



White Paper

RFID Supply Chain Applications

Building Test 1 February 26-28, 2002

Alien Technology

EXECUTIVE SUMMARY

Tests of an AIDC-compliant RFID system using Alien Technology's Class 1 emulator tags and readers at the AIDC demonstration site yielded significant performance data and early proof of AIDC spec viability for supply chain applications.

Discrete aspects of the application environment were tested to isolate performance characteristics and verify functionality. Among the most important results were those reflecting complex attributes. The tests demonstrated, for example:

1. Complete and accurate reading of all cases of Carefree Liners on fully-stacked pallets at distances of four to ten feet, regardless of: (a) tag orientation, (b) antenna polarization (linear/circular), and (c) number of cases between tag and antenna.
2. Complete and accurate reading of all facing cases of Coca-Cola and Bedtime Bath Shampoo at distances of 42 inches and greater, regardless of: (a) tag orientation, (b) number of tags in field, and (c) tag motion (direction and speed).
3. Complete and accurate reading of all cases of Maxwell House Coffee and Liquid All (containing problematic metals and liquids) on conveyors, at distances of 40 inches and greater from canopy reader, regardless of: (a) product type, (b) tag motion (direction and speed), and (c) conveyor motor operation.

These results demonstrate the viability of the AIDC-specified RFID technology to further automate key supply chain operations and improve visibility in a manner compatible with most existing manual and automated systems.

Data collected from these and other tests will help AIDC members develop business cases and optimal system configurations for some of the most desired applications.

The success of these interim evaluations supports the feasibility of early adoption and offers new focus for future building and field tests.

WHITE PAPER

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Table of Contents

RFID BUILDING TEST 1 OVERVIEW	2
TEST PARTICIPANTS	2
TEST OBJECTIVE	2
CONSTRAINTS	2
TEST CONDITIONS.....	3
TEST FACILITIES	3
GLOBAL TEST PARAMETERS	3
SPECIFIC TEST PARAMETERS	3
PRODUCTS TAGGED	4
RADIOLUCENT MATERIALS.....	4
PROBLEMATIC MATERIALS	4
EQUIPMENT USED AND RESULTS.....	5
INDUSTRIAL EQUIPMENT.....	5
ALIEN RFID SYSTEM EQUIPMENT	7
RF INTERFERENCE EQUIPMENT	8
TEST CONFIGURATIONS AND RESULTS.....	9
ANTENNA POSITION	9
TAG ORIENTATION.....	10
TAG READING CONFIGURATIONS.....	10
SPECIAL CHALLENGES	12
CRITICAL FUNCTIONALITY TESTS AND RESULTS.....	13
BASELINE RANGE AND READABILITY TESTS	13
READABILITY TESTS	13
READ REDUNDANCY TESTS (NUMBER OF READS PER TAG).....	13
CONCLUSIONS	14
RESULTS SUMMARY BY PRODUCT TYPE	14
RESULTS SUMMARY BY TEST PARAMETER	16
NEXT STEPS	18
“QUICK WIN” OPPORTUNITIES.....	19

RFID Building Test 1 Overview

Initial building tests of an AIDC-spec RFID system conducted at Wal-Mart facilities on February 26-28 provided relevant performance data and confirmed feasibility of applications.

AIDC field test products were tested with the Alien Class 1 tag emulator and reader system, at the pallet and case level, in a variety of representative reading situations. The Alien Class 1 emulator tag is designed to imitate the performance of a fully passive NanoBlock™ based tag. Passive tags are expected to be available by September 2002.

Test Participants

The tests were performed by an Alien Technology team, with Auto ID Centre staff Dan Engels and Silvio Albano present.

Test Objective

The objective was to test AIDC-spec compliant air-to-air (tag/reader) protocol and conduct preliminary experiments with various AIDC members' products using emulator tags to help assess feasibility of the anticipated passive tag system.

Constraints

The success of these tests must be understood within the context of a continuum of tests designed to reveal performance insights and to understand optimal system configuration. For the current series of tests, the following constraints are noted:

1. Only key aspects of operational environment were simulated.

Facility conditions are illustrative of key operational conditions relevant to these tests, but may not present all the challenges to be expected in the field.

2. True Class 1 tag performance remains unknown.

Alien Class 1 emulator tags cannot entirely reflect the actual performance of passive Class 1 tags. Actual read range, for example, will only be known when the first passive tags are assembled.

3. Only single reader antenna configurations tested.

Benefits of multiple antenna configurations are not reflected here.

4. Lack of "sleep" command limits anti-collision performance.

The "sleep" command—which enables the system to process multiple tags in field faster—was not available in readers at the time of these tests.

5. Read rate limited by slow serial interface.

The read rate (speed at which tag data is processed) was limited by the slow serial interface between laptop computer and reader.

Test Conditions

The following describe the general conditions applicable to all the tests conducted and reported in this document.

Test Facilities

Tests were conducted at the AIDC demonstration facility at a Wal-Mart Distribution Center in Bentonville, Arkansas, USA. While this facility provided a simulation of key operational conditions, it is understood to be removed from the typical activity and RF noise anticipated in a live operation. Future trials will test system performance under more realistic conditions.

Global Test Parameters

Many individual parameters were measured and evaluated. Together, these parameters were used to help the team understand:

1. Tag readability (core functionality) – *Can all tags be read successfully under the given conditions?*
2. Read redundancy (robustness) – *How many times can a given tag be read while in the read window?*

Specific Test Parameters

Beyond collecting performance data, these tests were designed to determine tag readability and read redundancy under a variety of conditions—tested singly and in combination. These conditions are shown in the table below:

Category	Condition/Parameter
Objects tagged	Pallets
	Cases
Location of tagged cases	On pallet on floor
	On pallet on forklift
	On pallet on pallet jack
	On conveyor
Antenna type	Circular polarization (orientation tolerant, less range)
	Linear polarization (orientation sensitive, greater range)
	Low-gain, linear, integrated w/reader (short range, orientation sensitive)
Antenna position	Side mount, warehouse aisle, 30 in. above floor
	Side mount, conveyor, 30 in. above the floor
	Canopy mount, 45 in. above conveyor belt (~5.5 ft from floor)
Tag orientation on case <i>(Relative to the floor)</i>	Vertical
	Horizontal
	Diagonal
Tag-antenna range/proximity	Minimum 2 feet – Maximum 17 feet
Angle of tag plane to antenna	Up to ~ 75° (with liquid product)
Number of tags in field	Single tag
	Two or more tags (tag discrimination/anti-collision) (Max 15 tested)

Category	Condition/Parameter
Tag movement	Stationary
	On forklift passing antenna at nominal speed (~ 4 mph) and high speed (~ 5.7-7.0 mph) forward and reverse
	On pallet jack passing antenna at nominal speed (~ 3 mph) and high speed (~ 5 mph)
Tag reading challenges	On conveyor passing antenna at ~ 90 ft/min
	Reading tags through other cases of product on pallet
	Reading tags adjacent to forklift cab (metal apparatus)
RF interference	Reading tags on and between cases containing liquid or metal products or packaging
	Forklift wireless computer transmitting in 915 MHz band
	Intermec RFID reader transmitting in 915 MHz band

Results for tested parameters are discussed throughout this report. The few performance anomalies observed are discussed in the Conclusions section.

Products Tagged

Both pallets and individual cases of AIDC field test products were tested.

Radiolucent Materials

Some of the products and their packaging are radiolucent, that is, RF signals can easily penetrate their materials.

Radiolucent materials in these tests included primarily organic and synthetic fibers with plastic or cardboard packaging:

- Bounty Paper Towels
- Carefree Longs



Problematic Materials

Some of the products and their packaging contained metal (which can block RF signals) or liquid (which can attenuate, absorb or divert RF signals).

Problematic materials in these tests included liquid products, metal products and metal containers, typically with plastic packaging.

- Maxwell House Coffee (1/2 lb metal cans)
- Bedtime Bath Shampoo
- Liquid All Detergent
- Coca-Cola Classic 2-liter



Equipment Used and Results

These tests required the use of industrial equipment as well as RFID system equipment for both tag reading and RF interference tests.

Industrial Equipment

Forklift

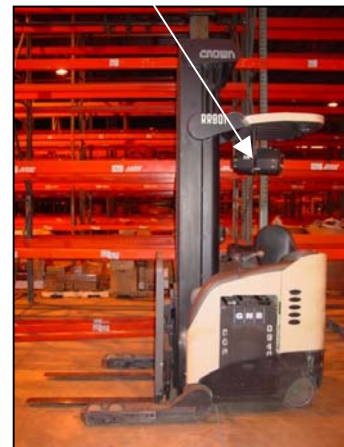
(Narrow Aisle Reach Truck) was used in various tests, both stationary and in motion.

Forklift nominal speed is approximately 4 mph. High speed is up to approximately 6-7 mph (forward) and 5.7 mph (reverse).

The primary challenges presented by the forklift vehicle included the potential influence of:

- a. RF signals scattering off or shielded by metal components on the truck's mast and reach mechanisms, especially when tags are in close proximity or in contact with such mechanisms.
- b. RF signals from the forklift wireless computer transmitting and receiving in the same 915 MHz band as the RFID readers.
- c. Speed of tag movement through read window at forklift nominal speed and high speed.

Forklift w/LXE wireless computer



RESULTS

Test data reveals adequate performance is sustained even with forklift radio operating and with tags moving at nominal or high forklift speeds past the reader antenna. Results also suggest proximity of tags to metal apparatus near forklift cab does not prevent either tag readability or read redundancy, except where tags are against the metal lift (within less than ~2 in.).

Pallet Jack

The pallet jack is a manually operated, metal apparatus with wheels and hydraulic lift. Its operating speeds are estimated to range from 0 to 3 mph (nominal) up to about 5 mph (fast).

Challenges presented by the pallet jack included the potential influence of:

- a. RF signals scattering off or shielded by the metal steering column, especially when tags are in close proximity or in contact with it.
- b. Speed of tag movement through read window at pallet jack nominal and high speeds.



RESULTS

All 8 tags on palletized Coca-Cola Classic 2-liter 8 pack shells facing reader were successfully read in all 3 trials regardless of pallet jack speed. No adverse effects were noted.

Conveyors

Conveyor tests were specifically designed to test readability of tags on and around problematic materials. The single-case conveyor presentation of product in relatively close proximity to the antenna was deemed to be a more favorable condition for reading tags on and around metal and liquid materials versus presentation of multiple cases on a pallet.

Two types of conveyors were used in the tests:

- Roller conveyor
- Motorized belt conveyor

Roller Conveyor. The roller conveyor presented few potential reading challenges and none appeared to compromise tag readability.

The primary challenges involved the potential influence of:

- a. RF signals bouncing off the metal rollers.
- b. Movement/speed of tagged objects pushed manually through read window at an estimated average of 90 ft/min.
- c. Noise induced by mechanical vibration.



Motorized Belt Conveyor. The belt conveyor also imposed few reading challenges and none appeared to compromise tag readability.

The primary challenges posed by the belt conveyor involved the potential influence of:

- a. Spurious EM outputs (including UHF-band RF noise) from the conveyor motor/controller.
- b. Movement/speed of tagged objects through read window at approximately 90 ft/min.
- c. Noise induced by mechanical vibration.



RESULTS

Tests with both conveyors yielded positive results with products/packaging containing problematic materials. All tags were read in the majority of trials. No tag misses were attributable to either EM interference or vibration.

NOTE: No radiolucent products were tested on conveyors, since previous trials had demonstrated that such products can be read reliably under far more challenging conditions.

Alien RFID System Equipment

Reader

The tests employed two configurations of the same Alien reader running AIDC-spec protocol, transmitting at FCC Part 15 unlicensed power levels or lower.

The Alien reader operates in the 915 MHz UHF band (902-928 MHz frequency hopping).

The primary reader configuration used two types of external antenna. The secondary configuration contained a low-gain, integrated antenna (shown here on top of the reader).



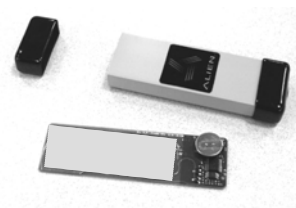
Alien reader, shown here with low-gain, integrated antenna (white) on top.

RESULTS

The Alien reader was able to successfully acquire tag data in all but a very small minority of tests (most commonly where test parameters were well beyond normal operating requirements).

Class 1 Emulator Tags

Alien emulator tags use discrete components to emulate the anticipated performance of NanoBlock™ passive tags. The maximum free-space read range of these emulator tags is approximately 5 meters, consistent with the performance of other known UHF passive tags. Tags were programmed with the 64-bit AIDC-issued product codes.



Alien AIDC Class 1 emulator tag.

RESULTS

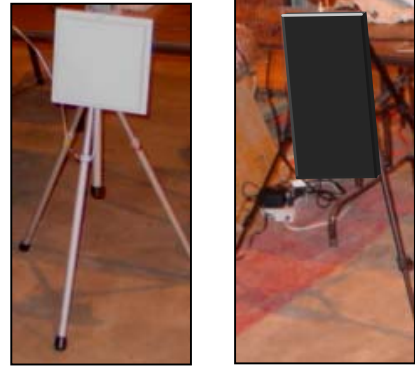
The Class 1 emulator tag performed effectively in the vast majority of tests. Performance appeared unaffected by tag orientation and the tags were read at distances of up to 17 feet (under optimum coupling conditions)—well beyond the AIDC-specified range (1 meter).

As expected, tags obstructed or surrounded by metal or liquid were least likely to be read.

Antennas

Three reader antennas were tested:

1. Commercially available antenna with circular polarization (designed to increase signal reception in environments with significant RF signal scattering).
2. Custom Alien design with linear polarization.
3. Low-gain, integrated antenna (see reader photo above) for short range using optimized tags/orientations.



(Left) Commercially available antenna w/circular polarization. (Right) custom antenna with linear polarization.

RESULTS

Although linear polarization is known to be more orientation-sensitive (tag-to-antenna) than circular polarization, no missed reads were attributable to antenna polarization.

RF Interference Equipment

Forklift Wireless Computer

The forklift's LXE wireless, vehicle-mounted computer provided interference challenges in the 915 MHz RF band for several tests. Read tests were performed both with the system on but not transmitting, and with the system transmitting.

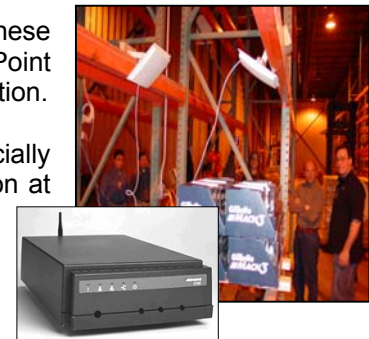
RESULTS

Tests conducted with the LXE (on only, or on and transmitting), were largely successful, suggesting the wireless computer has minimal, if any, impact on tag readability.

Intermec RFID Reader

The second source of interference used for these tests was the Intermec 2100 Universal Access Point (UAP) with the UHF (915 MHz-band) Intellitag option.

The 2100 UAP system operates with 2 commercially available external antennas, only 1 of which is on at any given time. The Intermec system was positioned approximately 10-12 ft from the Alien system.



RESULTS

Tests of interference from the Intermec RFID reader were conducted while the forklift LXE was also either on and not transmitting or on and transmitting, to demonstrate the effect of multiple sources of RF interference, including other RFID systems nearby.

All trials were 100% successful, suggesting these sources do not represent a significant impediment to reading Class 1 emulator tags with the Alien reader under the circumstances tested.

Test Configurations and Results

This section illustrates some of the basic configurations used in the tests and discusses the results of each type of test.

Antenna Position

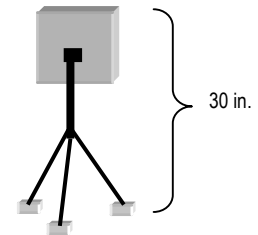
Two antenna-mounting positions were tested—side-mount, and overhead, canopy-mount—under a variety of conditions, to determine whether antenna position would significantly affect system performance, both at AIDC-specified range and at extended range.

Both configurations yielded 100% successful results in multiple trials, with exceptions occurring only when conditions exceeded those expected in the normal operating environment.

Side-mount, for Pallets, Forklift and Pallet Jack

For reading empty pallets, loaded pallets on the floor, and pallets on the forklift (whether stationary or moving), the antennas were mounted upright on tripods at a height of 30 in. from the floor in all tests.

All three antenna types (external antennas with circular and linear polarization, and low-gain integrated antenna) were tested in this configuration.

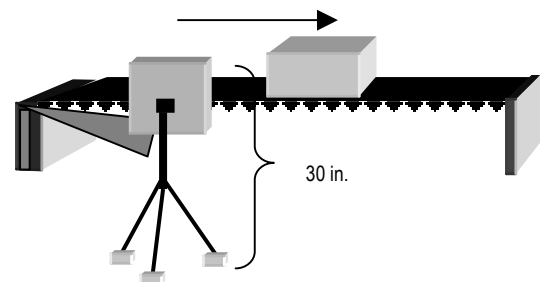


RESULTS

Side mounting proved effective for reading pallets with both external antennas in all but a very small minority of trials. The few instances of missed tags appear unrelated to antenna side-mount position.

Side-mount, Conveyor

For side reading cases on a conveyor, the external antenna with circular polarization was tripod-mounted at a height of 30 in. from the ground and between 2 ft and 2.5 ft from the product tags.

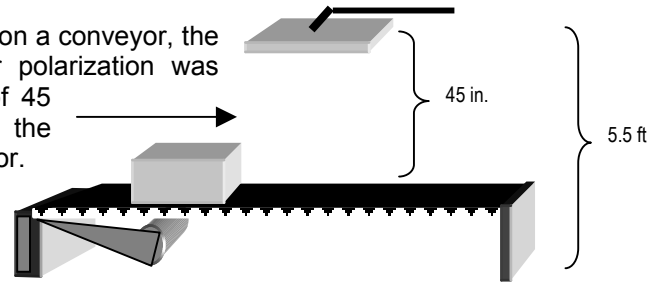


RESULTS

Side-mounted antennas (circular polarization) proved 100% effective for reading individual cases/shells of Coca-Cola Classic (2-liter, 8-pack shells) at ranges of 2 feet to 2.5 feet, regardless of conveyor movement, under all conditions but one. Only the worst-case scenario failed to yield adequate results.

Canopy-mount, Conveyor

For overhead reading of cases on a conveyor, the external antenna with circular polarization was canopy-mounted at a height of 45 in. above the surface of the conveyor and 5.5 ft from the floor.

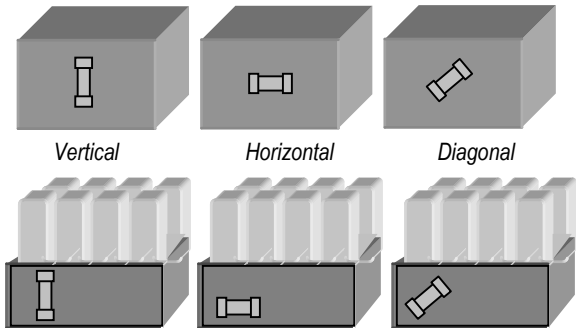


RESULTS

Canopy-mounted antenna (circular polarization) proved 100% effective for reading individual cases/shells of Carefree Longs, Maxwell House Coffee, Liquid All and Coca-Cola Classic, regardless of conveyor movement, under all conditions except one (see Exceptions on page 17).

Tag Orientation

Tags were positioned on products in three orientations (relative to the floor): vertical, horizontal and diagonal*.



The goal was to determine whether tag orientation would significantly impact reading performance, both at AIDC-specified range and at extended range.

**Tags were specially designed for diagonal mounting on Coca-Cola shells.*

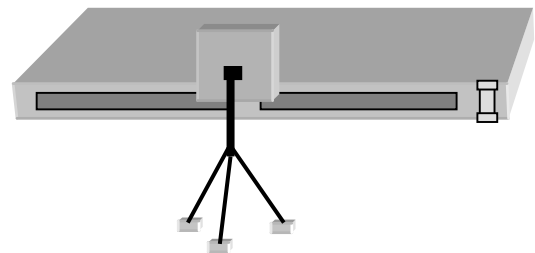
RESULTS

Tag orientation appeared to have no impact on reading performance. All orientations were effective in all tested scenarios, with only one exception (see Exceptions on page 17).

Tag Reading Configurations

Pallets

Tags were placed on one leg of pallets in the vertical orientation. Reading pallet tags was tested with an empty pallet and with a loaded pallet of Coca-Cola Classic shells.



RESULTS

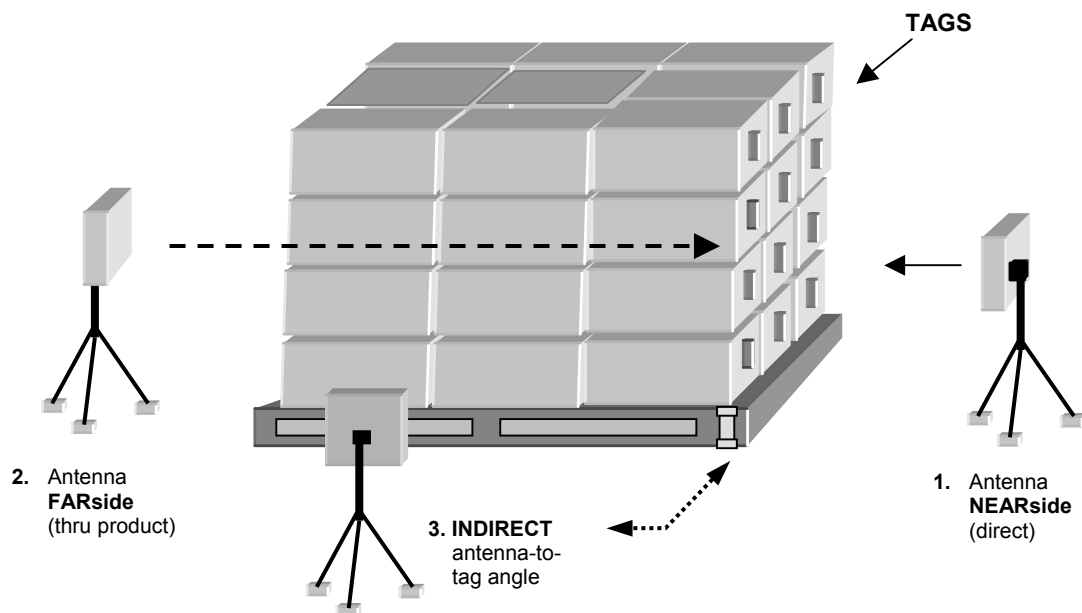
Pallet tags were read successfully under all tested conditions.

Cases on Loaded Pallets

Tags were positioned only on the outermost cases (usually on only one side at a time) on a given pallet.

Reads were conducted with tags at a three basic positions relative to the antenna:

1. **Antenna nearside.** Reading tags with direct and unobstructed line-of-sight between tag and antenna.
2. **Antenna farside.** Reading through product cases to tags on opposite side of pallet.
3. **Indirect.** Reading tags positioned at right angles (narrow edge facing antenna) and oblique angles (other than straight-on presentation and right angles) to the antenna backplane.



RESULTS

Antenna nearside. As expected, the system was able to successfully read 100% of tags located on the antenna nearside when presented directly (face parallel with antenna) at all ranges up to 17 ft (maximum tested range). Readability declined by a small degree in only a single instance at maximum range.

Antenna farside. Reads through radiolucent materials (Bounty Paper Towels and Carefree Longs) were 100% successful at distances of up to 10 ft when tag face was parallel with the antenna. Readability declined by a only small margin when certain complex challenges (e.g., reading multiple tags at extended range, with interference present and tags too close to forklift metal apparatus) not typical of application environment) were imposed.

Indirect. Reads involving tags at less than optimal presentation (at 90° and oblique angles to the antenna) were largely successful, except when additional challenges (e.g., tags positioned too close to the metal lift apparatus on a moving forklift with interference present) were imposed.

Special Challenges

A greater variety of tag positions were employed in testing problematic materials than was used for radiolucent products and packaging.

Metal

The metal used for packaging coffee presents an obstruction to RF signals. To overcome this challenge, the team tested cases of Maxwell House Coffee using various combinations of attributes:

- Tag on metal lid of can (top photo)
- Tag on the outside of the case (bottom photo)
- Tag on the inside of the case
- Tag oriented vertically
- Tag oriented horizontally
- Tag sandwiched between cases
- Case turned sideways



RESULTS

Tags were read successfully on the motorized conveyor in all trials using horizontal orientation. The number of repeat reads (read redundancy) ranged from 110 (tag on top of cans) to 934 (tag inside case, case turned on its side).

Liquid

Because liquids can attenuate, absorb or scatter the RF signals, special tagging strategies were employed to determine performance and optimal tag placement for such products.

Tags were positioned on the outermost locations on cases of liquid product and on the handle for the most favorable reading conditions.

To test more difficult scenarios, combinations of challenging tag positions were employed:

- At antenna farside
- Inside cases and shells
- Between products
- Under products (near conveyor bed)



Liquid All Detergent

RESULTS

Tag reads were 100% successful in all practical scenarios.

Critical Functionality Tests and Results

Baseline Range and Readability Tests

Initial tests used 1 or 2 tags only to determine unchallenged baseline readability parameters including: read range, angle of tag to antenna, and tag orientation.

RESULTS

- *Minimum range tested: 2 feet*
- *Maximum read range tested: 17 feet*
- *Maximum effective tag-to-antenna angle: ~75° (w/liquid product)*
- *Optimal tag orientation: All proved effective at application range (~1 meter)*

Readability Tests

Single Tag

Readability of single tags was tested at various ranges and with several combinations of potential challenges imposed.

RESULTS

As expected, single tags were read under all but the most difficult conditions.

Readability performance was most affected by metal and liquid materials obscuring or surrounding the tag. To a lesser extent, tag angle greater than about 75° to the antenna (specifically at 90°, or perpendicular, to the antenna) had a more noticeable impact on performance when combined with other challenges such as extreme range or tag-reader angle, problematic material, etc.

Multiple Tags (Anti-collision)

Multiple-tag trials were designed to test the system's ability to discriminate and read individual tags with several other tags in the read window simultaneously (anti-collision capability). Anti-collision performance was tested using loaded pallets containing:

- 15 tags on cases of Carefree Longs
- 15 tags on cases of Bounty Paper Towels
- 8 tags on Coca-Cola Classic 2-liter, 8-pack shells

RESULTS

The majority of readability trials using multiple tags were successful. Readability declined by only a small margin in the few observed exceptions (see page 17).

Read Redundancy Tests (Number of Reads per Tag)

The robustness of a given system can be measured by its read redundancy. Technically, only a single good read is necessary to acquire tag data. Realistically, however, a dozen or more repeat reads help ensure the system will be able to tolerate most transient conditions that could interfere with tag-reader transactions.

The read redundancy tests recorded the number of reads per tag under a variety of conditions, including those representing challenges such as: tag at antenna farside (reading through product), product moving on forklift or conveyor, reading with interference present, and reading tags on or between problematic materials.

RESULTS

Tests demonstrated adequate-to-high robustness in all trials using Carefree Longs, Maxwell House Coffee, Liquid All and Coca-Cola Classic, except in worst-case scenarios (see Exceptions on page 17).

- **Lowest number of reads.** *The lowest number of repeat reads (9) occurred using Maxwell House Coffee, with tag wedged between metal cans, moving on the belt conveyor.*
- **High end.** *The highest number of reads per tag was 2096 for Liquid All moving on the belt conveyor, tagged inside the top of the case in front of the product, with the tag at the antenna's nearside.*

Conclusions

Data collected through these limited tests confirms the feasibility of using RFID technology to enhance supply chain operations, without interference with or from currently effective systems and operations.

The findings were generally positive, indicating the system is able to successfully read:

- Tagged pallets carrying all products.
- Tagged cases of all tested products on a belt conveyor.
- Tagged cases of radiolucent products on a pallet.
- Tagged facing cases of liquid or metal materials on a pallet.

EXPECTATIONS OF FUTURE TRIALS

Because tag antennas were not optimized for each product's unique characteristics, it can be assumed that performance under many, if not all, relevant conditions will be improved in subsequent tests.

Results Summary by Product Type

The results demonstrated that for all types of products/materials tested **tags could be successfully and reliably read within one or more realistic operating scenarios.**

In several instances, readability was tested to the point of failure, to gauge the performance limits of the system. The results of these extreme trials, and any other exceptions that occurred, are shown in the Exceptions section on page 17.

Radiolucent Materials

In general, tags on radiolucent product (Carefree Longs, Bounty Paper Towels) could be read successfully at distances up to and including 17 ft from the

antenna, both when positioned nearside to the antenna and when read *through* the product (antenna farside).

When located within AIDC-specified range (1 meter) radiolucent materials showed no obvious preference toward antenna type or tag orientation. Successful reads were obtained when tags were moving at both nominal and high speeds, when product was on forklift or pallet jack, and when interference was present.

Problematic Materials

Successful and reliable results were obtained even for products/packaging containing problematic materials—including Maxwell House Coffee (metal), and Bedtime Bath Shampoo, Liquid All, and Coca-Cola Classic (liquid).

Summary of Conditions Yielding Read Success

Read Situation	CONDITIONS YIELDING READ SUCCESS		
	Radiolucent Materials	Problematic Materials Liquid	Metal
Tag Placement			
Pallets with product	✓	✓	✓
Product on pallet	✓	✓	✓
Product on conveyor (canopy ant.)	✓	✓	✓
Product on pallet jack	✓	✓	✓
Motion			
Stationary	✓	✓	✓
Nominal speed	✓	✓	✓
High speed	✓	✓	✓
External Antenna			
Circular polarization	✓	✓	✓
Linear polarization	✓	✓	✓
Tag Location Relative to Antenna			
Nearside (direct line of sight)	✓	✓	✓
Farside (reading through product)	✓	X	X
Tag Orientation			
Horizontal	✓	✓	✓
Vertical	✓	✓	✓
Diagonal	✓	✓	✓
Range			
10 ft or less	✓	✓ (facing cases)	TBD
Over 10 ft	✓	✓ (facing cases)	TBD
Angle (tag-to-antenna)			
Face parallel with antenna	✓	✓	✓
Face perpendicular to antenna	✓	X	TBD
Multiple Tags in Field			
2-15 tags	✓	✓	TBD
Interference Present			
Forklift LXE wireless computer	✓	TBD	TBD
Intermec RFID system	✓	TBD	TBD

Exceptions

The following table shows the conditions under which tags were missed:

Missed Tag Conditions					
#	Product	Range	Test Condition	% of Tags Read	Comments
1	Carefree	17 ft	Only bottom tags at pallet corners	87	Test-to-failure (range)
2	Carefree	10 ft	Passing forklift with RF interference	93.3	Test-to-failure (speed, range, interference)
3	Carefree	8 ft	Passing forklift with RF interference	88	Test-to-failure (speed, range, interference)
4	Carefree	10 ft	Forklift at full speed	87/93	Test-to-failure (high speed, range)
5	Carefree	6.5 ft	Low-gain antenna	93.3	Insufficient data to assess cause (distance)
6	Coffee	3.75 ft	1 tag wedged between cans on motorized conveyor	0	Test-to-failure (metal)
7	Coca-Cola	2.5 ft	1 tag wedged tightly between shells on motorized conveyor	0	Test-to-failure (liquid)
8	Coca-Cola	3.75 ft	1 tag wedged tightly between sodas on roller conveyor	0	Test-to-failure (liquid)

Results Summary by Test Parameter

The tests conducted at Bentonville yielded useful data and demonstrated acceptable RFID system performance under all key conditions, summarized in the table below:

Parameter	Conclusions/Implications
OBJECTS TAGGED	
Pallets	Empty pallets tested were easily read. Insufficient data to determine read reliability for tags on full pallets with all tested products.
Cases	Cases of all tested product types can be read reliably under one or more supply chain conditions. More research is needed to determine optimal scenarios.
LOCATION OF TAGS	
On pallet on floor	Tags are easily read on pallet exterior, especially when tags face the antenna.
On pallet on forklift	Tags are easily read on pallets on the forklift, especially when tags face the antenna. Reading is more difficult when tags are adjacent (too close) to the metal lift apparatus. This limitation may be overcome by: (a) increasing the distance between tags on the side of pallet nearest forklift cab, or (b) positioning antennas/readers on both sides of the pallet/aisle.
On pallet on pallet jack	Tags are easily read on pallet jack when positioned at antenna nearside. Reliability of reading interior cases of radiolucent materials is TBD.
On conveyor	Tags on even the most challenging products tagged on or near the case exterior are easily read on conveyors, primarily because tags are presented singly at fairly close range to the antenna. Conveyor implementation may be considered for reading tags on problematic materials where palletized reading may not be practicable. Using battery tags on reusable cases may also improve performance.

Parameter	Conclusions/Implications
ANTENNA TYPE	
Circular polarization	Effective in all tests. No missed reads attributable to this type of antenna.
Linear polarization	Effective in all tests. No missed reads attributable to this type of antenna.
Low-gain, integrated w/reader	Only one test, with 93.3% success. Missed 1 of 15 tags at 6.5 ft. where range exceeded antenna design spec optimum.
ANTENNA POSITION	
Side mount, warehouse aisle	Side mount of a single antenna proved effective in all tests. Performance was consistently higher when antenna had a clear line of sight to tag (antenna nearside). Less favorable tag positions performed well, with minor exceptions, which may be overcome by: (a) using a battery-powered tag for reusable applications, or (b) positioning additional antennas/readers to increase coverage.
Side mount, conveyor side	Side mount of a single antenna near the conveyor was effective in all tests – except in worst-case scenarios, where reads were through problematic materials to tags positioned at antenna farside. This limitation can be easily overcome by employing one of the several more favorable tag positions.
Canopy mount above conveyor	Highly effective in all but worst-case scenarios, where tags were sandwiched between liquids or metals. This limitation is easily overcome by employing one of the several more favorable tag positions.
TAG ORIENTATION ON CASE (relative to the floor)	
Vertical	Effective in all tests. No missed reads attributable to this orientation as tested.
Horizontal	Effective in all tests. No missed reads attributable to this orientation as tested.
Diagonal	Effective in all tests. No missed reads attributable to this orientation as tested.
TAG-ANTENNA RANGE	
Minimum 2 ft	The shortest range was employed in conveyor tests with side-mounted antenna. Similar conveyor tests with optimal tag positioning on cases should be conducted at AIDC minimum range (1 meter) to verify performance to spec.
Maximum 17 ft	Performance at the longest range was tested on radiolucent product on a stationary pallet. All tags on antenna nearside were read. On antenna farside (reading through product) 2 tags were missed. Future tests should be conducted at typical operating range to determine farside readability under more realistic conditions.
Average ~ 7 ft	The majority of trials were conducted at ranges between 5 and 10 feet. It is assumed that performance at closer (AIDC-spec) range will typically yield even higher performance.
ANGLE OF TAG PLANE TO ANTENNA	
Up to ~ 75°	Tags presented with their faces parallel with the antenna performed best in all trials. Tags perpendicular (at 90°) to the antenna were read successfully in most trials of radiolucent product. With liquid product, however, the maximum angle was about 75°, beyond which the liquid prevented adequate signal transmission. This limitation can be overcome by: (a) using a battery-powered tag, or (b) positioning additional antennas/readers to increase coverage.
NUMBER OF TAGS IN FIELD	
Single tag	Single tags are easily read under all but the most extreme conditions.
Multiple tags	Multiple tags are easily read under all but the most extreme conditions. The ability to read multiple tags simultaneously will be improved by implementation of the “sleep” command, allowing the reader to temporarily “turn off” tags as they are successfully read to minimize collision.

Parameter	Conclusions/Implications
TAG MOVEMENT	
Stationary	Tags are easily read when they are stationary.
On moving forklift	Tags were effectively read on a moving forklift. No missed reads attributable to movement, direction of movement or speed.
On moving pallet jack	All tags were effectively read on a moving pallet jack, regardless of speed. Future tests may determine whether direction of movement or other types of product will impact performance.
On moving conveyor	Tags were effectively read on a moving conveyor. No missed reads attributable to conveyor movement.
TAG READING CHALLENGES	
Through product	Tags are most easily read through radiolucent materials. Reading through cases containing metal or liquid product/packaging is difficult at best, and may be managed by: (a) using a battery-powered tag, (b) placing tags on cases in known favorable positions, (c) placing tagged sides of cases toward the outsides of pallet stacks, (d) presenting cases singly on a conveyor, and/or (e) using additional antennas/readers to increase coverage.
Adjacent to forklift	As tested, tags can be read successfully even when adjacent to the forklift cab. However, reading is difficult if tags are too close to the metal lift apparatus. This limitation may be overcome by: (a) using a battery-powered tag, (b) increasing the distance between tags on the side of pallet nearest forklift cab, or (c) positioning antennas on both sides of the pallet/aisle.
RF INTERFERENCE	
Forklift wireless computer	Tags were effectively read both with the LXE on but not transmitting, and with it transmitting. Any missed reads were more likely attributable to extreme tag angle and/or proximity to lift mechanism than to LXE interference.
Intermec RFID reader	Tags were effectively read with the Intermec reader transmitting simultaneously, both while the LXE was either on but not transmitting, and while it was transmitting. No tags were missed under the tested circumstances.
Conveyor electrical noise & vibration	Tags were read successfully on conveyors. No missed reads were attributable to either electrical noise or vibration.

Next Steps

The results reported here suggest that RFID will be ready for use in supply chain operations in the near future. The technical challenges remaining now involve three primary efforts:

- Developing optimized implementation strategies based on insights gained through testing.
- Refining tag and reader designs and configurations to optimize performance for individual products/types.
- Optimizing equipment and components (such as application-specific tags/readers and customized tag antennas) to enhance readability for individual products and applications.

“Quick Win” Opportunities

The results demonstrated in these tests are highly relevant to the applicability of RFID technology for a variety of “quick-win” opportunities identified by the AIDC’s Business Case Action Group.

These building-test results may be useful to evaluate the following selected quick-win opportunities:

QUICK WIN OPPORTUNITY	Pallet	Cases on stationary pallet	Cases on moving pallet	Stationary cases	Cases on conveyors
Reduce out-of-stocks	--	✓	--	✓	--
Reduce warehouse & distribution costs	✓	✓	✓	✓	✓
Streamline goods transfer processes & proof of delivery	✓	✓	✓	✓	✓
Efficient pallets	✓	✓	✓	--	--
Benefits for Direct Store Delivery	--	✓	✓	✓	✓