table 2.3 shows the typical characteristics and applications for these three ranges (Radio Frequency Identification, 1998). High-frequency (850-950 MHz and 2.4-5 GHz) systems are suitable for applications requiring a longer read range such as toll collection, railroad cars, and intermodal containers. Intermediate-frequency (10-15 MHz) systems are emerging in the financial transaction processing area of smart card use. Low-frequency (100-500 kHz) configurations are used for applications requiring shorter read ranges such as access control, work-in-process tracking, time-and-attendance management, vehicle identification, laundry/textile identification, and asset management (What is RFID?, 1996). One advantage of lower frequencies is their ability

to read through obscuring materials and around corners (Moore, 1998). It should be noted that the Federal Communication Commission restricts frequency use to either the very low (50-500 kHz) or microwave (0.9-2.5 GHz) range (Datalogic, 1996).

Table 2.3: Frequency Bands and Applications

Frequency Band	Characteristics	Typical Applications
Low (100-500 kHz)	Short to medium read range Inexpensive Low reading speed	Access control Animal identification Inventory control Car immobilizer
Intermediate (10-15 MHz)	Short to medium read range Potentially inexpensive	Access control Smart labels
High (850-950 MHz) (2.4-5.8 GHz)	Long read range High reading range Line of sight required Expensive	Railroad car monitoring Toll collection systems

2.2.3 Data Storage Characteristics

The most efficient and frequently used method to store data on an RFID tag is as a coded bit map. Figure 2.7 represents a 64-byte memory tag with addresses from 0 to 63. Note that each address contains 8 bit locations (from bit 0 to bit 7), and each bit can be either a “1” or “0” (Balogh, no date). Each address may represent a binary code (e.g., 01100001 represents the lower-case letter “a” as shown in Address 8 of Figure 2.6) or a characteristic of a product being manufactured as the next example discusses.

Address	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7
0	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
2	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
3	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
4	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
*								
8	0	1	1	0	0	0	0	1
*								
63								

Figure 2.7: Tag Memory Map

As an example of a typical manufacturing operation involving RFID tagging, consider a computer being assembled on a production line. An RFID tag is attached to the computer frame to provide the operators with configuration assembly information and record inspection status. Figure 2.8 shows the memory map for information programmed onto the tag. In this example, the tag has four addresses (0, 1, 2, and 3). Address 0 identifies the hard disk size (2, 3, or 6.4 gigabytes) and if the hard disk passed an inspection. Address 1 identifies the type(s) of disk drives that will be included in the computer (3.5", Zip drive, CD-ROM) and if the disk drive(s) passed the inspection. Address 2 relates to whether the computer will be configured with a modem and also includes memory to indicate the inspection status. Lastly, address 3 indicates how much internal memory will be configured in the computer (32, 48, or 64 kilobytes of random access memory [RAM]) as well as an inspection status indicator.

Address	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7
0	2 Gig HD	3 Gig HD	6.4 Gig HD	PASSED	FAILED			
1	3.5" Drive	Zip Drive	CD ROM	PASSED	FAILED			
2	Modem	PASSED	FAILED					
3	32 RAM	48 RAM	64 RAM	PASSED	FAILED			

Figure 2.8: Tag Memory Map for Computer Example

Suppose a computer configuration is to include the following components: 2-gigabyte hard disk, 3.5-inch disk drive, Zip drive, CD ROM drive, modem, and 64 kilobytes of RAM. After the computer has been assembled and all components have successfully passed the inspections, the tag memory appears as shown in Figure 2.9.

Address	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7
0	1	0	0	1	0			
1	1	1	1	1	0			
2	1	1	0					
3	0	0	1	1	0			

Figure 2.9: Tag Memory Map for Selected Computer Configuration

2.2.4 Data Communication Protocol

To transfer data efficiently between the transponder and the reader requires the information to be "...superimposed upon a rhythmically varying (sinusoidal) field or carrier wave," (Radio Frequency Identification, 1998). This is done by varying one of the main components of the wave: its amplitude (amplitude modulation [AM]), its frequency (frequency shift keying [FSK]), or its phase (phase shift keying [PSK]) (Radio Frequency Identification, 1998). The most common transmission technique is FSK

between 123.2 kHz and 134.2 kHz. It has a slower data transfer rate than the other two methods but a strong immunity to background noise. While PSK also has good noise immunity, it requires more complicated readers (Sharp, 1998 b).

The 123.2 kHz to 134.2 kHz frequencies are the most popular because operating below 135 kHz does not require a frequency allocation from the necessary regulatory organization, making the system very cost effective to implement (Transponder News, 1998). Figure 2.10 shows an example of FSK (TIRIS Technology Overview Catalog, 1992). Note that the binary character “0” is designated by the higher frequency (134.2 kHz) and the binary character “1” is designated by the lower frequency (123.2 kHz). Specially designed electronic circuits are capable of detecting this frequency shift.

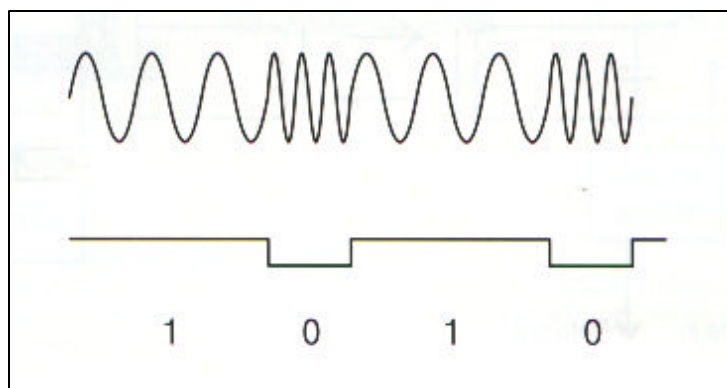


Figure 2.10: Example of Frequency Shift Keying

Moreover, there are three different design communication principles in the passive, low frequency RFID market related to full-duplex (FDX), half-duplex (HDX), and sequential approaches (SEQ). In the FDX approach, the data transfer from the reader to the tag takes place at the same time as the data transfer from the reader to the transponder (Finkenzeller, 1999). This means that the transponder returns the interrogator signal once the beginning of the interrogator signal is received and the smoothing capacitor has been charged. As long as a continuous interrogator signal continues, the return signal is received without interruption. With FDX, data are transmitted from the transponder at a completely independent or “an harmonic”

frequency which means that a transponder does not need to store energy to return its entire code.

On the other hand, with the half-duplex approach, the data transfer from the reader and the transponder alternate with each other. This means that the return signal is sent once because it initiates only after the complete receiving of the interrogator signal and after the storage capacitor has been fully charged. It is important to note, the two approaches are completely different. However, in the two approaches, the transfer of energy from the reader to the transponder is a non-stop, meaning that it is independent of the data transfer direction. Although a compromise is easy to reach by having compatible readers that can read both types of transponders. A reader of such specification would degrade the FDX performance by inheriting the drawbacks of the HDX system. The read speed performance of the FDX will drop to that of HDX because of the slower HDX system. The result is a more expensive reader that is designed to read two types of technology with lower efficiency than it would be the case of having only a single system.

With the sequential systems (SEQ), the energy transfer between the tag and the reader occurs for a limited period of time. The transfer of data from the tag to reader is, therefore, performed in the pauses between the power supply to the tag. Figure 2.11 graphically depicts the FDX, HDX, and SEQ approaches over time. In this figure, the term “uplink” refers to the data transfer from the tag to the reader, while the term “downlink” refers to the opposite direction of data transfer.

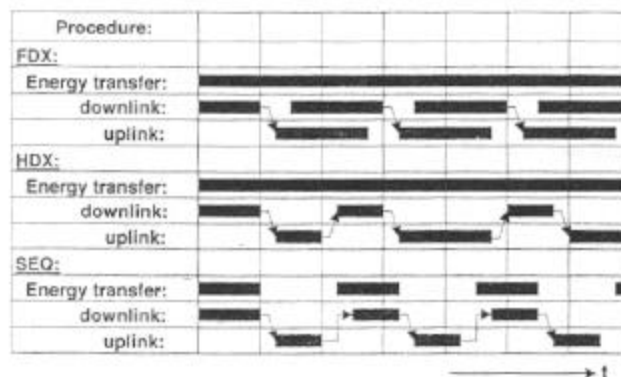


Figure 2.11: Comparison of FDX, HDX, and SEQ Approaches (Finkenzeller, 1999)

2.2.5 Batch Reading

One of the issues associated with RFID involves reading multiple tags in the same inquiry zone (Hawkes, 1998). The interrogator becomes confused because signals from multiple transponders will overlap with respect to time. As can be seen in Figure 2.12, this often causes some of the signals to go unread. Incompatible transponders or readers can compound this problem. Batch reading is one of the potential major advantages of RFID over other scanning systems such as bar code. Scanning multiple items, as opposed to each item individually, saves significant time and money. Because of this concern, several companies have developed some creative solutions to the batch-reading issue. The solutions can be broken down into three categories. One is using tags that “die” or “sleep” when their signal has been read. Another category is to have the receiver act as a searchlight over the entire zone with a beam narrow enough to hit each transponder singly. The third is the use of multiple interrogators (Hawkes, 1998).

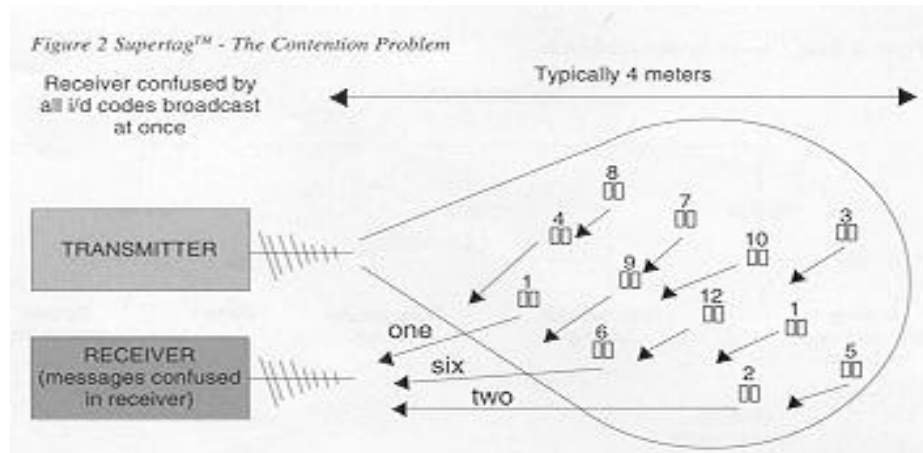


Figure 2.12: Schematic of Batch-Reading Issue (Hawkes, 1998)

One example of the sleeping tag technology is SAMSys Technologies Inc.'s Fastrak System, a unique system that can scan, identify, and count up to 50 assorted or identically coded items every second, eliminating the need to scan each item individually and quickly. The system's proprietary anti-clash protocol permits the reading of identically coded tags without conflict. According to the company, this RFID system is the only one that incorporates an electronic counting capability. The length of sleep or shutdown time is programmable. This "change-of-state" feature ensures that the tagged item is cleared before it passes a checkpoint, which guarantees that no tag is read twice (SAMSys, no date). This type of tag is ideal for scanning groceries in a shopping cart, vehicles on a highway for toll collection purposes, or passenger baggage for the airline industry.

Savi Technology, Inc. has a batch collection (copyrighted) algorithm for its Savi Asset Management System that can accurately and automatically identify thousands of tagged assets at a single location in a matter of minutes (Savi Technology, 1993). This algorithm uses the multiple interrogator approach. The Department of Defense has implemented the Savi batch collection technology for materials management and asset tracking. Using multiple readers connected to a computer, a grid system is erected over

large sites containing thousands of items. The exact location of one particular item can be determined or an inventory of the entire site can be easily performed (Lawlor, 1993).

2.3 Benefits

The primary benefits of using RFID are its ability to operate in a non line-of-sight capacity and to store data in a changeable database. Moreover, while other identification technologies rely on optics and require a relatively clean, moisture-free environment, RFID technology is ideal for dirty, harsh, and hazardous environments. Radio frequency identification technology can also survive temperatures ranging from - 40 ° C to 200 ° C (What is RFID?, 1996). The technology is very reliable and can operate flawlessly for an extended period of time. Moreover, data security is high because it is very difficult to copy the code. A complete, more detailed list of benefits follows.

- RFID tags and readers have no moving parts, so they rarely require maintenance.
- Unlike bar codes, RFID is very difficult to copy and is ideal for confidential identification purposes.
- RFID tags can store much more data than bar code labels, allowing more information to be tracked.
- RFID is fast: the tag and reader can communicate in milliseconds without requiring contact or an unobstructed view.
- RFID reads are highly accurate (Telsor's advanced error detection algorithm ensures less than 1 in 100 trillion chance of reporting a label's data erroneously or mistaking "noise" for a valid transponder response) (Telsor, 1991).

2.4 Costs

The cost of RFID varies considerably, depending on the types of tags and readers necessary and the application requirements. Many RFID vendors assign lump sum costs to different applications, depending on the application's size and specialization. Currently, individual RFID components are more expensive than other forms of automatic identification; however, these costs have significantly decreased in recent

years. This trend of declining prices will most likely continue as RFID vendors experience lower manufacturing costs.

Table 2.4 reveals the approximate costs of this technology. Notice that passive tags cost between \$1.00 and \$150 each, while active tags can cost up to \$250 each. The \$0.50 active tags, for instance, require an external antenna that is not included in this low price. Tag packaging can vary greatly in price, depending on its operating environment. Moreover, a longer read range and increased memory also increases tag price.

Reading units generally cost between \$200 and \$10,000 but average around \$4,000 each. Software development can range from a low \$100 (for minimal programming requirements) to several thousand dollars for development of customized software applications.

Table 2.4: RFID Costs

ITEM	PRICE RANGE
Active tags (each)	\$0.50 - \$250
Passive tags (each)	\$1.00 - \$150
Readers (inc. scanner board) (each)	\$100-\$10,000
Antennas (each)	\$100 - \$1,000
Software	\$100 - \$100,000 and up

In addition to the cost of the components, vendors also include the costs associated with designing the RFID system, implementing the system, training personnel to operate the system, and support and maintenance costs. These costs are usually hourly rates or per diem amounts comparable to those of other consultants who specialize in electronic or computer technologies.

2.5 Limitations

The limitations associated with this technology are important to understand. The main limitation of RFID concerns standardization. Currently, most RFID systems are “closed”, meaning that one manufacturer’s reader cannot read a tag made by another manufacturer, which does not present a problem to those closed RFID systems contained within a factory or a company. However, if a company, such as a construction company, wants to track products and materials from different suppliers and manufacturers, this poses a problem. It might be difficult to get suppliers to agree on a common RFID system, and it would be too costly to purchase a reader for each type of RFID system used. Standardization and multi-tag readers will hopefully solve this problem. This concern would be mitigated if RFID standards are established early on such that all vendors and suppliers are directed to use the same equipment and tagging technology for a given project. Currently, various standards organizations and interested companies are expending significant effort on developing standards for RFID use. Appendix D provides a description of the standardization efforts to date.

Another limitation of RFID is that metals can hamper RFID operations by blocking and canceling the radio frequency (RF) signals. When placed directly behind metal, the tag is unreadable, because the metal either absorbs or reflects the signal. Mounting tags some distance away from metal objects, however, may minimize this limitation. In any case, tags mounted on metal objects can be successfully read if the tag is raised slightly off of the metal surface or if it includes a metal back plane that is oriented with the antenna.

Interference from nearby RFID systems can also pose communication problems between the reader and tags. The interference is frequency dependent with lower frequencies, creating simple interference concerns, and with high frequencies, resulting in multipathing problems. However, the most evasive interference that affects tags comes from cathode ray tubes. Selecting RFID systems whose frequencies do not interfere with frequencies commonly used near the construction site may alleviate this concern.

Furthermore, batteries wear out on active tags, limiting their life expectancy. When tracking key project equipment from vendor shop to the site, this might not present a significant concern, since the duration is generally short term. A battery management program will need to be implemented, however, for longer life asset tracking requirements.

2.6 Complementary Technologies

Several technologies complement RF tagging including radio frequency data communications (RFDC), global positioning systems (GPS), and on-board sensors.

2.6.1 Radio Frequency Data Communications

Radio frequency data collection (RFDC) systems link automatically collected data from bar code or RFID and transmit it to a central controlling computer. Radio frequency data communication systems enable field employees with access to a portable, wireless terminal to communicate with the operation's controlling computer via a radio link. One of RFDC's key benefits is that company staff can instantaneously and accurately collect on-site data and transmit it to decision makers without the use of hardwire links. This feature is ideal for conditions where considerable movement or physical flexibility is required, as in warehouses and processing plant floors. An RFDC system eliminates the need for managers to wait for a report, voucher, or order form to be filed. This real-time, paperless system shortens the operational lead-time traditionally needed and efficiently utilizes available resources.

The RF link for an RFDC system using low to high frequencies in the microwave range transmits data from the portable terminal to a host computer up to several miles away. For instance, the hand-held scanner in the RFDC system employed in the Iowa Department of Transportation's (IDOT) warehouse can relay information up to two miles away via RF, according to IDOT officials (Gray, 1993; Lande, 1993). Modems may also be linked via frequency modulation (FM) transceiver technology, a telephone line, or a cellular telephone. Radio frequency data communication has already been linked to data collection using radio frequency identification technology.

Recently, Amtech partnered with WaveLink Technologies, Inc. to develop a wireless transaction network for real-time inventory management using RF data communication technology. WaveLink's Wireless Network provides interactive data communication for real-time inventory control in warehouses, transportation terminals, and manufacturing facilities. This system gives users the freedom to move about the facilities while communicating instantaneously with the host computers (Amtech Data Technology Solutions, 1996).

2.6.2 Global Positioning Systems

Global positioning systems (GPS) use satellites in space and mobile receivers on earth to identify the location of objects on earth. Based on observations of transmitted signals from orbital satellites, GPS facilitates fairly accurate location of points upon the earth (up to millimeter accuracy, if desired). The two main objectives of GPS are navigation and precise positioning. Unlike conventional means of precise positioning, GPS provides for greater "speed, accuracy, lack of intervisibility requirements between stations, operational capability day or night and in any weather" (Wolf and Brinker, 1989).

The most important piece of GPS hardware is the GPS geodetic receiver. The receiver picks up the signal sent from the satellite and translates it into a usable form. Multiple GPS receivers allow the determination of points that may then be tied together. In addition, the receivers record the data, which can be downloaded into a computer. These receivers consist of one or more radio channels, an internal clock, and a computer to perform the analyses and store the information (Huxhold, 1991). The internal clock is a very important part of the receiver; it records the time it takes for a signal to reach the receiver from its satellite origin. This time is then used to calculate the distances used in the triangulation process. Micron Communications has already implemented this positioning technology.

Micron Communications, Inc. developed the Ambit Mobile Asset Control System that integrates both RFID and GPS technologies. This system may be used to track cargo and know both its location and specific contents (Micron, 1998). The AmbiTag 512K RIC (remote intelligent communications) unit with GPS sells for \$1,000 to \$2,200,

depending on the quantity purchased. Other components include the reader (\$2,600 to \$5,200, depending on quantity ordered), and other peripherals associated with this system include the powerpack, power adapter, antenna, and cable.

2.6.3 On-Board Sensors

On-board sensors can also be implemented with RFID to monitor a vehicle's performance level such as temperature, oil pressure, odometer reading, ride quality, and exhaust emissions. Actually, the features that may be monitored on a vehicle are unlimited. This information is then written to the tag and read from an RFID reader. Amtech has already integrated some on-board sensors into their RFID tagging technology. Some of these innovations are discussed in the next chapter about current RFID applications.

3.0 CURRENT RFID APPLICATIONS

Since radio frequency identification technology (RFID) was marketed as a usable product in 1979, companies have begun to develop innovative applications in areas such as transportation, manufacturing, agriculture, security, construction, sports, and power. Additional applications are being tested for airline baggage identification, grocery labeling, and postage stamps. Radio frequency identification users have identified several benefits as a result of implementing RFID in their business operations. In applications related to production applications, benefits included improved work scheduling, increased productivity, absolute error-free identification, real-time data and control, workflow optimization, and improved planning. In applications related to inventory control, benefits included product identification, positive location identification, real-time inventory tracking, reduced inventory shrink, lower labor costs, reduced retrieval time, and greater accuracy. Benefits associated with material handling included simplified control systems, positive position location, real-time materials tracking, improved planning, and improved management. Moreover, the benefits of applications related to access control and personnel management included accurate job costing, improved security, location reporting, and hands-free identification. Transportation application benefits related to efficient fuel reporting, real-time maintenance reporting, real-time asset management, and increased security (Telsor, no date b). Several RFID applications are discussed in the balance of this chapter.

3.1 Transportation

The transportation industry is becoming a leading user of RFID technology. Radio frequency identification can be found in many applications related to railroad car management, traffic management, tolls and fees, fare collection, equipment identification, solid waste hauling, fuel dispensing, and vehicle access. Each is described in more detail as follows.

3.1.1 Rail Car Management

The Association of American Railroads mandated the use of a universal RFID system for freight carriers. By July 1994, 1.4 million railroad cars and 25,000 locomotives were expected to be tagged, and radio frequency (RF) readers installed at strategic locations. Each car carries two 128-bit tags (20 cm by 5 cm by 2.5 cm), mounted on diagonally opposed corners, bearing the rail car or locomotive identification code that can be read at speeds up to 322 km/hr. These tags could be replaced with read-write tags providing detailed information about each car's contents. The technology is compatible with proposed advanced train control systems (Kachmar, 1992).

3.1.2 Traffic Management

Houston Transtar is a comprehensive traffic management system developed to manage traffic on freeways throughout Greater Houston and Harris County, Texas. Transtar uses Amtech RFID equipment to monitor traffic. Readers are mounted on overhead signs and can accurately identify the tagged vehicles that pass below, providing real-time traffic speed and traffic flow information, essential to the development of effective traffic control strategies and useful to commuters (Amtech Newsletter for ETTM, 1996). Eventually this information will be transmitted to display units in each vehicle (Breslin, 1995).

An RFID system is also being used to speed up public transportation in urban and city-center traffic near Southampton, United Kingdom. A RFID system helps by giving buses and emergency vehicles a green light as they approach a traffic signal. The system optimizes traffic signal time, alleviates congestion problems, and reduces fuel consumption and environmental damage. Siemens installed this system, which consists of passive tags fitted to the chassis of the buses, a loop aerial embedded in the road surface, and a roadside tag reader. When a tagged bus passes over the loop, the tag is read by the roadside tag reader, which sends a demand to the traffic signal controller or the centralized traffic control system that incorporates bus priority. The system also can be further expanded to log and record bus movements on a local basis and then send this information to central traffic control computers where it updates passenger display systems at bus stops or improves bus fleet management (Greavy, 1998).