The New Zealand RFID Pathfinder Group Inc.

RFID Technical Study

Evaluation of Commercially Available UHF RFID Tag Technology for Animal Ear Tagging.

Author: Grant Pugh

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Acknowledgments

Deer Trials

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Sheep Trials

Pathfinder wishes to thank ANZCO Foods and CMP Canterbury for kindly allowing the use of their facilities and in particular Murray McMannus, CMP farmer supplier, for the use of his farm and animals. Thanks also to Jamie Seymour for his assistance with field research. Pathfinder is grateful to Mark Rance of ANZCO Foods for facilitating and organising this research.

This report should be read in conjunction with:

Hartley, G, (2013), The Use of EPC RFID Standards for Livestock Traceability. The New Zealand RFID Pathfinder Group Incorporated. January. 2013

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1 Executive Summary

The availability of commercially available passive ultra-high frequency (UHF) RFID animal ear tags has improved significantly since the New Zealand RFID Pathfinder Group (Pathfinder) first reviewed the technology in 2008 (Pugh & Sundermann 2008). The lack of suitable tags was seen then as a barrier to the adoption of the technology by the agricultural sector community and the use of UHF technology for farming applications regarded as immature by the National Animal Identification and Tracing project (NAIT). NAIT mandated the use of low frequency (LF) RFID technology for use with cattle in New Zealand in 2012 with other species scheduled in the coming years (deer in 2013).

A key differentiator of UHF RFID technology from the low frequency form is the ability to identify and capture tag data from tags on multiple animals moving at speed in a group across longer read ranges.

This report outlines findings from research undertaken by Pathfinder conducted over a period of twelve months that assessed 400 commercially available tags sourced from four manufacturers with the objective of determining if passive UHF RFID ear tags for use on livestock meet or exceeded the performance specifications established by NAIT for use on livestock in New Zealand. The performance criteria for testing borrowed heavily from the standards established for use at low frequency RFID on cattle. These criteria were then applied to deer and sheep in on-farm research.

The researchers augmented the performance criteria with a more rigorous performance benchmark targeted at animals that exhibit “mob” behaviour. The researchers suggest that this will provide additional added- value for farming related applications involving deer and sheep in particular.

The research concludes that in the best test scenarios, tags can be read reliably (100%) as animals moved unencumbered along races. Of the nine tag formats examined, three met the extended research criteria.

The researchers found that tag performance varied across tag designs and form factors. Further, as new tag iterations were introduced into the research over time, performance enhanced in general. Tag performance tests were repeated continuously and for some tags the best readability performance that was achieved was in the 80th percentile. The researchers consider that introducing a tag performance screening procedure to screen out ‘poor or under performers’ before application to animals, the average readability performance will improve beyond the 80th percentile for the moving animal scenarios in particular.

A higher rate of adoption of the technology should be expected if industry stakeholders have confidence that tag performance meets established standards. Quality systems for ensuring consistent tag performance should be introduced.

Current NAIT requirements for round “button tags” notwithstanding, the researchers found that “flag” styled tags (also ready for large visual identifiers) were accurately read. Good results were also identified with button tags where the EID was located in the male part of the tag. A conclusion drawn by the researchers is that subject to tags meeting retention performance criteria, a flag tag may offer acceptable readability performance in addition to useful ‘human readable’ identification opportunities. Dual LF and UHF tags are also feasible in this form factor.

Consistently high readability (frequently 100%) was achieved when animals were read while stationary. Tag readability performance measurements on deer were undertaken using both a fixed RFID reader infrastructure as well handheld readers when small mobs (typically 4 – 5 animals) were held in pens. Tag performance when used on sheep was measured one at a time in a weigh box.

The researchers recommend continued research is undertaken in several areas including on-going tag performance characteristics especially on ‘quiet’ tags, ‘unintended reads’ and antenna configuration. Continued research and development is also recommended for the tag vendor community on tag design and optimisation.

Standardised UHF RFID technology based on the suite of EPC standards presents an outstanding opportunity for significant value-add for livestock applications in New Zealand and globally. RFID applications based on EPC UHF standards are preferred in extended, global supply chain applications transcending many industry sectors. The EPC RFID standards are in place and with an increasingly voluminous global vendor and user community, opportunities are increasing for accelerated use of UHF RFID for livestock applications.

2 General

2.1 Introduction

The New Zealand cattle and deer industries have committed to establishing life time traceability as a mandatory requirement through the functioning of the National Identification and Tracing (NAIT) programme under empowered legislation. The electronic identification technology currently selected to deliver the programme is based on well-established low frequency (LF) RFID technology per the International Standards Organisation document - Radio frequency identification of animals -- Code structure, and ISO 11784:1996, Radio frequency identification of animals -- Technical concept, ISO 11785:1996 (ISO 1996).

Clampitt (2006) outlines that Ultra High Frequency (UHF) RFID promises larger tag populations able to be read faster, over longer read ranges, with multiple smaller antennas connected to a single reader. The supposition is that UHF technology will prove more efficacious than LF technology especially for “mob” animal management and further, new applications will be enabled to leverage the technical performance differentiators that UHF provides. This position is supported by Finkenzeller (2003).

Advances in UHF technology over the last four years have been well documented for deer and sheep (Pugh & Sundermann 2008) and cattle (Moxey & Stuart 2012). Early evaluations indicated that tag readability performance between 96% and 100% were feasible but suffered from wide tag performance spread and lack of commercially available tag form factors meeting NAIT requirements (Cooke et al., 2010), (NAIT 2012a).

Commercial tag manufacturers have responded with new tag designs allegedly in ‘ready for market’ use in New Zealand. This report documents the performance assessment for passive EPC UHF RFID tags on deer and sheep with an objective of determining if they meet or exceed NAIT requirements for readability. The researchers established extended performance criteria against which candidate tags were tested to determine if UHF technology as outlined, not only compliments LF RFID technology but added additional value for applications involving deer and sheep.

2.2 The New Zealand RFID Pathfinder Group

The New Zealand RFID Pathfinder Group (Pathfinder) is an independent, membership based, not-for-profit incorporated society. Incorporated in 2006 under the Incorporated Societies Act, Pathfinder was established by a number of high profile New Zealand based organisations to educate, promote and increase awareness of RFID and EPC (Electronic Product Code) technologies and global standards in New Zealand. Through the utilisation of these technologies and standards, additional business value for New Zealand organisations is envisioned beyond what other technologies have been capable to date.

Pathfinder has a specific focus on the use of RFID /EPC technologies and standards within the New Zealand supply chain and internationally and is both sector and vendor agnostic. Within the context of research, Pathfinder’s charter is to take cognisance of and align with certain Government aims and objectives, namely to;

- Promote trade facilitation and border security.
- Enable and enhance traceability outcomes – QA & Food Safety.
- Drive efficiency and productivity through technology.

Pathfinder accomplishes its research mandate through two primary channels:

- Literature searches, information collation and publishing to its website library.
- Feasibility studies, practical on-location trials and exemplars.

More information – refer: www.rfid-pathfinder.org.nz

2.3 The National Animal Identification and Tracing Scheme (NAIT)

NAIT[1] (National Animal Identification and Tracing) is an animal identification and tracing scheme linking people, property and livestock. By enabling individual animals to be traced, NAIT enhances New Zealand's ability to respond more quickly if there is a biosecurity threat such as a disease outbreak.

NAIT is mandatory for cattle and will be mandatory for deer from 1 March 2013. Approximately 80% of New Zealand's beef and venison is exported each year and meat and dairy products constitute more than 62% of New Zealand's total agricultural exports.

NAIT Ltd is the industry-owned company implementing the scheme. NAIT Ltd.'s shareholders are Dairy NZ, Beef + Lamb NZ and Deer Industry New Zealand. The company is not-for-profit and is registered with the Charities Commission.

2.4 Objectives

The research objective was to measure and assess EPC UHF RFID tag performance involving a selection of tags from numerous tag vendors against NAIT tag performance criteria and an extended researcher defined criteria. By measuring tag performance on deer and sheep in numerous typical on-farm scenarios over a twelve month period, a comprehensive assessment was able to be achieved.

2.5 Scope

The research focused on the use of passive EPC UHF RFID ear tags on deer and sheep and performance measurement was assessed based on various typical on-farm scenarios using tags and RFID readers from multiple vendors. All RFID readers utilised in the research complied with EPC standards to ensure performance comparison was able to be assessed. Research was undertaken on small animal populations (typically 10-30 animals). This analysis outlines research that was constrained to species exhibiting "mob behaviour" (deer and sheep), wherever time constraints or health and safety issues prevailed. Research that was out of scope included:

- Applications involving cattle as complimentary research is currently being undertaken in Scotland in which the researchers are involved with (ScotEID).
- Assessment of colour, marking and visual identification.
- Detailed research on tag retention, given the duration of the research assignment.
- Tag and reader costs.

2.6 Definitions

For the purposes of this report, the following definitions apply:

- Readability - Readability is the ability to interrogate an EID transponder (tag) with a machine (typically an RFID Reader) and resolve its encoded numerical Identity. Readability is otherwise known as Read Accuracy.
- Normal Tag - A normal tag is a tag that has passed an initial grading test to establish its suitability for testing on an animal.
- Quiet Tag - A quiet tag is a tag that is readable but only from a very short distance (much less than normal or less than say 25%). A tag may move from being normal to being quiet if it is damaged.
- Dead Tag - A dead tag is not readable at all. For example a dead tag occurs if a normal tag has been destroyed with a hammer.
- Over-read - Unintentional capture of an EID from a nearby animal instead of or as well as the intended EID of a specific animal.

[1] This information was gathered from the NAIT Website www.nait.co.nz

2.7 Performance Criteria

NAIT have published the tag performance specifications for use on deer (NAIT 2012) and cattle (NAIT 2012a) which is summarised below. In addition, the researchers extended the tag performance measurement criteria to examine and determine any additional benefits that UHF RFID may provide.

Criteria	Set by	Applicable to this research
Under New Zealand conditions, there is to be no apparent physical deterioration (other than colour) in NAIT devices due to ultraviolet radiation, rain, heat and cold or other environmental influences for the lifetime of animals.	NAIT	Out of Scope
Following application, the transponder contained within the female portion of the NAIT device shall be machine readable for the life of the animal.	NAIT	Applicable
The physical loss of NAIT devices from deer on typical New Zealand properties shall not exceed 2% within 6 months of application.	NAIT	Out of Scope
The physical loss of NAIT devices from deer on typical New Zealand properties shall not exceed a 3 year rolling average of 1% (per species) under normal field conditions.	NAIT	Out of Scope
NAIT devices must not be susceptible to damage under normal application conditions when applied as the manufacturer specifies.	NAIT	Applicable
Printing on NAIT devices shall remain visually readable for the lifetime of the animal.	NAIT	Out of Scope
In the absence of electromagnetic interference, 99.5% of all NAIT devices must be machine readable without duplication or omission in deer in a controlled enclosure set up for that purpose.	NAIT (deer)	Applicable
In the absence of electromagnetic interference, 99.5% of NAIT devices must be machine readable without duplication or omission in cattle moving freely at a rate of up to 2 metres per second in single file past a reading point with a portal width of 0.8 metres.	NAIT (cattle)	Applicable
In the absence of electromagnetic interference, 99.5% of UHF devices must be machine readable without omission in deer or sheep moving freely at a rate of up to 2 metres per second in single file past a reading point with a portal width of 1.8 metres.	Pathfinder	Applicable (note increased read range)
In the absence of electromagnetic interference, 97.5% of UHF devices must be machine readable without omission in deer or sheep moving freely past a reading point with a portal width of 1.8 metres.	Pathfinder	Applicable (note no speed limit or requirement for single file)

Table 2.1 -Tag performance criteria.

3 Tag Evaluation

3.1 UHF Tag Supply

In their initial research Pugh and Sundermann (2008) outline that there was a paucity of supply of commercially available UHF RFID tags at the time of research. The researchers outlined their awareness of a single tag from one manufacturer and their research was conducted with a tag specially designed in New Zealand for analysis. Cooke et al., (2010) conducted tests with three (3) tag styles from a single manufacturer.

Today the researchers are aware of at least thirty (30) suppliers of UHF tags (mainly Asian based) with tags also being manufactured by European and North American manufacturers. Significantly, the researchers observe that UHF RFID tags are becoming increasingly more commercially available from NAIT approved suppliers.

3.2 Tag Dimensions and Formats

NAIT currently accredit tag manufacturers and approve tags for use on animals. Typically the approved tags are of a button style (though not exclusively) and NAIT recommends the following:[2]

- To ensure high retention of the NAIT-approved RFID ear tag, it should be applied to the inner part of the ear between the two veins close to the head and with the 'female' part facing forward.
- NAIT recommends tagging the right ear, as this will assist meat processors, sale yards and farmers who have fixed panel readers, set up to read on the right. However, the left ear can be used if it better suits your on-farm management purposes.

The research was conducted using tags positioned in either ear of the animal and with the electronic part on the inner or outer part of the ear, whichever was considered to provide optimal readability performance.

Examples of the print content of the tags are presented below:

Figure 3.1 -Examples of printing on tags.

Other formats such as flag or visibility enhanced tags are currently under consideration by NAIT for EID use. The printable panel area of these tags varies in size and readable distance as they hang from the animal's ear. Two examples of these tags are provided below. The researchers conducted tests with flag tags and compared their performance with button tags.

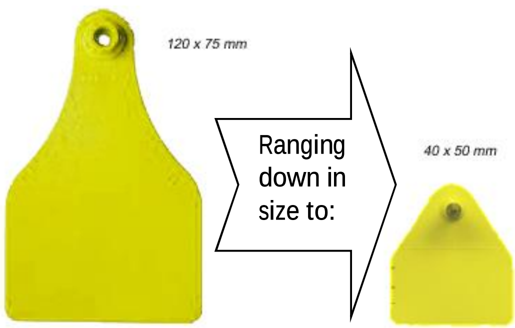

Figure 3.2 -Examples of Flag tags.

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[2] "*How to Apply NAIT Ear Tags*", retrieved from NAIT web site, www.nait.co.nz

3.3 Tag Retention

Notwithstanding in-ear tag retention is out of the scope for this research, the researchers' note that of the tags submitted for testing, all suppliers are currently supplying animal ear tags into the New Zealand market and off-shore. These vendors appear to be utilising the same ear application techniques that is currently being used for LF tag applications. It is reasonable to expect that if the tag supplier has LF-EID or non-EID tags already approved by NAIT on the basis of retention, then an equivalent UHF EID version should perform consistently also.

Once tags were applied in the animal's ear, it was observed by farm managers that the risk of losing tags from the animals ears (i.e. poor retention due to the tag breaking (the two parts separating)) was low and the greater risk was of the animal catching the tag on an object and the tag being ripped out of the ear.

The researchers collected data on the movement of twenty (20) animals tagged with Type D2 button (see below) in one ear and type C4 flag in the other, from Downlands Deer farm, Geraldine, to Mountain River Processors-Rakaia.

Of the twenty (20) animals observed:

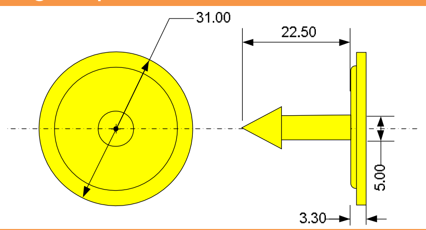
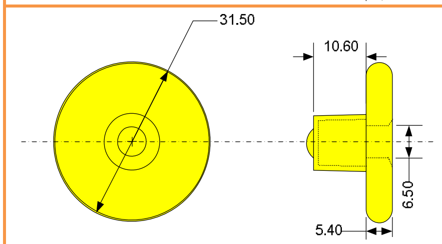
- One (1) animal escaped from the farm holding pens and therefore failed to be loaded onto the transportation vehicle; two (2) tags effectively lost.
- One (1) tag (Type D2 button) was lost (and could not be located) between the Processor holding pens at Mountain River and the stun box, presumably ripped out as evidenced by the animals torn ear.
- The remaining thirty seven (37) tags maintained integrity.

Occasional inspection of animals as they were brought in for testing during the 12 month test period revealed no outward evidence of physical damage to tags aside from minor surface scratching.

3.4 Devices for Testing

Each tag was referenced to the relevant tag manufacturer using an assigned letter (A,B, C etc.). Each batch or form of tag provided by the manufacturer was referenced by a number (1,2,3 etc.). Tags/Batches were named A1, B3 etc.

All tag dimensions shown below are approximate.

Tag Shape	Type	Name
	Button (male).	A1 – first batch. A2 – second batch.
	Button (female).	B1 – first batch.

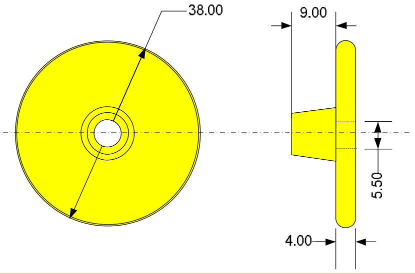
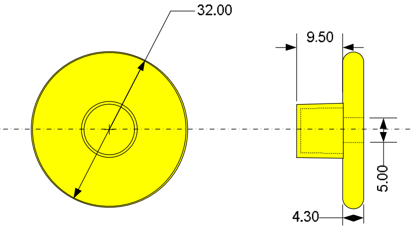
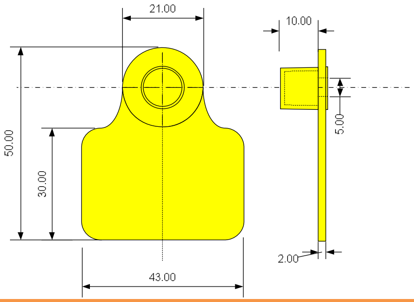
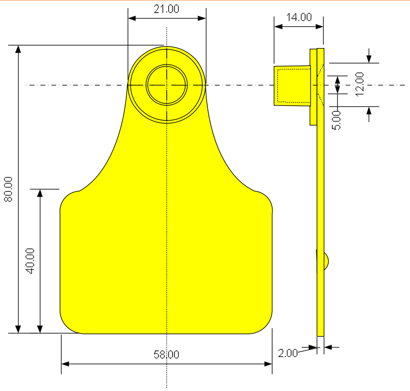
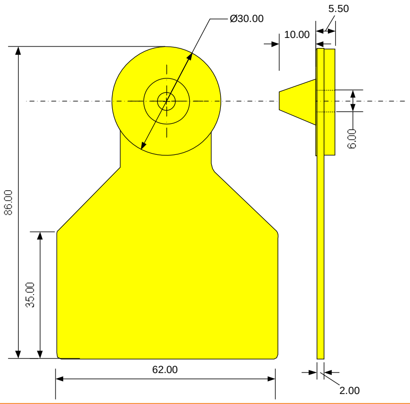
Tag Shape	Type	Name
	Button (female).	C1- first batch. C2- second batch. C3- third batch.
	Button (female).	D1- first batch. D2- second batch.
	Flag, (EID in flag part).	C4 – first batch.
	Flag, (EID in flag part). (this tag has yet to be tested at the time or writing).	D3-first batch.
	Flag, (EID in flag part). (this tag has yet to be tested at the time of writing).	A3- first batch.

Table 3.1-Tag form factors.

3.5 Methodology

3.5.1 Order of process

Grading tests were undertaken to ensure that tests performed on animals used tags that met minimum performance requirements. Tags were supplied by manufacturers to the researchers in batches. Each batch provided by the tag manufacturers was treated as a separate batch. All manufacturers were supplied with a basic acceptance test document (Pathfinder 2012) before any acceptance of the tags for test purposes to ensure the tags could be pre-screened and evaluated for efficacy before shipping to the researchers.

On receipt of tags, the researchers performed an acceptance test followed by a grading test to group tags into approximate read range categories. All acceptance tests were undertaken with the tag mounted on cardboard in 'free space' with the tag facing an antenna. All grading tests were undertaken by holding the tag between thumb and forefinger pointing face on towards an antenna. Once tags were graded, they were encoded with a unique, traceable test number. Quiet or dead tags were removed from test batches.

Tags were tested for performance attributes at least once for each sample species, once graded and encoded. Farm staff applied the tags to the animals. Animals were tagged in an arbitrary manner with respect to left or right ear and tag orientation. Both manufacturer and NAIT tag application guidelines for low frequency EID tag placement in ears were followed where practicable. Where the circuitry component of the tag was in the female part of the tag, this was placed inside the ear. Where the circuitry component of the tag was in the male part of the tag this was placed outside the ear.

Tests conducted with sheep were undertaken outdoors under roof cover. All tests conducted with deer were conducted indoors. For test scenarios where animals moved along drafting races, the tag ID and a timestamp were recorded and the results of the frequency of detection were accumulated for each "run". Animals were herded past the antennas in one direction, in a loop.

For test scenarios where animals where standing (e.g.: a weigh scale), a simple count of read or no-read was recorded. If it took an unusually long time (>30s) for the tag to be read this was noted. Tests were also conducted to measure against defined research criteria (Section 2.7). Once this testing was completed, the better performing tags were tested again against NAIT criteria to ensure completeness.

Testing in wet weather conditions was not performed. Performance of UHF RFID in these conditions is covered in the Scottish cattle project (ScotEID), and is outlined in Pugh and Sundermann (2008).

3.5.2 Equipment

The RFID test equipment utilised in the research consisted of commercially available readers and antennas including:

- 1 x Motorola FX7400 4 port reader set to NZ (nominal 866 MHz) frequency band).
  Nominal transmit power 30 dBm.
- 2 x Motorola AN480 circular polarised antennas.
- 2 x Times – 7 A4030L linear polarized antennas (866 MHz).
- 4 x 6m r.f. cables (terminated, nominally 50 ohm impedance).

The researchers acknowledge that performance specifications of UHF RFID reader equipment affect (positively or negatively) results of tag readability performance given (for example) a higher reader radio sensitivity which may provide measurable improvements on read range over an otherwise limited radio link power budget (Clampitt 2006). The researchers made no attempt to use high performance (gain) antennas or high performance specification (high power/high sensitivity) readers as this would provide contrived results.

Usually, UHF RFID readers (handheld or fixed) have the technical capability of reading tags up to hundreds of times per second, yet an issue of duplicate tags reads found occasionally in low frequency systems is not relevant because UHF systems can register the inventory of a single tag and filter subsequent readings so that they are not recorded.

3.5.3 Test Fixtures

Two test fixtures were developed:

1. A race which could also be used for loading or unloading from a truck or configured into a loop configuration to allow animals to circulate.
2. A weigh scale that functioned as a holding pen for up to five (5) animals at a time (deer), or one animal at a time (sheep).

An overview is shown below (Figure 3.3). A handheld reader was also used for ad hoc measurements of tag readability with individual animals.

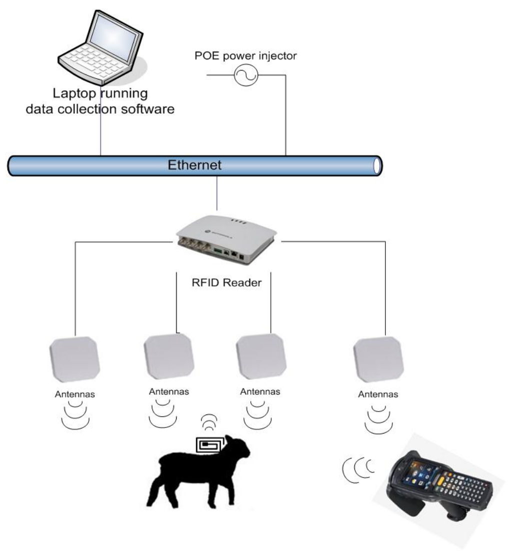
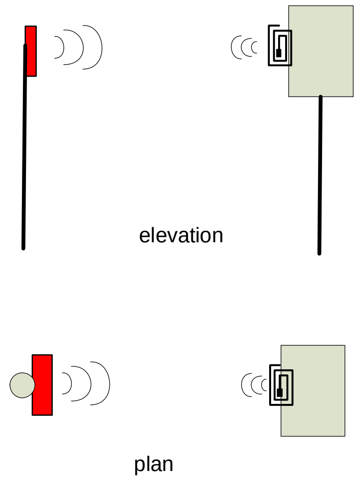
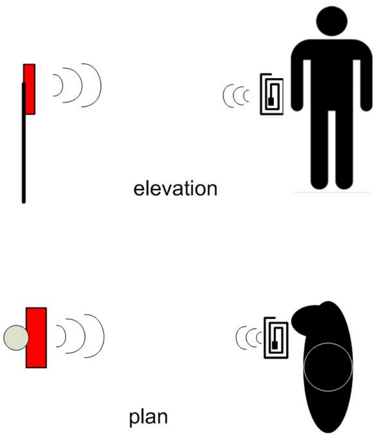
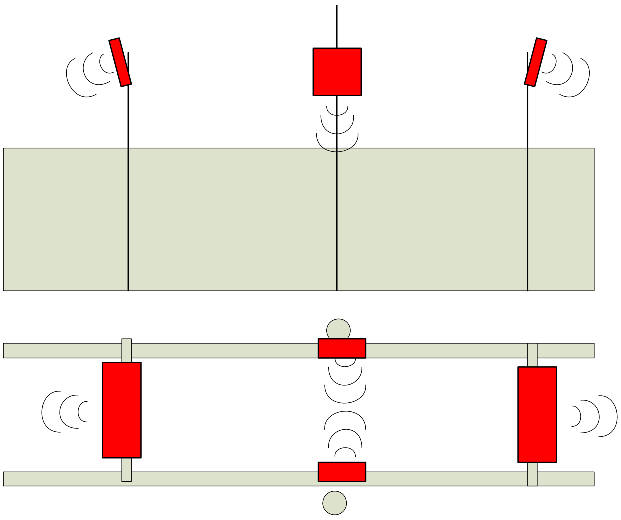


Figure 3.3 -Functional block diagram of test system.

Schematics of the antenna layouts are shown below. In both fixtures antennas were mounted above the animals and facing inwards to the race or pen.

Antenna Configuration	Purpose
	Pre-screen • The Pre-screen fixture used an antenna mounted on a vertical pole pointing towards a cardboard box with the tag affixed at the same elevation and a fixed distance (1.8m) apart.
	Grading • The grading fixture uses the same antenna arrangement as the pre-screen fixture except the tag is held in the hand and is pointed face on towards the antenna. • The distance to the tag from the antenna when the tag fails to read is measured.
	Race • Animals move in one direction along the length of the race and are detected both approaching and receding from the antennas. • The race is long enough to avoid animals backing up along the corridor. • End mounted antennas point along the race. • Side mounted antennas pointing across the race accommodate variations in whichever ear the tag is placed. • Four antennas are connected to a single reader. • This configuration was used for sheep and deer. • One of the end antennas was not used in early phases of testing but was subsequently added to cover make button tags placed outside the ear.

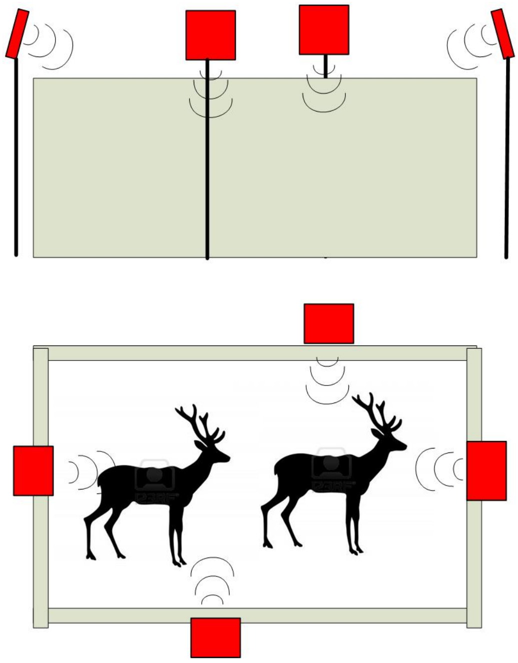
Antenna Configuration	Purpose
	Pen v Animals move into the pen via a gate or door and are free to move within the pen. v Up to 4 Antennas are mounted above the pen pointing in from all sides. v This configuration was used for deer. Sheep were tested either in a weigh scale cage or when held one behind the other in the race

Table 3.2 -Antenna Configurations.

3.6 Tag Readability

Tag readability was measured according to the following test scenario:

- Moving scenario.
- Standing scenario.

In the moving scenario, each time the mob moved past the antenna array in the race configuration it constituted a test “run”. Each test run counted the number of occurrences of each unique tag from the total population of tags (animals might have one or more tags). Early tests recorded the total read count only. Subsequent testing incorporated recording of the actual Tag EID so that individual tag performance could be assessed. Tests were conducted over several months and a number of test runs would be conducted daily. Test runs were limited to mitigate potential stress to the animals. Readability was measured as the number of tags read as a percentage of the tag population that were in each run. Overall readability is assessed as the average of these results over the number of test days (sessions). The animal’s speed was not measured but they were encouraged to move briskly.

In the standing scenario, animals were herded into a pen (or weigh scale) one or more at a time. The count of tags read was recorded against the number of animals in the pen. Readability was measured as a percentage tags read in relation to the total number of animals loaded.

In addition to the average readability of the tags, the frequency of tags being read was recorded. Some tags would appear to be read more frequently read than others which may be due to a number of factors including:

- “Quietness” of the tag.
- Position of the tag on the ear.
- Individual animal behaviour.

Rather than measure the entire spread of tag visibility, the researcher’s defined two thresholds to provide a feel for the distribution in the area of research interest where the desired readability required was high:

- Proportion of tags that were read 90% or more of the time over all the runs in the test session.
- Proportion of tags that were read on every (100% readability) occasion in the test session.

3.6.1 Deer Tests

Deer tests were conducted indoors either in a weigh scale for standing tests, which holds 4-5 animals at a time. Antennas were mounted above the weigh scale (approx. 2.2m high) pointing into the enclosed space.

Moving tests were conducted in a race used for loading on transport vehicles but re-configured for the research purpose so that animals would move in a circuit configuration. The race was approximately 9m long and approximately 1.8m wide by 2.2m high. Figure 3.5 and Figure 3.6 show the antenna mounting positions (4 in all) for the race viewed from either end.

Figure 3.4 -Deer moving along race.

Figure 3.5 -Race Configuration Entrance.

Figure 3.6 -Race Configuration Exit.

3.6.2 Deer Test Results

Table 3.3 illustrates results associated with the researcher's extended performance criteria - multiple animals moving as a mob. Two tags (A2 and D2) achieved 100% readability.

Tag C4 performance is sub optimal although it performed well with sheep (section 3.6.4). One explanation posited is that in testing the tag performance on sheep, the flag tag was mounted on the outside part of the animal's ear and on deer it was mounted on the inner part of the ear. Another possible explanation is the small size of the tag compared to the size of the ear. On sheep the tag tended to protrude from the ear into free space whereas on deer the tag was more enclosed in body tissue.

Tag A2 performed sub-optimally in Session 1 but well in Session 2. The researchers cannot fully explain this however in Session 1, the researchers were also testing for optimal antenna positions which may have contributed to the result.

Test Session	1	2	2	3	3	4
Tag	A2	A2	C3	D2	C4	C4
Type	Button	Button	Button	Button	Flag	Flag
Scenario	moving	moving	moving	moving	moving	moving
% Tags read less that 100% of time (i.e. >90%)	39%	100%	not recorded	100%	50%	79%
% Tags read every time (100%)	39%	100%	not recorded	100%	40%	79%
Average Readability	69%	100%	85%	100%	79%	84%

Table 3.3 -Deer tests, moving scenario.

The results from tests with standing animals were anticipated to be good against both objective measures. The results outlined in Table 3.4 support this, however anomalies were noted. One tag format (i.e. C3) underperformed (92%) and one tag format (i.e. C4) performed markedly differently on two separate occasions - 55% on one day and 100% on another, albeit with different tag samples.

The researchers conclude that tag C3 underperformed in both standing and moving tests due to its design (i.e. sensitivity or polarization), however bench tests completed on earlier batches of the same tag (i.e. C1) indicated that sensitivity was superior than A2 on at least one axis (Figure 3.13). Further testing in three dimensions is needed to establish a more definitive the root cause. Further testing is also required to account for the anomaly outlined with tag C4. One tag appeared to be quiet but with no outward signs of damage to the tag.

Test Session	1	2	2	3	3	4
Tag	A2	A2	C3	D2	C4	C4
Type	Button	Button	Button	Button	Flag	Flag
Scenario	standing	standing	standing	standing	standing	standing
Readability	100%	100%	92%	100%	55%	100%

Table 3.4 -Deer Tests, Standing Scenario.

3.6.3 Sheep Tests

Sheep tests were conducted outdoors under cover at two sites: Ashburton and Oxford. Single animal tests were made in a weigh box or with the animals held in a race. Antennas were mounted above the weigh box pointing inwards.

Tests involving moving animals were conducted in a drafting race approximately 15m long and approximately 1m wide. Side antennas were pole mounted 1.5m above ground. End mounted antennas were mounted approximately 1.3m above ground. Note that the desired portal width of 1.8m could not be configured with the available test facilities so side antennas were set outside the race, higher and at an angle to simulate the effective width as best as possible. Animals were still able to move in a mob fashion along the race.

Figure 3.7 and Figure 3.8 show the weigh box and antenna for standing tests. Figure 3.9 and Figure 3.10 illustrate the race antenna configuration at the Oxford site for 'moving' tests.

Figure 3.7 -Sheep tests, weigh box.

Figure 3.8 -Sheep tests, weigh box and antenna.

Figure 3.9 -Sheep tests, race configuration.

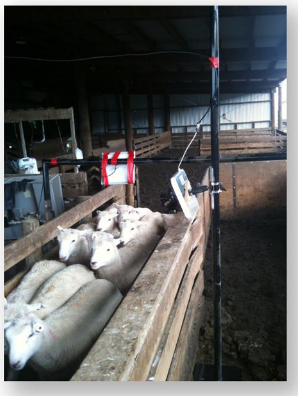


Figure 3.10 -Sheep moving through race.

3.6.4 Sheep Tests Results

Table 3.5, Table 3.6 and Table 3.7 illustrate the results of sheep tests conducted over eight sessions testing the moving scenario.

For all tests involving moving animals, the average readability for all tags ranged from 79% to 100%, apart from Session 1 because earlier tests were used to establish optimal antenna positions which may have affected the results. The researchers extended performance criteria were satisfied in five (5) instances by three (3) of the tag formats, namely, (A2, D2, C4).

Test Session	1	2	3	3	3
Tag	A1	A2	A2	C1	C2
Type	Button	Button	Button	Button	Button
Scenario	moving	moving	moving	moving	moving
% Tags read less that 100% of time (i.e. >90%)	not recorded	not recorded	93%	43%	29%
% Tags glimpsed every time (100%)	not recorded	not recorded	50%	14%	14%
Average Readability	77%	100%	95%	80%	79%

Table 3.5 -Sheep tests, moving scenario, sessions 1-3.

Test Session	4	4	4	5	5
Tag	A2	C1	C2	C3	D1
Type	Button	Button	Button	Button	Button
Scenario	moving	moving	moving	moving	moving
% Tags read less that 100% of time (i.e. >90%)	100%	57%	86%	67%	77%
% Tags glimpsed every time (100%)	100%	57%	86%	60%	70%
Average Readability	100%	89%	89%	84%	89%

Table 3.6 -Sheep tests, moving scenario, sessions 4-5.

Test Session	6	6	7	7	8
Tag	D2	C4	D2	C4	D2
Type	button	flag	button	flag	button
Scenario	moving	moving	moving	moving	moving
% Tags read less that 100% of time (i.e. >90%)	55%	100%	85%	100%	100%
% Tags glimpsed every time (100%)	10%	90%	85%	100%	100%
Average Readability	83%	99.5%	97%	100%	100%

Table 3.7 -Sheep tests, moving scenario, sessions 6-8.

However, it should be noted that the size of the sample population ranged from 10-25 animals at a time and as a consequence failure of one tag has a significant impact on results – i.e. 4-10% impact on a single test. Where possible, runs were repeated up to ten (10) times to provide for potential tag performance irregularities.

If a tag could be read at all then it generally could be read repeatedly. This argument is supported by the fact that readings were skewed towards the ninety (90) percentile for more than two thirds of the tags. There were three (3) instances where a tag could not be read using the system and closer inspection revealed that the tags were quiet.

Test involving standing sheep and sheep moving in single file were conducted with tag D2. Standing tests were performed with a handheld reader (section 3.6.7) and with a single antenna rigged over a weigh box where the sheep could be constrained. In both cases, the NAIT criteria were fulfilled. Of note is where tests were conducted without over-reads occurring. An over-read is not desirable in situations where the farmer must positively identify a specific animal. Over-reads were eliminated by placing the antenna in specific positions over the weigh box and operating the reader at full power or by reducing the transmit power of the reader.

Single file tests were conducted by opening both ends of the weigh box and allowing the sheep to move freely, one at a time through the box. Two antennas were placed over the weigh box (Figure 3.11). 100% readability was achieved with this configuration. This configuration also eliminated over-reads of tags placed adjacent to the weigh box, which might otherwise affect an accurate stock count of animals passing through the weigh box. Other configurations may be possible with open wooden framed single file races.

Figure 3.11 -Single file moving test setup.

3.6.5 Manufacturer Grading

Initial tests showed variability in the performance of individual tags. Considering that the manufacturers were, in some cases, offering prototype devices for testing purposes, the researchers introduced a simple grading system to avoid testing prototypes that were poor performers that would skew results.

As outlined, tags were pre-screened using the pre-screen antenna configuration to determine any dead tags. The tags were then graded using the grading antenna configuration and tags reading only marginally at 1.8m were rejected for next stage testing.

Of 530 tags encoded, seven (7) tags were found to be either dead, quiet or rejected when pre-screened or graded. This represented approximately 1% of the sample tag population.

After encoding approximately 400 tags, they were applied to animal's ears. Using the grading process, the maximum read distance of all tags measured was found to be 2.4m.

3.6.6 Laboratory testing

All the tags received for testing exhibited some degree of polarization dependence; the tag read range having a dependency on the orientation of the tag with respect to the antenna. The effect of polarization was mitigated somewhat by a) the choice and position of antenna configuration and b) the speed of the animals moving past the antennas providing an opportunity to read the tag with optimum orientation. The effect was not entirely eliminated and may negatively impact on tag readability to some degree. Further research should be undertaken in this area.

Some vendors supplied tag sensitivity graphs accordingly to antenna orientation for example below (Figure 3.12).

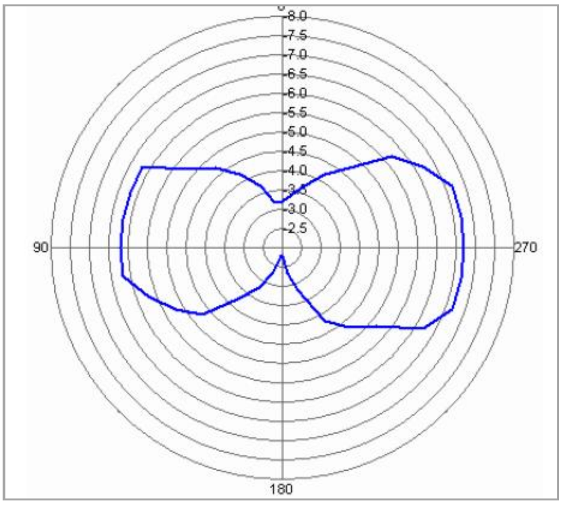


Figure 3.12 -Tag polar sensitivity.

Tags also exhibited sensitivity variation according to the frequency of operation. There are two spectra in New Zealand allocated for UHF RFID use: 864-868 MHz (A band) and 921.5-928 MHz (B Band) (GS1 2012).The researchers tested a small sample tags at the commencement of the project to identify the spread of tag sensitivity by frequency as an indicator of performance readability.

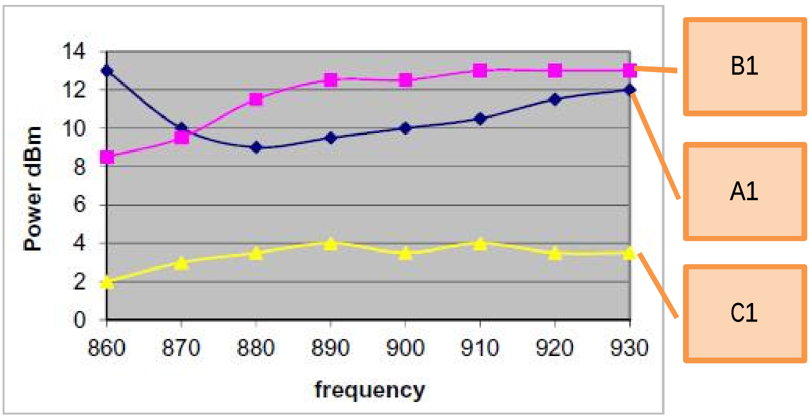


Figure 3.13 -Tag energization levels across the frequency spectrum.

The power required to energize a tag to transmit its EID was measured with the tag fixed in a predetermined orientation. Figure 3.13 shows the minimum power required to energize a tag. Less power needed to energize a tag means the tag is more sensitive and more likely to respond at a longer read range (a desirable feature).

From the graph it appeared for example that tag B1 was most sensitive at the lower frequency (860 MHz) and least sensitive at the higher frequencies (930 MHz) making it more suitable for use in the A band.

Initial results indicated that some tags were more likely to respond better in the A band than the B band. The researchers advise that not all tags were tested in this manner. Optimal tag response at different frequencies will have implications on the selection and configuration of readers, which operate in the A or B bands but not both simultaneously.

3.6.7 Handheld Reader -Tag Readability

The researchers utilised a handheld RFID reader on four (4) occasions; two (2) occasions with deer and two (2) with sheep, to provide a stock count and to obtain empirical measurements of tag read range performance. In larger pens (about.25 m^2) where animals were free to move, it was difficult to get in close enough proximity to all animals in the pen but when constrained in smaller pens (about 5 m^2) or in a single file race (with sheep) reading tags was relatively easy. On analysis, total readability in larger pens was approximately 75% with 100% readability in more constrained conditions.

Read ranges varied from about 0.5m to 1.5m, irrespective of species. When tags were physically and easily visible, the read rate for a single tag was about 20-40 reads/s. Therefore, the limiting factor on the number of animals that could be read was the time taken to move from one animal to the next. Tags were sometimes obscured from view; for example if the animals head was obscured by the body of another animal. In these instances, it could take up to 10 seconds to move the RFID handheld reader into a suitable position to read the tag. A handheld RFID reader was not used as an alternative to the fixed RFID reader infrastructure used for moving animal scenarios because the limited read range was not expected to meet the augmented test criteria. However the application of handheld reader for moving scenarios should be further researched.

Figure 3.14 -Handheld reader tested with standing deer.

Figure 3.15 -Handheld reader tested with standing sheep.

4 Conclusion

The source of supply and variety of commercially available UHF RFID tags for animals has increased significantly in the last five (5) years suggesting the enhanced evolution and efficacious nature of the technology for livestock applications. Notwithstanding this, the adoption of UHF RFID technology within the broader agri-business community remains minimal.

This research illustrates that UHF RFID provides a technical and therefore potentially an economic advantage in the management of livestock species that exhibit mob behaviour such as deer and sheep. It has been demonstrated that UHF RFID technology has advantages whenever it is time consuming and of no benefit to force animals into moving in single file, or slowly, solely to fulfil the requirements of the RFID technology to capture an EID. UHF RFID technology also has benefits in operating over longer distances than LF RFID options as outlined.

The evaluation of nine different (9) tags forms from four (4) different manufacturers utilised in this research has demonstrated that three (3) candidate samples met the researcher's extended performance criteria for animals moving in a mob scenario. Readability of 100% performance was achieved on numerous occasions but inconsistently. The researchers are confident that as the technology continues to improve through global research and development efforts, tag performance and consistency will to continue to improve.

Fixed RFID reader and antenna infrastructure was erected and installed on/ over typical on-farm fixtures such as drafting races and weigh pens. The read ranges of tagged animals were measured consistently at between 1.2-1.8m. Tag readings were secured using commercially available RFID readers and antennas with industry standard performance specifications. During the pre-installation tag grading process, the maximum tag read range recorded was 2.4m.

Manufacturers provided both button and flag styled tags (also ready for large visual identifiers). In one instance, the circuitry component of the tag was mounted on the male part, not female part of a button tag as specified by NAIT. Notwithstanding variations from the NAIT requirements, it was found that the male button tag (A2) and flag tag (c4) could produce high levels of readability reliability (100%) on sheep when affixed behind the ear. Subsequent tests on deer produced less favourable results (84%) when the RFID section of the C4 tag was mounted on the inside the ear. Further research is recommended to determine the optimum placement for flag tags on both species for performance readability.

Over-reads were controlled by antenna placement or the control of the RFID reader's transmitting power. The researchers conclude that there are no technology concerns for application scenarios that are sensitive to over-reads such as weighing and identifying a specific animal, because they can be controlled.

Possible causes of a tag becoming quiet after fitting it to the animal's ear require further research. The researchers recommend that a 3-dimensional analysis of the tag sensitivity be undertaken to assess the performance of a tag irrespective of orientation to the antenna or tag obscured by any part of the animal's body.

When using the handheld RFID readers, read ranges of 0.5m to 1.5m were reported meaning the lessened requirement to be in close proximity to animals. Handheld RFID readers when used in the standing tests proved very effective. In general, this resulted in high readability performance. Readability denigrated quickly as animals were permitted to roam freely from the RFID reader suggesting that handheld RFID technology requires further development to be completely efficacious for on-farm applications.

Evaluation of UHF RFID tag and RFID reader technology is continuous to assess and determine efficacy for regulatory requirements. This analysis concludes that tag performance criteria for UHF RFID NAIT tags could be extended to include high read accuracy for animals moving together and all at once.

Finally, the researchers recommend continued research be undertaken to incorporate other aspects of tag performance, such as tag retention, as interest in the use UHF RFID technology as a candidate for livestock applications increases from regulators and legislators around the world, including New Zealand.

5 Summary of Recommendations

The researchers recommend the following:

- Tag vendors manufacture tags that perform independently of orientation when fitted into an animal's ear.
- Research into dual frequency (LF/UHF) continues.
- Tag vendors manufacture tags optimized for operation in New Zealand.
- Tag chipsets with -20 dBm sensitivity (or better) be considered.
- Vendors continue to implement quality assurance processes to screen for quiet or dead tags and provide declarations to support tag performance standards. Evidence of underperforming tags received for testing indicates improvements to assurance process are warranted.
- Vendors are encouraged to collaborate to produce standardized performance specifications for tag when applied to animals for the benefit of consumers using the tags for various on-farm applications.

The New Zealand RFID Pathfinder Group

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7 Contact Information

Enquiries regarding this document or technical studies by the Pathfinder group should be directed to the Secretary.

Organisation Name:	NZ RFID Pathfinder Group
Name	Gary Hartley
Role	Secretary
Telephone	+64 4 494 1050
Cell	+64 21 348 687
Fax	+64 4 494 1051
E-Mail	info@rfid-pathfinder.org.nz

Research Team:	
Grant Pugh	Grant.pugh@tracient.com
Mark Rance	Mark.Rance@anzcofoods.com
Erik Sundermann	Erik.Sundermann@gs1nz.org
Gary Hartley	Gary.Hartley@gs1nz.org

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