THE USE OF ULTRA-HIGH FREQUENCY (UHF) TRANSPONDERS AS A POTENTIAL REPLACEMENT FOR CATTLE PASSPORTS

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1. INTRODUCTION

1.1 Purpose

Ultra-high frequency (UHF) transponders are potential candidates for the replacement of cattle passports. The project will consider the technical and practical feasibility of the widespread deployment of UHF transponders in ear tags of cattle to enhance the efficiency of traceability of cattle. In other sectors UHF systems are widely used to track, trace and stocktake goods. UHF systems are considerably cheaper than the alternative low frequency (LF) systems. Importantly UHF transponders also have advantages over LF systems in that UHF transponders can contain significantly more information, including essential information (such as an animal's unique identifier) in a permanent, non-modifiable format, and additional information that can be 'written' during their lifetime. An additional advantage is that UHF tags[1] have a collision avoidance capability that enables many to be read simultaneously in real time. The overarching aim of the project is to review the state of knowledge of UHF in relation to its use in livestock systems and to carry out research to assess the suitability of UHF transponders and antenna throughout the Scottish cattle supply chain including its use on farms, and in markets and abattoirs.'

1.2 Background

Over the last few decades, the use of UHF transponders has gained in popularity due to their low cost, information storage capability and the emergence of standards for implementation. There are many companies who manufacture transponders for a wide range of applications - asset tracking, access control and inventory management in diverse disciplines within different industries. The range of industries using radio frequency identification (RFID) transponders is similarly diverse and includes aerospace, agriculture, automotive, chemical, textile, food, healthcare and logistics.

For disease control and public health, European legislation determines that national competent authorities must legislate for and ensure that cattle are identified and their movements recorded. The combination of cattle ear tags, passports and electronic reporting fulfil this obligation. Government backup systems to achieve this include the Ear

[1] The word 'tag' is widely used in RFID business. However, the word tag can have different meanings. It can be used meaning ear tag and might not have any electronic components; it can be an inlay packaged/moulded in plastic, e.g. a plastic ear tag or it can be a transponder, which is a technical term which can be used for inlay, or any other device which can transmit and respond automatically (TRANSmitter- ResPONDER).

Tag Allocation System (ETAS) and the Cattle Tracing Scheme (CTS) operated by British Cattle Movement Service (BCMS, part of RPA). At the present time in Scotland it is not compulsory to use an Electronic Identification System (EID) for cattle. Additionally, the Cattle Tracing System is not fully developed for the use of EID. However, there is a requirement for electronic movement reporting. Therefore, there is some use of electronic systems for farmers to report moves to CTS, but plastic, non-electronic tags and paper passports are still the essential components of the system [1][2].The present study is only concerned with evaluating the potential usage of UHF RFID transponders within the industries associated with bovine animals.

1.3 Standardization

The following are the two Standards which provide the technical guidelines for RFID system manufacturers.

1) EPC UHF Class-1 Gen 2: Electronic Product Code Global (EPC-Global) is a standardization organization which specializes in the development of industry driven Standards for the Electronic Product Code (EPC) and supports the use of UHF RFID Tags. Currently, EPC UHF Class-1 Generation-2 (EPC UHF Gen-2) [3] is the latest standard to be widely adopted by RFID manufacturers. It defines the physical and logical requirements for a passive-backscatter communication link used for RFID systems, which consists of a reader (also called Interrogator) and transponder(s). The reader sends information to one or more transponders by modulating an RF carrier using double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK) or phase-reversal amplitude shift keying (PR-ASK) with pulse-interval encoding (PIE). The transponder itself is passive; it has no on-board power source and receives energy from this carrier for its operation. For receiving information from a transponder, reader transmits an un-modulated carrier and listens to the backscattered reply.

In addition to the physical layer, EPC UHF Class-1 Gen 2 defines the structuring of the tag memory, which shall be - as per this standard - logically divided into following four memory banks:

a) Reserved memory: reserved for kill and access passwords. It also specifies the physical memory addresses for passwords.

b) EPC memory: this section contains a 16-bit cyclic redundancy check code (CRC-16), protocol-control bits (PC) and an identifier code. This unique code is the identifying signature used to specify the object being tracked (in this case bovines).

c) Transponder Identifier (TID) memory: an 8-bit class allocation identifier, information of any custom or optional commands each tag supports and some vendor-specific information.

d) User memory: user defined for user-specific data storage.

2) ISO/IEC 18000-6: A second important Standard, potentially of some interest to this study, is ISO/IEC 18000-6 published in 2010 [4]. It defines the air interface for the RFID communications protocol which includes physical interactions between a reader (a handheld or fixed device which reads information off the transponder) and transponder(s). It contains technical specifications for one mode with four types.

a) Type A uses PIE in the forward link and an adaptive ALOHA (see for example [12]) collision–arbitration algorithm.

b) Type B uses Manchester encoding in forward link and an adaptive binary-tree collision arbitration algorithm.

c) Type C uses PIE in the forward link and a random slotted collision-arbitration algorithm.

d) Type D is based on Pulse Position Encoding or Miller, M=2 encoded subcarriers.

Type A, B and C define an Interrogator-Talks-First (TIF) protocol whereas Type D defines a Tag-Only-Talk-After-Listening (TOTAL), RFID system.

2 RFID TRANSPONDERS AND READERS

There are a wide variety of UHF RFID transponders available on the open market. The presence of these large numbers of UHF RFID manufacturers, addressing diverse applications using different solutions makes the task of selecting transponders for a given application problematic without first reviewing the available options.

2.1 Selection of Transponders

In the present study, the following criteria have been used to constrain the range of transponders under consideration. Those selected are further compared based on their read range and size in Tables 2 and 3.

a) Transponders are designed for specific applications e.g. for parcel tracking, and not recommended by the manufacturer for use in other applications. As very few transponders are recommended for animals, transponders which were considered general purpose and for relatively rugged environments were selected as a first pass criterion.

b) Secondly there are a large number of transponders recommended for mounting on metal surfaces; these too were not considered.

c) The final criterion was based on the measurements carried out by ScotEID [5] and a measurement based characterisation campaign carried out by researchers at Rutgers, The State University of New Jersey [6].

d) In addition, two UHF ear tags (eTattoo by Eriginate/HerdStar and RaFid UHF tag by Hana Innosys [7][8]) approved by the US Department of Agriculture, has been selected for further investigation.

2.2 Transponder Memory

Transponders are made of an integrated circuit (IC or chip) and a passive antenna [5]. Although there are many manufacturers, there are a relatively low number of companies making ICs for transponders. Table 1 summarises the six main types of transponders grouped according to the ICs used to manufacture them; the available ICs and their corresponding memory specifications are shown. For the definition and functionality of the memory banks, refer to Section 1.3.

User memory is an important criterion for the selection of transponders, particularly in relation to the implementation of an animal passport. While the Tag ID, and the EPC Memory can be used to provide a unique and traceable label for an animal, additional memory that is accessible by the user, is required as this can be used to record animal movement information in addition to unique animal identifier or EPC. It should be noted that in the present context, the user refers to organisations such as the British Cattle Movement Service (BCMS) or others responsible for operating the infrastructure that would present at cattle movement points e.g. marts.

Table 1: Major types of transponders based on IC used and memory specifications

Tag IC	Monza 2	Monza ID	Monza 3	Monza 4	G2XL	G2XM	Higgs 2 &3
Tag ID Memory	0	32 bits	32 bits	-	64 bits	64 bits	64 bits
EPC Memory	96 bits	96 bits	96 bits	128-496 bits	240 bits	240 bits	96 or 480 bits
User Memory	0	0	0	36-512 bits	0	bits	512 bits

2.3 Transponder Read Range

In terms of read range, transponders are loosely specified by the manufacturers into three categories; short, medium and long and long rang. In this context, short range refers to a read range of less than 3 m, medium between 3 m and 6 m and long range refers to read distances in excess of this. Table 2 summarises the read ranges derived from transponder specifications provided by the manufacturers and are available online on their respective websites. A hyperlink to each of these transponders is associated with each entry. It should be noted however that there is no standard test procedure to be followed in order to define a read range. Manufacturers tend therefore to specify a value that represents their devices positively. For example, the read range measurement may be highly dependent upon the orientation of the tag, depending on the radiation pattern of the antenna. Furthermore, the read range obtained by measuring the distance that a transponder can be from a reader before the reader stops being able to read it, is markedly different from the distance to reader where the transponder first becomes readable. For these reasons, the specifications are best used as a loose qualitative measure of performance.

2.3.1 Range Implications in Operation

The operational requirements on UHF transponders are such that they should be capable of transmitting and receiving data, in such a manner that the use of the system does not compromise the normal operating practice of the farm, market or abattoir. This means that the transponder should be instantly readable, be robust to radio packet collisions and thus operate effectively (without error) in situations where many transponders can be attempting to transmit at the same time.

2.4 Transponder Size

Within the cattle monitoring environment, the physical dimensions of the antenna (transponder) must be constrained such that the transponder does not become an encumbrance nor that it becomes vulnerable to damage. Bovine animals will tolerate the presence of transponders packaged in an ear tag to a degree but if they are large enough to snag or to irritate, then they will have a limited lifetime. Usually transponders with the longest edge less than 50 mm in length are considered small. Anything between 50 mm and 100 mm in length is considered medium size and large transponders are those where the length of the longest side is greater than 100 mm. The dimensions of a range of common transponders are recorded in Table 2.

2.5 Potential transponders for further investigation

The manufacturer's specification of operational range, coupled with a working form factor of the transponder dimensions is a crude method with which to make a preliminary judgement of what may be the most appropriate transponder to use. For the purpose of this study, it is assumed that the operational read requirement should be consistent with that of a reader position above moving cattle, either in a race or in a relatively constrained channel, managing many cattle moving through the point below the reader at any given time. Given these general constraints, transponders with a short read range (<3 m) have been assumed to be inadequate given that the operational environment is more likely to diminish rather than enhance the read capability; therefore the focus is on transponders which have a medium to long range performance specification.

The mechanical dimensions of the transponder were considered to be appropriate if the overall transponder size was less than the dimensions of a cattle typical ear tag – between 45 mm and 110 mm in height and 55 mm wide [9]. A typical eat tag is shown in Figure 1.

Table 2 Read range and size summary.

Manufacturer	Model Name	Type	Read Range			Size (mm)
			Short (0 > 3m)	Medium (3m > 6m)	Long (> 6m)	
Alien	ALN 9662 – Short	Inlay			✓	17 x 70
	ALN 9654 - G	Inlay			✓	19 x 93
	ALN 9634 - 2"x 2"	Inlay			✓	44 x 46
	ALN 9629 - Square	Inlay		✓		22 x 22
Avery Dennison	AD-223	Inlay			✓	95 x 8
	AD-224	Inlay			✓	95 x 7
	AD-230	Inlay			✓	70 x 14
	AD-641	Inlay			✓	70 x 70
	AD-824	Inlay		✓		30 x 50
	AD-826	Inlay			✓	30 x 50
	AD-827	Inlay		✓		18 x 40
	AD-828	Inlay	✓			15 x 40
	AD-833	Inlay			✓	38 x 93
Sirit	RSI-670	Inlay		✓		76 x 76
	RSI-674	Inlay			✓	98 x 12
	RSI-675	Inlay	✓			57 x 19
Tageous	EOS500	Inlay	✓			100 x 26
Invengo	XCTF-8603	Tag	✓			50 x 30
	XCTF-8605	Tag	✓			65 x 48
UPM	Frog 3D	Inlay		✓		53 x 53
Smartrac (new company name)	Web	Inlay			✓	34 x 54
Fujitsu	WT A511/A611	Tag	✓			55 x 10
Metalcraft	Universal Hard Tag	Tag			✓	107 x 44
Omni-ID	Prox	Tag	✓			35 x 10
	Flex	Tag		✓		75 x 15
Eriginate/HerdStar	eTattoo	Tag		✓		76 x 11
Hana Innosys	RaFid UHF Tag	Tag				78 x 58

Figure 1: Typical ear tag.

Within these operational constraints, several options are available from a number of manufacturers. Avery Dennison manufactures a variety of transponders aimed at supply chain management operations within retail, particularly pallet tracking. There is no reference to Avery Dennison within the DEFRA approved ear tag manufacturers listing [10] however several transponders have appropriate technical specification and can therefore be considered for experimental evaluation. The Tageos and Invengo transponders are short range, as are those from Fujitsu; therefore these were de-selected for initial investigations.

Metalcraft manufacture a range of transponders that have a medium range capability. There are none that are specifically designed for the agriculture sector therefore a custom housing will be required to translate their operation into the agriculture. This may compromise the transponder operation and for this reason these transponders have been omitted from this initial study.

The strongest candidates from the immediate search of transponders were:

- UPM – Frog 3D (Inlay)
- UPM – Web (Inlay)
- Avery Dennison – AD 824 (Inlay)
- The Alien- ALN 9634 - 2"x 2" (Inlay)
- Eriginate – eTattoo (Tag)
- Hana Innosys – RaFid (Tag)

All have compatible dimensions and medium to long range read capability. Of these – the UPM Frog 3D, UPM – WEB have been investigated for range performance under different physical orientations in order to determine their sensitivity to polarisation and have been found to perform well [5]. In all cases, the transponders were readable at distances of a few metres independent of orientation. The characterisation also determined the repeatability of the measurement using alternative reading technology in order to assess variability.

The final two transponders that were selected in our preliminary list of suitable for investigation is the Eriginate/HerdStar – eTattoo and Hana Innosys – RaFid – Both have recently been approved by the U.S. Department of Agriculture (USDA). The key technical parameters relating to all of the six selected transponders are shown below in Tables 3 – 8.

Table 3: UPM – Frog 3D (Inlay).

RF Protocol	ISO/IEC 18000-6C, EPC Global Gen 2 UHF
Operating Frequencies	800-960 MHz
Integrated Circuit	Impinj Monza 4
Inlay Size	53 x 53 mm
Read Range	Medium

Table 4: UPM-Web (Inlay).

RF Protocol	ISO/IEC 18000-6C, EPC Global Gen 2 UHF
Operating Frequencies	800-960 MHz
Integrated Circuit	Impinj Monza 4
Inlay Size	34 x 54 mm
Read Range	Large

Table 5: Avery Dennison - AD824 (Inlay).

RF Protocol	ISO/IEC 18000-6C, EPC Global Gen 2 UHF
Operating Frequencies	800-960 MHz
Integrated Circuit	NXP G2XM
Inlay Size	30 x 50 mm
Read Range	Medium

Table 6: The Alien - ALN-9634 (Inlay).

RF Protocol	ISO/IEC 18000-6C, EPC Class 1 Gen 2	
Operating Frequencies	840-960MHz	
Integrated Circuit	Alien Higgs-3	
Inlay Size	47 x 51 mm	
Read Range	Medium	

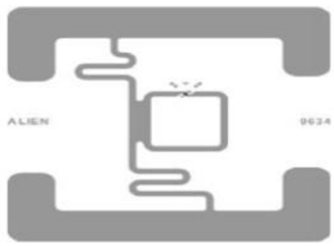

Table 7: Eriginate – eTattoo (Tag)

RF Protocol	ISO/IEC 18000-6C, EPC Global Gen 2 UHF	
Operating Frequencies	866-928 MHz	
Integrated Circuit	NXG-G2XM	
Inlay Size /Tag Size	25 x 63 mm / 76 x114 mm	
Read Range	Medium	

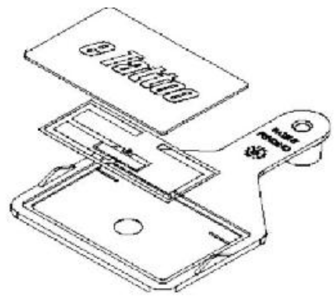

Table 8: Hana Innosys - RaFID (Tag).

RF Protocol	ISO/IEC 18000-6C, EPC Global Gen 2 UHF	
Operating Frequencies	800-960 MHz	
Integrated Circuit	Not Available	
Inlay Size / Tag Size	Not Available / 78 x 58mm	
Read Range	Large	

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2.6 Transponder Prices

From open source information i.e. published pricing, there is not a great deal of variability between vendors in terms of transponder pricing. Prices range between £1.50 and £0.40, depending upon volume. Although it is clear that price will be a strong influence on the end implementation, at this stage the focus has been on technical performance.

2.7 Readers

The term 'reader' is often used for not only readers but also for the devices which have functionality of scanning, interrogating and writing the data to the transponders. Readers are designed to be mounted on objects (entrances, walls etc.) or to be used as handheld device which can be carried around to read the target transponders. There are a relatively small number of key manufacturers of readers - Impinj, Alien Technology, Invengo, Caen, Sirit and Motorola.

A reader has following four main parts for performing the tasks of reading/writing or interrogating etc. [13] (general information on a range of readers can be found, for example at www.rfidreader.com).

1) Application Software – It provides an interface for the user to access the recorded data or initiate read/write operations.
2) Processing Unit – It enables the Reader to modulate the data, implement the anti-collision procedures and code the data for sending read/write commands to the transponder.
3) RF Interface and Antenna – It does the tasks of transmission/reception of RF signals. Antenna gain, directivity, beam pattern and orientation are the key design parameters for any application-specific reader.

An important aspect of readers is the communication interface for the transfer of data from Reader to main database or asset management system. Readers either come with serial communication interface (RS-232, RS-485 or USB) or they have networking capability and support multiple network protocol e.g. Ethernet, WLAN etc. A survey of the readers available in the open market is summarised in Table 9.

Table 9: Summary of key readers available on open market.

Vendor	Model	Antenna Type /Ports	Processer/ Memory	Network Connectivity/ PoE	Applications/Comments
Impinj	Speedway Xportal (R640)	Integrated Dual Linear Phased Array (DLPA)	Intel IXP420 (266MHz) 64MB RAM 64MB Flash	Ethernet PoE support	Tagged items in retail office and other indoor environments.
	Speedway Revolution(R220/ R420)	2 or 4 monostatic ports optimized for Impinj antennae	-	Ethernet PoE support	-
Alien Tech.	ALR9900	4 reverse polarity TNC monostatic ports; circ or linear polarization; near/far field compatible	Intel Xscale 64MB RAM 64MB Flash	Ethernet PoE not supported	Supply chain, Manufacturing and Assets Management
	ALR9900+EMA	-	-	-	-
Invengo	XCRF-860	Up to 4 SMA type connectors	Intel Xscale 64MB RAM 64MB Flash	Ethernet PoE not supported	Logistics Assets Tracking/ Management Supply Chain
	XCRF-804	Up to 4 SMA type connectors	Intel Xscale 64MB RAM 64MB Flash	Ethernet PoE not supported	Logistics, Supply Chain W/house Automatic Vehicle ID Manufacturing
Motorola	FX7400	4 mono-static ports (Reverse Polarity TNC)	Processor specs – not available 64 MB RAM 64 MB Flash	Ethernet PoE support	Retail inventory, Applications in any environment where RFID deployment requires a SMALL footprint.
Motorola	FX9500	4 monostatic or 2 bistatic ports Or 8 monostatic or 4 bistatic ports (Reverse Polarity TNC)	Intel PXA270 (624 MHz) 128MB (DRAM) 128MB Flash	Ethernet PoE not supported	For high density tag environments, High-throughput applications For tough industrial environments
	XR450	4 mono-static ports (default operation); or 4 bi-static ports (4 transmit ports, 4 receive ports)	Processor specs – not available 64MB DRAM 64 MB Flash	Ethernet / PoE not supported	In dense-reader deployments Flexibility to meet a wide range of application and environment needs.
	XR480	Up to 8 read points in single-port mode; up to 4 read points in dual-port mode	Intel Xscale 64MB DRAM 64 MB Flash	Ethernet PoE not supported	In dense reader environments

Sirit	INfinity 510	4 TNC Reverse Polarity	Not Available	Ethernet PoE not supported	Supply chain Conveyer systems Access control
Caen	R4300P Ion	4 TNC Reverse Polarity	Intel Atom Z510 (1.1GHz) 512MB RAM	Ethernet PoE not supported	Industrial control Point of sales devices Access control systems

On paper there is little to choose between different UHF readers because they are all compliant to standards. The following illustrates the key parameters and the degree of consistency across the range.

Air Interface/Protocol: Readers manufactured by Impinj, Alien Technologies, Invengo and Motorola are compliant with EPC UHF Class-1 Gen-2 and ISO/IEC 8000-6C standards.

Transmit Power /Radiated Power: Impinj, Alien Technologies and Motorola (only XR480) have explicitly stated of their compliance to ETSI EN 302-208 regulation for RFID equipment operating in the band 865 - 868 MHz with power levels up to 2 W. However all readers (Table 10) have capability of operation in this frequency band with same transmit power levels.

Receiver Sensitivity: Impinj, Alien Technologies and Invengo readers have receiver sensitivity in the range of -82dBm. Some of the Motorola readers e.g. FX9500 have receiver sensitivity in the range of -104 dBm when deployed in certain antenna configuration, refer to the detailed specifications for details.

For the present evaluation we are concerned primarily with fixed readers. The bulk of the readers that are available have, on paper, similar characteristics and prices are in the £1000- £2000 range.

For the transponder evaluation phase we have aimed to find readers that are compatible with circular or cross polarised antennae since linearly polarised solutions, whilst potentially offering the best in read/write ranges, are vulnerable to changes in transponder orientation. Alien readers are a natural candidate since they too manufacture transponders that are strong candidates.

The Impinj Speedway series are also suitable for reading crossed or circularly polarised transponders and are readily available in evaluation kit form and can be powered directly over Ethernet cabling which is advantageous from an installation perspective. These are therefore a strong candidate for the second phase evaluation.

A previous review into UHF transponders undertaken by ScotEID [5], evaluated a subset of the tags that are selected above with an alternative reader manufactured by Deister [14]. It is our intention to select alternative readers to complement with work. To support this study, ScotEID have agreed to grant us access to the Deister reader to perform comparative measurements. It is our intention to reciprocate with the reader choices above. Additionally, a recent report [11], published by ODIN Technologies research laboratories recommended the Sirit, Caen and Impinj readers are being among the top industry performers – the Sirit 510 was the joint trial favourite. The Sirit reader is also strongly recommended by ScotEiD who have trial systems based on this reader. To augment the studies that have been reported elsewhere we have selected to examine the performance of the Impinj reader in order to determine whether or not performance is broadly consistent across the recommended reader types.

Read range is a key to the operation of UHF transponder based system. However the write range is equally as important, especially where tags may have the dual purpose of performing the role of a cattle passport. To the best of our understanding, the most relevant previous studies have focussed upon read range. For this reason we intend to expand the scope of evaluation to encompass write range within the reader/transponder evaluation phase.

3 EXPERMINETAL READ/WRITE ASSESSMENT

A detailed assessment of transponder read range has been undertaken by ScotID [5]. This analysis demonstrated that read range can be influenced by transponder orientation and reader antenna polarisation. In general however, the investigation confirmed that read ranges in excess of 3m were readily obtainable using a variety of different transponders. This work was carried out using a Deister RFID reader.

3.1 Experimental Methodology

To compliment this work, we have undertaken a preliminary assessment of the read range of a selection of RFID transponders using alternative readers. In addition to this, a key factor with respect to the implementation of RFID based cattle passports is the ability to write to the tag. As with the read range, the specifications that are provided by the manufacturers of readers are generic. The performance is also strongly dependent upon the type of transponder that is being read/written and the transponder orientation.

3.2 Laboratory Trials

In the following experiments we have examined two readers Impinj SpeedwayR-420 and the Alien x800. In both cases circularly polarised antenna were deployed since this eliminates the possibility of cross polarisation states when used to address a linearly polarised tag.

Sample availability restricted the evaluation of the available transponders and UHF ear tags to the following

- eTattoo
- Invengo
- UPM Web
- UPM Frog 3D
- Avery Dennison AD230, AD828, AD805
- Danish Pig Ear Tag

It should be noted that the Invengo ear tag is different from the series previously excluded from consideration. This tag is a recent addition to the list as it has recently been manufactured to compete with the eTattoo ear tag.

3.2.1 Alien ALR 8800 Reader

Tags: eTattoo, Invengo and Danish pig ear tag

Transponder Orientations: Vertical, horizontal, and at 45 degree from line of sight (LOS) (Table 10)

Table 10: Read ranges measured using the Alien ALR 8800 reader.

Tag name	Read Range (m)	Orientation
eTattoo	3.4	Vertical
Invengo	3.2	
Danish pig tag	0.70	
eTattoo	3.4	Horizontal
Invengo	3.4	
Danish pig tag	0.50	
eTattoo	2.85	45 degree from LOS
Invengo	2.85	
Danish pig tag	0.50	

3.2.1.1 Observations

Reader:

1. Alien x800 reader was difficult to work with in terms of reliability of network connectivity. This is probably due to the fact that the reader is a slightly older version. Newer firmware versions, if they are available, may improve ease of use.
2. This model use separate transmit and receive antennae. Hence a minimum of two antennae is required to make a measurement. Newer versions of the reader are now available that do not have this constraint.

Transponders:

1. Both eTattoo and Invengo have adequate overall performance with an average read range of 3 m.

3.2.2 Impinj SpeedwayR-420 Reader

Tags: eTattoo, Invengo, UPM Web, UPM Frog 3D, AD230

Transponder Orientation: Horizontal and Vertical

Tag name	Read Range (m)	Write Range (m)	Orientation
eTatto	> 5.0	1.0	Horizontal
Invengo	> 5.0	2.0	
UPM Web	4.0	3.0	
UPM Frog 3D	> 5.0	4.0	
Avery Dennison AD230	> 5.0	4.0	
eTattoo	> 5.0	2.0	Vertical
Invengo	4.0	2.0	
UPM Web	> 5.0	4.0	
UPM Frog 3D	> 5.0	5.0	
Avery Dennison AD230	> 5.0	4.0	

3.2.2.1 Observations

Reader:

1. The Impinj SpeedwayR-420 is very easy to configure and use. It also maintains good network connectivity during operation.
2. When compared to Alien ALR 8800 reader, it has shown a noticeable improvement in the read range of same transponders. The read range was in general around 6 to 7 m. While this can be problematic for the present application, appropriate antenna positioning to constrain the read beam and/or transmit power regulation can be used to ensure that transponders outside the read area are not detected.
3. The read range for this reader was considerably greater than for the Alien reader therefore all write experiments were carried out using the Impinj. Write ranges are notably shorter than the read ranges. In the case of the two UHF ear tags recommended for cattle, the Invengo and eTatto tags, the write range is reduced to 1 to 2m. This could be problematic as the ranges are likely to decrease within a practical environment.
4. Write failures at the edge of the write range, can lead to data corruption. For both the Invengo and eTatto tags, it was noted that, at the edge of write range, the reader can partially complete the write operation. This results in a partially complete write which,

while alerted by the reader software there is no mechanism to undo or complete the incomplete write operation automatically. This may be addressable with appropriate write protocol implementations but is presently a concern with both types of tag. The reason for this is that the Write command issued by the reader has four fields: a memory bank address; a pointer to a 16-bit word inside that memory bank; 16 bit data to be written; and a handle to the tag. The transponders memory is logically divided into four memory banks. This means that if we try to change more than one EPC field, we are asking the reader to issue the multiple independent write commands. Some transponders appear to be sophisticated enough to keep track of all write commands and accommodate this. However in accordance with the standard, transponder shall support a write command to change 16-bits of data in one command. Any reader shall give the error message if it does not receive the Write_Success_ACK from the transponder within 20ms, for each write command. Hence we need to be careful about transponders on the edge of range or implement a protocol that only allows one field to be changed at a time.

Transponders:

1. Avery Dennison transponders AD828 and AD 805 were short range transponders (<1 m) and were therefore not further considered.
2. eTattoo, UPM web and UPM Frog 3D have read range of around 5 m, which is more than sufficient for usage of transponders to replace the cattle passports. This may need to be constrained to 3 m in field deployments to avoid the capturing of any unwanted RFID transponders.
3. Both UPM web and UPM Frog 3D outperform the eTattoo in terms of read and write range however these are not currently available in a package form that is compatible with the application needs.
4. The write errors that were introduced in the eTattoo and Invengo ear tags were not repeated in the UPM web or UPM frog 3D transponders. The exact implementation of the write protocol is not wholly understood at present and therefore the possibility that these transponders could be corrupted cannot be excluded.
5. The Danish Pig ear tags were observed to have a performance that is consistent with a near field transponder and were therefore not recommended for further evaluation.

3.3 Farm trials

In order to assess the performance of the UHF ear tags within a representative environment, two sets of farm trials were carried - a beef and a dairy farm trial.

3.4 Beef farm trial

78 steers were tagged with dual UHF and LF tags manufactured by ScotEID. The project team was specifically asked to test these UHF ear tags. The outer packaging of the transponder was a Size 4 ear tag. 64 tags contained a manually modified UPM Frog 3D transponder integrated with the Impinj Monza 4QT silicon. 14 ear tags contained UPM Web transponders. The transponders were glued into one side of the plastic tag. The steers were weighed regularly as part of a separate trial therefore the weighing process linked to the UHF transponder readings provided a convenient means of gathering representative movement data. An Impinj UHF Gen 2 RFID Speedway® Revolution (Impinj, Inc., Seattle, USA) reader with two far-field antennae was used to read the UHF ear tags. The antennae were located above a 76 cm wide raceway leading up to the crush. The first antenna was located at the entrance (Location 1) at a height of 236 cm high. The second antenna was mounted at a distance of 5 m along the raceway at a height of 190 cm (Location 2; Figure 2). An application was written to read the transponders to identify them and then immediately attempt to write. Read/Write performance details were automatically logged.

A further trial was carried out with the antennae mounted on scaffolding and across the holding pen which was traversed by the cattle en route to being weighed. The antennae were positioned centrally at a height of 238 cm and 110 cm apart (115 and 125 cm away from either side of the pen). This configuration was intended to replicate a less constrained measurement case, for example if UHF cattle tags were read en masse as they were moved through an open doorway.

A detailed analysis of the read/write statistics for the trial was hampered by the fact that there were significant levels of transponder failure. One of the 14 UPM Web transponders failed between the 7th of June and the 16th of July. A further transponder showed intermittent operation failing at one session but was functional at subsequent weighing sessions (Table 10). Out of the 78 Frog transponders, nine transponders failed. Figure 3 charts the attrition rate of the transponders over time.

Figure 2: Location 1 and 2 of the antennas for the beef trial.

Table 11: Performance overview of UHF ear tags over a 7 week period.

	ScotEID Size 4 Web transponder	ScotEID Size 4 Frog transponder
Transponder Count	14	64
Failed transponder	1	9
Read failure*	1	1

* Read failure is defined as transponder failed to be read on one or more occasions but was read on subsequent occasions. Failed transponders were not counted as read failure.

The results of this trial indicate clearly that the UHF ear tags were not sufficiently robust to meet the demands of the environment that they were placed in. Transponder failures during the read/write processes were sufficiently regular to obscure any statistical analysis of the read/write process. Thus the results presented here are inconclusive. It is likely that this high rate of attrition is due in the main to the fact that the UHF tags were produced using a hand assembly process (this is discussed later). UHF ear tags manufactured specifically for use in the farm environment could be engineered to be more robust. This illustrates that there is a pressing need for close collaboration between a UHF tag manufacturer and a producer of cattle tags. It is likely that additional protection is required of the UHF ear tag in order to make it robust within this environment. The nature of such protection cannot be determined without a detailed analysis of the failure modes of the ear tags being carried out.

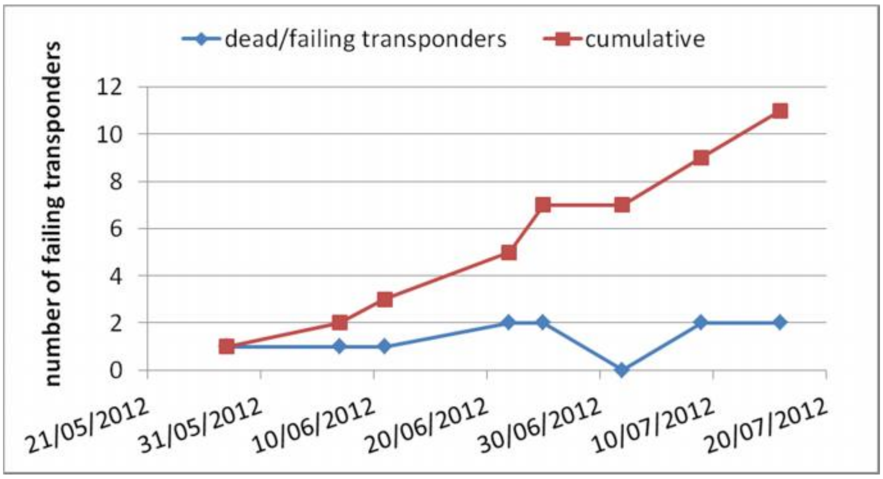

Figure 3: Failing of transponders over time.

3.5 Dairy farm trials

Ninety dairy cows were tagged with UHF ear tags. Three different tags were used with an even spread of 30 ear tags of each type (Table 11).

Table 12: Overview of UHF ear tags used in dairy trial.

Ear tag type	Transponder	Picture
Hana Innosys	Higgs-3 by Alien	
Herdstar Etattoo	Sirit RSI 654 with the NXP silicon	
ScotEID selfmade tags using Size 5 ear tag as outer packaging	full size unmodified Frog 3D with the Impinj Monza 4QT silicon	

An Impinj UHF Gen 2 RFID Speedway® Revolution with two far field antennae was used during this evaluation over two different physical arrangements for the dairy herd.

3.5.1 Trial 1 - Raceway

The antennae were located adjacent to each other at the top of a single raceway in front of the weighing scale (Figure 4). The cows were milked three times daily but not all cows passed through the raceway. Therefore the analysis that we present includes only those cows that were weighed, i.e. that passed through the raceway and therefore passed under the antennae. Table 12 gives an overview of the performance of the different UHF ear tag types. It demonstrates clearly that the reading success rate for each of the three UHF ear tag/transponder types is excellent at over 99 % in all cases.

Figure 4: Location of antennae at Setup 1 for dairy trial.

Table 13: The successful read rate in percent for three different ear tags with integrated UHF transponders.

Tag type	Number of reading attempts	Success rate (%)
Herdstar	1223	99.75
Hana Innosys	1302	99.62
ScotEID-selfmade Size 5	1029	99.61

The above measurements indicate that there was a high degree of reliability within the system. In the case of the Herdstar eTattoo ear tags there were 3 instances where the tag was not read within a total of 1223 readings. A similarly low number of failed attempts was recorded for other UHF ear tags. The reasons for these failures are not known at this stage. It is possible that the antenna position was not optimised and therefore that coverage was not achieved over the entire area of the race. It is also possible that one animal could shield another while passing under the area of the antenna. The measurements were automated and unattended therefore it is not possible to explain the exact cause. Nonetheless the reading percentages are sufficiently high to suggest that a robust system could be designed.

3.5.2 Trial 2 – Holding Area

To test the UHF ear tags under more difficult conditions, the two antennae were positioned at the gateway to the holding area in front of the milking parlour. The antennae were located at a height of 2.7 m in the middle of a 3.5 m gateway, next to each other. The software used for data collection is the Impinj MultiReader software (Impinj, Inc., Seattle, USA; Figure 5).

Figure 5: Antennae above passage way to the milking parlour.

Table 13 shows data taken from 15 milkings over a period of 19 days. One of the Hana ear tags failed after a single reading. It was observed during the experiments that transponder reading could be intermittent. It was also noted that intermittent reading were not be the result of any deficiency in the UHF connection but in fact due to intermittent operation of the tags.

It should be noted that the two recorded read failures for the Herdstar tags belong to one ear tag which was not read on two consecutive days. The highest degree of failure was observed in the Hana tags. In addition to a direct failure, the Hana tags were observed to transmit an incorrect EPC number.

Table 14: Overview of performance of three UHF tag types read during 15 milkings.

	tag type		
	Hana	Herdstar	ScotEID-made Size 5
No. of ear tags	15	16	17
Failed transponder	6	0	0
Read failure*	0	2	0

* Read failures are defined as transponders not read during one or more occasions but read afterwards again.

3.6 Transport trials

3.6.1 Abattoir

A sub-sample of the steers were also recorded during loading en route to the abattoir and during unloading at the abattoir. Due to organisational constraints, two different readers were used for loading and unloading at the abattoir. At the loading bay at the farm, an Impinj reader with custom read/write software was used. Two antennae mounted on scaffolding and facing downwards were placed at the loading bay. At the abattoir, a Motorola reader (Motorola Solutions, Inc., Schaumburg, Illinois, USA) with its original software was used. Two antennae were mounted 253 cm high, facing downwards, at the lairage entrance to the sliding door rails. They were 90 apart from the sides of the entrance and 110 cm were between them.

3.6.1.1 Abattoir Measurements

Six steers were recorded going onto the lorry. Four of the transponders were read. One was known to have already failed[2]. A further transponder was unreadable but

[2] The transponders were observed to degrade over time. Once retrieved from the abattoir a significant number were readable only at close range and some of them were completely dead.

subsequently recovered intermittently. The batch of six consisted of 4 Frog transponders and two UPM Web transponders. The issues occurred only among the four manually modified Frog transponders.

3.6.1.2 Measurements at Abattoir - 2

These trials were hampered by an excessive failure level of the tags for any meaningful information to be determined.

Twenty-two steers were sent to the abattoir at the 2nd Session. Out of the 22, 11 transponders were read as the steers went on the lorry and 10 when they came off the lorry. Table 14 gives an overview over the condition the transponders were in after they were retrieved from the abattoir.

Table 15: Transponders retrieved from the abattoir.

Status	Frog	Web
Working*	19	6
Failed	12	2

*Transponders working but often reading distance reduced or reading is intermittent. Signs of failing evident for most of the transponders.

3.7 Noise Profile Measurements at Abattoir

Measurements were made of the background radio emissions within an abattoir using a portable spectrum analyser (WiSpy 900 Channelizer). An example of these measurements is shown in **Error! Reference source not found.**.

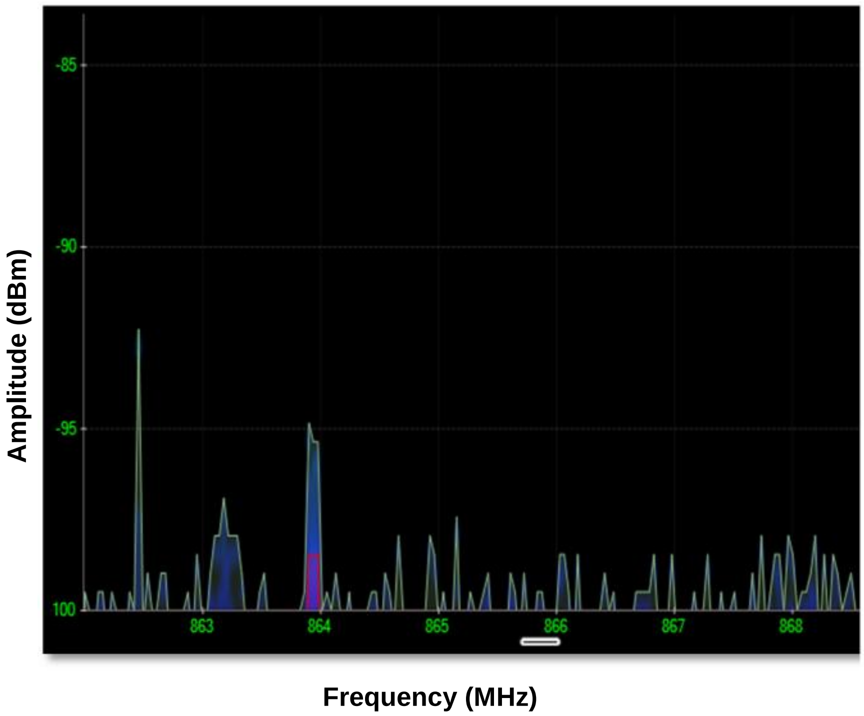

Figure 6: Abattoir Noise Profile.

Although there is evidence of signals present within the range of interest (around 860 MHz), these are at very low levels (10^{-12}W) and would not be able to energise a transponder.

3.7.1 Loading trials

Loading trials were carried out on two different days, once onto a lorry and once onto a trailer. The setup was as described above (Figure 7). During the first trial the steers were read in the morning during weighing and afterwards during loading. During weighing, 60 out of 74 transponders were read and during loading 59 out of 68 transponders were read. The conclusion that was reached again here was that the transponders were failing and hence meaningful data was hard to obtain.

Figure 7: Setup for transport trial.

3.8 Writing capability evaluation

In order to function as a cattle passport, UHF ear tags must support a write capability as well as being able to be read. To assess the performance of writing in a normal operating environment, a routine was written to identify when a tag was in range and then to immediately attempt to write to it. The process continued for as long as the transponder remained in range of the reader. This was carried out between the 6th July and 16th July during the times when the cattle were moved for weighing. Figure 8 shows the number of read and write attempts along with successful writes for all UHF ear tags.

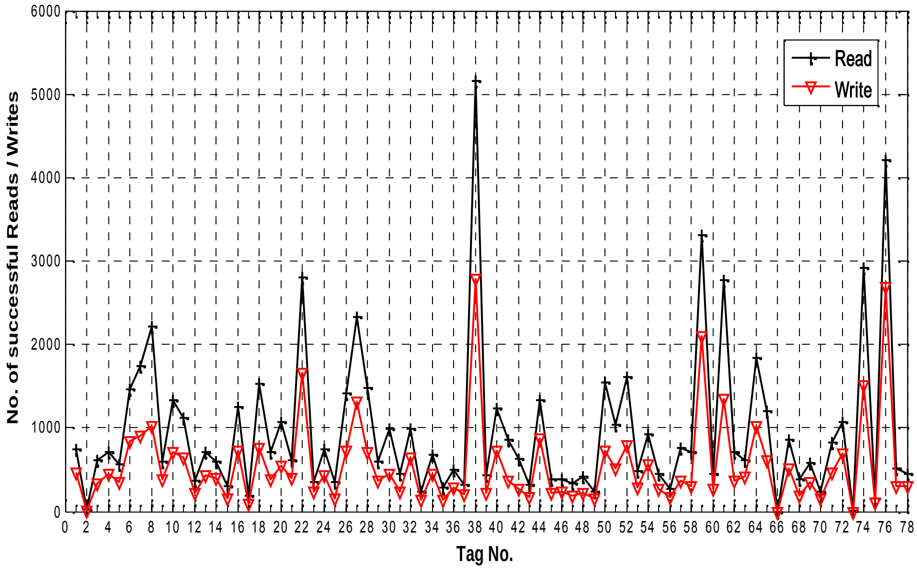

Figure 8: Comparison of average number of successful read and write operations at SRUC Easter Howgate beef farm between June 06, 2012 and July 16, 2012.

Figure presents the average values of the daily read/write for transponders on an individual basis. The daily rates are averaged over 7 weighing trips. The average daily read rate (i.e. the number of reads per weighing session) is around 500. The average read rate for the system was between 18 and 21 reads per second. This means that each animal was in range of a reader for around 25 seconds on average per session. During this time a slightly lower number of successful write events was recorded around 300 per transponder. This is totally consistent with the read/write protocol which establishes that a transponder is in range by reading first before attempting to write to it.

A small number of transponders did not read/write – see for example 'tag 66' and 'tag 73' in Figure 8, as these transponders had failed. More details will be given in relation to this later.

3.9 Transponder Failures

Due to the high incidence of apparent failure of the transponders, a batch were sent for x-ray analysis at SMARTRAC, a leading developer, manufacturer and supplier of RFID transponders and inlays (unpacked transponders).

Figure shows an ear tag manufactured with a WEB Inlay transponder. The dark spot in the centre is the transponder integrated circuit and the silver traces are the antennae and connection tracking.

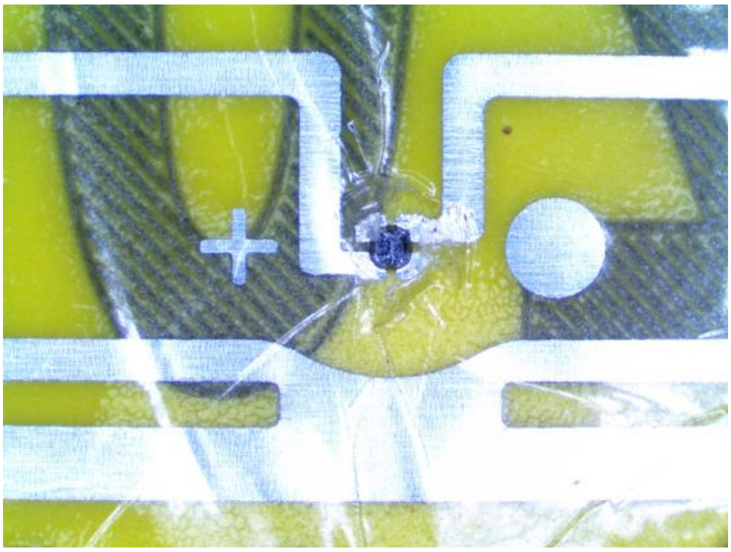

Figure 9: Cattle Ear Tag with Web Inlay (Photo: Smartrac).

Figure 10: Web Inlay Transponder at Higher Magnification (Photo: Smartrac).

Shown at greater magnification in Figure above, the investigation reveals a hairline crack in the connection between the antenna and the microprocessor. This type of failure is likely to result in an intermittent connection to the antenna and/or a high impedance path to the antenna. This would be observed as intermittent operation with reduced read/write range which is consistent with what was noted in the experimental trials.

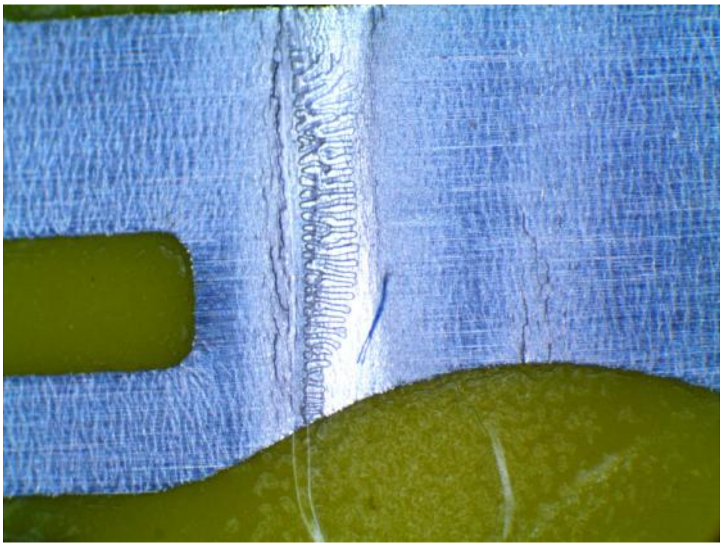

Figure 11: Cracking on the tracking to antenna (Photo: Smartrac).

Additional evidence of cracks developing on the antenna tracking can be seen in Figure 11. This is symptomatic of the transponder failing as a result of mechanical stresses due to bending.

A further photograph under high magnification shown below in Figure 1 shows discoloration around the area of the chip. The reason for this is not known, but may be associated with dielectric breakdown if the antenna had been positioned in the immediate vicinity of a reader to determine if it had completely failed.

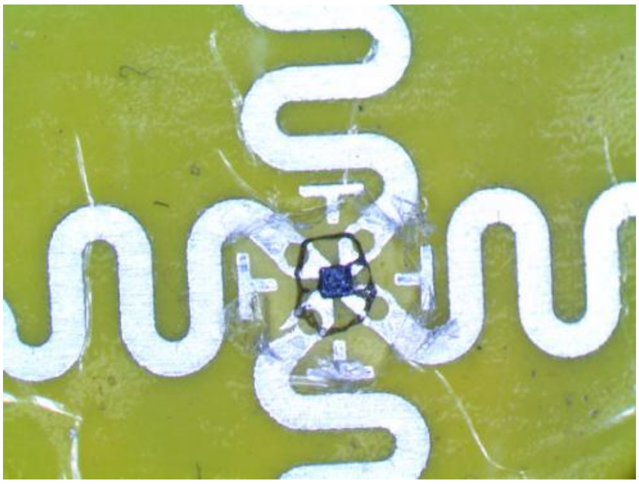

Figure 1: transponder showing discoloration (Photo: Smartrac).

Lack of bonding between the chip and the antenna traces is observable in the above case at higher magnification.

Other examples of mechanical stressing leading to tracking failure of the devices were observed during the course of this examination. While the results are not exhaustive, there is clear evidence that transponders were failing and that physical damage is the cause.

3.10 Field Trial Conclusions

A selection of field examinations of the performance of the UHF RFID tags within representative farm environments has been undertaken. Significant operational issues were encountered during these trials and this has limited some of the analysis that could be undertaken with the measured data. Nonetheless several key observations can be made.

1. The read/write performance of the tags is good and with reasonable care in locating antennae can be robust. Read performances of better than 99.6 % were recorded.
2. The transponders can be read and written to within a timescale that is consistent with the operational requirements. A cow would need to be in range for a fraction of a second in order to complete the operation. This would satisfy the requirements for simultaneous multiple readings.
3. The operational range of the transponder meets the general criteria of the application within a representative environment (around 2 m).
4. The level of background radiation within the frequency band of interest is low and is unlikely to cause interference issues.
5. The environment is harsh and will require close cooperation between ear tag manufacturers and transponder manufacturers to produce a robust UHF tag. Size 4 tags packaged by ScotEID were observed to have a high failure rate. Even commercially available UHF tags were observed to fail. Mechanical failure of the tracking due to stresses associated with UHF tag bending was identified through microscopic investigation.

4 UHF RFID SECURITY

4.1 Threat Model

In order to establish the security requirements of a system it is essential to develop an understanding of the risks or threats that are relevant to the effective operation. In this very simple scenario, we assume that all the various actors within the system, the farmers, hauliers, markets and abattoirs each pose a possible threat. It is also possible that external entities not part of the system could have malicious intent.

The threats that each of the above make in relation to the successful operation of the system are:

- they could add/hide movements
- they could modify movements (time, location)
- they could substitute animals.

External players could force changes on to the system through coercion for some personal gain, or simply as an act of vandalism. Given that there might be a significant financial incentive for performing some of the above, particularly altering movement records, a robust security solution is essential for effective operation.

We make a number of basic assumptions. The first is that because we are using RFID transponders rather than more sophisticated systems like smartcards we can store no confidential data on the device. Also, because RFID transponders do not store state (or at least not in a particularly usable form) then there is no way for the RFID transponder to identify that it is continually being read, or attempted to be read using a device which is trying multiple passwords. Hence they are prone to exhaustive search attacks – simply trying every possible key. This means that we cannot trust the tag.

Transponders also have limited storage – we assume a minimum of 512 bits of user storage. Therefore storage of large amounts of movement data is not feasible. We must also make the assumption that while it may be convenient from a security perspective to have an Internet connection to the reader, this will not always be available. The system should be able to continue to work without such a connection. We do however assume that an Internet connection will be available to every reader at some point.

4.2 Transponders cannot be trusted

Because we cannot trust the transponder to store information, we must validate the data in some other way. To do this we use the reader. The reader validates – signs – the data before storing it on the tag. This is exactly akin to having a trusted person verify a document with a signature. Other trusted readers can check the signature to verify the data. If the data has been altered, the signature will be corrupted and will no longer be valid. However, we must store some information on the tag, because we will not always have a network connection and the system must work without it.

We assume that there is a central database for recording movements, and that that database is provided by a trusted entity. The database provider – presumably a government agency – can also validate readers and assign identities to them. This would involve the installation of custom software on the reader. Most readers allow such applications. This basic scenario is illustrated below in Figure 2.

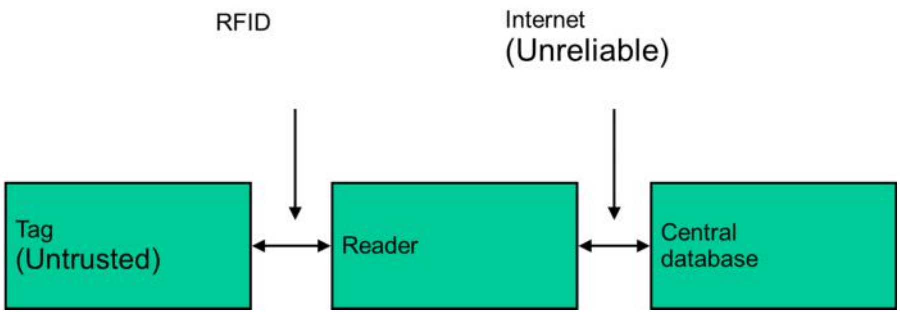

Figure 2: Basic Model of RFID passport system.

It is important to remember that the threats that have been identified involve modifying movement records. Knowing the contents of movement records themselves is not a problem, so there is no need to encrypt the movement record so that that data would remain confidential. Indeed, the ID of the transponder can be read in any case. We therefore store the movement data in the clear rather than trying to encrypt it, which solves some key management problems, and we add a signature to the data to prevent modification.

4.3 Symmetric or Anti-symmetric Security Systems

There are two possible security schemes. Symmetric cryptosystems are so called because they use the same process – i.e., are symmetrical – for both encryption and decryption. The encrypting and decrypting parts of the system share the same key. This means that the key must be stored securely.

An alternative system is an asymmetric system. In this case, the key that is used to encrypt the data is different from the key that is used to decrypt the data. The encrypting key can be made public and published so that anyone that wishes to send data to a recipient can encode it. Only the intended recipient has the decrypting key and so only the recipient is in a position to decode the data. This system is also known as a public key cryptosystem.

In this case we are not using the system to encrypt data but to sign it. In order to use a public key cryptosystem to sign data, the message is taken as enciphered data which the signing entity "decrypts" with their private key. The result is the signature. Since anyone in a public key system can encrypt data, they can "encrypt" the signature and see if it matches the message. If it does match the message, then the signing entity has the capability of reversing the encryption process. Only an entity with the private key is capable of doing this, and therefore the signature must be valid.

An important aspect of public key systems is that the confidential key never leaves the device. A private key can be generated randomly and stored on the device, and the corresponding public key published. Obviously, the public key does not need to be kept secret. This avoids having to distribute confidential keys round the network.

In a system such as the one proposed, symmetric cryptosystems are impractical. The key would have to be shared amongst thousands of devices, and where a key is shared in such a manner it will not remain confidential. This is why we cannot use the transponder password. Either all the transponders would have to have the same password, in which case it would quickly become known, or we would have to manage a key distribution system, which would provide little security in practice because of the number of entities that would be involved.

A disadvantage with asymmetric cryptosystems is that keys are large, which means that signatures are large. The also operate more slowly, but still in the order of milliseconds, and so will not slow down an RFID system.

4.4 Network Failure

Since the system must operate without a network link, movement records must be stored on the tag. If we assume that the transponder only has 512 bits of storage, this has significant implications for storing movements on a transponder – it will be explained that in fact there is only space for one movement record. We assume that readers are able to connect to a central database at least intermittently. Whenever a reader interacts with the transponder it stands the movement record from the transponder to the central database after validating it. It also sends the central database any movement record it writes to the tag. Whenever it creates a movement record, it signs it so that other entities within the system can validate it. This is shown schematically in Figure 3.

The movement record itself consists of the device ID which is stored separately, along with a nine digit – 30 bit – location, a time expressed in days since an epoch – 13 bits – and the sequence number which is implemented each time a new movement record is written to the device. The sequence number consists of seven bits. Finally there is a 20 bit identity for the reader. This allows for 1 million reader IDs. It is possible that this number of reader IDs would exceed this and therefore the number of unique IDs would be exceeded an duplicate IDs used to identify RFID readers. Hence we can consider this ID to be a colour code which identifies a group of readers rather than being a globally unique identifier. If there are more readers than colour codes the signature would have to be validated against each of the identities with the same colour code.

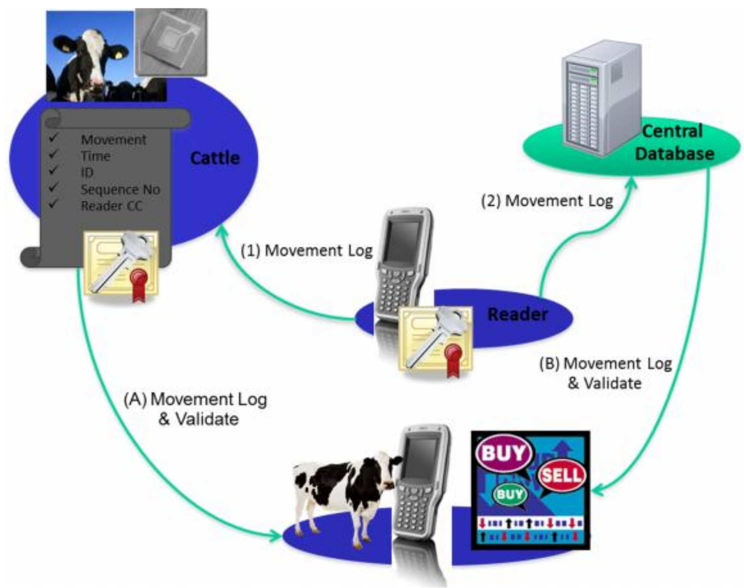

Figure 3: Schematic of Operation

Finally, the movement record contains a 320 bit signature value. 320 bit is required in practice to allow the use of the digital signature scheme. Ideally, for high security applications the signature would be as long as 2048 bits. However, this would require more expensive RFID transponders and 320 bits is considered as being adequate for the present purpose.

4.5 Operation of the system

The reader reads the transponder and the movement record or records. It checks the signature of the records to ensure their validity. If the signatures are valid it caches the records for onward transmission to the database. If the signature is not valid, it communicates this to the central database. If the movement record has to be updated, the reader creates a new record. Rather than signing the record itself, the reader takes a coded version of the record (known as a hash of the record) and signs that. The reason for this is that the hash code is designed to be radically different from the original coded message. This prevents an attack on the signature which may be possible if the item being signed was only to change by a small amount, for example if only the sequence number was to change and the other signatures were known. By using a hash coded version of the original movement, even a small change in the record will produce a very large change in the hash value. The reader sends the new record to the central database, and writes it onto the tag.

Since the movement record is stored on the transponder and sent the central database, two copies exist in the system at all times. If the movement record is not sent to the central database by the reader that creates it for some reason, it will be sent to the database by the next reader to read the tag. If the database received several copies of the same record it ignores them. The transponder will also store the last record to be created along with the signature. This means that the last movement can be verified even without a network connection. In order to verify the signature without a network connection, each reader has to know the public key of other readers in the system. However in a relatively small system this is practical, and as new readers are introduced and authorised by the central database, their key values can be distributed to other readers when the other readers connect to the database in order to send their updates.

The system can be made more robust against network outage by increasing the number of movement records stored on the tag. However, this will require more expensive RFID transponders with larger amounts of user memory.

The system achieves the cryptographic objectives set out for it. Any change to a movement record will render the signature invalid. If a false record is created, it will not be possible to sign that record and validate it. If a reader is stolen, its credentials can be revoked by the central database and other readers informed through the key update process. If the reader is cloned, which would allow the creation of false records, the cloner faces a choice. Either they can leave the network connection functionality intact, in which case the central database would detect the fact that another reader was being used with the same key value and detect the clone, or the cloner could disable network functionality, but the cloned reader would still be detected when the movement records it created were sent on to the central database the next time they were read. There is a trade-off between making the system robust against network outage and the speed detection of cloned devices. However, even with relatively sparse network coverage, given the time it takes to move animals, a cloned reader would still be detected quickly enough to mean that such an attack on the system was not worthwhile.

The proposed system protects movement records. There are two other considerations which must be taken into account. The cryptographic protection applies to the transponder – there must still be a way of binding the transponder to the animal. It is recommended that transponders are tamperproof, or at least tamper evident, and that an initial record be placed on the transponder by a trusted party, for example a vet.

4.6 Kill Codes

If standard product RFID transponders are used, these contain a kill code which will stop the transponder working. The kill code is protected by a 16-bit password, but because the RFID transponder does not store state exhaustive search attacks are possible. To prevent transponders being maliciously killed, the kill password should be set to 0 and made read only.

5 RFID SYSTEMS WITHIN THE LIVESTOCK INDUSTRY

Stockman published a paper in 1948 entitled “Communication by Means of Reflected Power”. He discovered that radio waves could possess enough electromagnetic energy to power a remote transmitter. This discovery was the foundation for the passive transmitters of today [16]. Ruiz-Garcia and Lunadei (2011) [25] review the use of RFID (Radio Frequency Identification) in agriculture and the scale of current usage. Examples of its RFID in livestock farming range from animal identification to body temperature measurement. Banks et al. (2007, p. 28) [16] reported that in 1978 Matt Lezin and Tom

Wilson successfully implanted an RFID transponder under the skin of a dairy cow. Today, the application of implants into animals is used all over the world in different species ranging from wildlife, to livestock and pets. Banks et al. (2007, p. 461) [16] state that one of the largest RFID systems is in the Columbia River basin where transponders have been injected into salmon (*Oncorhynchus)* and steelhead (Oncorhynchus mykiss*)* to follow their life cycle. Over 15 million fish have been tagged and monitored since 1987 [45]. However, for many livestock the use of electronic Identification (EID) is more common in the form of ear tags, although microchips and boluses are also used.

5.1 The rationale behind EID

Electronic identification (EID) is a tool to improve farm management and many farmers started implementing EID in the 1980's [19][17]. With foot and mouth disease and food-related health issues the interest in traceability has increased and governments across the world have started to look into using EID as a mandatory or voluntary means of increasing food security and safety. For some countries, one of the main reasons stated is to ensure traceability, in order to protect or enable export access [17][19][38]. Consumer confidence can also be an important driver [17]. Either way, the main reasons for the use of RFID in livestock are the ability to pinpoint a disease outbreak quickly, to have a record of animal movements to minimize the disease spread and to minimize the number of culls, to improve the compliance with quality assurance and for the monitoring of subsidies [44]. In order to secure traceability, transparency and quality, for example in the meat production chain, it is important to enable the flow of information up and down the supply chain [20]. The author lists the information downstream, such as animal data (ear tag number, age, breed, origin), farm data, feed, medication, transport duration, carcass data, production hygiene of slaughterhouse, and up stream, for example sales information, results of product monitoring, carcass classification and carcass data (pH, muscularity, intramuscular fat) to name just a few.

Another positive aspect of implementing an electronic system is to do with health and safety. To give an idea of the extent to which health and safety issues could be improved if close contact with cattle were to be reduced, Turner et al. (s.a.) looked into fatal and non-fatal injuries from handling beef cattle. The authors reported that of 64 non-fatal injuries to producers, 31.3% were due to kicks or hits to the head. Of 437 injured veterinary surgeons, 41.7 % were due to kicks or hits to the head, and from 44 fatal injuries, 15.9 % were due to kicks or hits to the head.

5.2 Use of EID

Within in the livestock industry EID is generally categorised into two different usage types: (1) Animal identification only (2) Management use

5.2.1 Animal identification

The use of RFID transponders for animal identification as the only purpose is very common in for example pets and horses. In the European Union, EID for sheep is compulsory and many sheep farmers also only use EID for animal identification, which is the minimum mandatory requirement.

In some cases, unfortunately, the requirements do prevent further use. For example, the mandatory microchip for horses cannot be used for automated concentrate feeders because of the short reading distance is inadequate due to the chip size. Farmers or horse owners wishing to implement this facility need to use an additional RFID tag, usually attached to a collar.

5.2.2 Management use

In other areas of the livestock industry there is already a long history of EID use for automation purposes. The electronic identification is the basis of precision livestock farming. It is used for example for identification at concentrate feeders for cattle, pigs, horses and sheep (in ram central testing stations), milking robots for the cattle, and sorting gates for all species.

Apart from the operation of these devices, new uses of management options are being developed. One very interesting approach is the Targeted Selective Treatment (TST). This is a response to increasing anthelmintic resistance. To prolong the efficacy of current anthelmintics, one proposed method is to maintain a parasite population unexposed to a drug which will maintain the genes for susceptibility within the parasite population [21]. With TST, only a proportion of the flock is treated at any one time and the ability to effectively target anthelmintic use relies on the identification of animals which will benefit most from the treatment [21]. Van Wyk [42] suggests that the successful uptake of this worming strategy can only be achieved with the use of automated electronic decision support systems. Stafford et al. [33] reports on a weight based targeted selective treatment of gastrointestinal nematodes in a commercial sheep flock using electronic identification and an automated weighing system. New management approaches like this demonstrate how development into new unexpected areas of use can rapidly occur.

Further applications and benefits can be seen in the “write” capacity. The FARMA project in Greece worked on the deployment of mobile computing, combined with RFID technology and wireless and mobile networking [43]. The authors describe a platform for livestock management based on RFID-enabled mobile devices including the capacity to write important information, such as animal behaviour towards humans, on the tag. Other interesting data that could be stored includes animal movement and medication data [17].

5.3 Technology

There are different RFID options which could be used for animal identification, although the main technology used is low frequency RFID. However, the literature review has shown that there is also an interest in other technological options. Sundermann and Pugh [36] state that the costs of the UHF (Ultra High Frequency) option have fallen 10-fold over the last 5 years for paper label transponders, whereas the cost of the LF (Low Frequency) transponders remained relatively static. The advantage of UHF is that the technology can read multiple transponders and also at a wider distance and speed. Sundermann and Pugh [36] found a near 100% identification rate in drafting races where animals were not constrained to move slowly. This report covered the species sheep, cattle and deer in New Zealand. No discernible difference between ‘wet’ and ‘dry’ tests regarding read rates were found [36]. For comparison, during Phase 1 of the ScotEID project LF tags in sheep showed a reading rate in excess of 96% [26]. Factors decreasing the read rate include broken tags, lost tags, the speed at which reads are attempted, and the orientation of the reader to the tag. However, it should be pointed out that paper based systems cannot be expected to be free of errors. Apart from issues with paper documents being lost, destroyed or unreadable, or ear tags faded and lost, other errors can be also expected. For example, Pollock and Zamora (1983) found rates of misspelling of text of 0.2 %.

Suriyasomboon and Chavananikul investigated low and high frequency (HF) ear tags in pigs in Thailand [37]. The authors also report that there have been tests done using high frequency tags in Japan and China. Reiners et al. also reported trials with HF RFID as a means of identifying piglets at feed troughs [24]. The authors reported a 97.3% identification rate. Another example from the pig industry is the PigTracker project run in Denmark. Swedberg [40] reports that up to 3,000 pigs were tagged with UHF tags and the scientist from this project found that the UHF tags were read at a higher rate than the LF technology. However, it was also stated that the tags were rendered ineffective if they became extremely dirty. Spiessel-Mayr et al. [32] investigated the implementation and validation of a double EID and DNA system for tracing pigs. They looked into the use of

LF transponders implanted into the pigs and then transferring the data onto HF labels at the slaughterhouse in order to trace individual parts of the carcass.

An interesting approach from Thailand is reported by Ketprom et al. looking into the deployment of UHF at a government animal checkpoint along the road and how it can offer services such as automatic data acquisition and verification service through RFID and also an arrival time estimation service [22]. The authors describe that users can identify the key parameters such as the number of movement permits on the Animal Checkpoint Center website and look up information on animals, movement routes, origin and destination. Also interested in a transport based system is the USA [34]. The author describes a pilot solution which deploys wireless, Internet-based mobile communications, RFID, GPS, and GIS in commercial multi-deck livestock transport vehicles. RFID will be read during loading at the origin of shipment and off-loading at the destination. The RFID data will then be linked to GPS-based date/time/location stamps, and wirelessly transmitted, in near–real time, to a third-party information management system [34]. Another report was recently conducted in NZ looking into the use of UHF in deer and sheep farming [17]. Furthermore, the ScotEID pilot is investigating the use of RFID in livestock in Scotland, conducting a large study which is currently in Phase III. UHF equipment will be tested here alongside LF equipment [31].

5.4 Global Use of EID

Many countries are considering implementing or have already implemented a mandatory or voluntary EID system for cattle and/or other species. Table 16 shows a number of these countries and their different approaches. It is interesting to see the spread across the world, even though this list is not exhaustive.

Table 15: Examples of some electronic identification systems used in livestock farming from around the world

Country	Species	Date	Frequency	Voluntary/mandatory	Source
Australia	Cattle	2005	LF (ear tag/ rumen bolus)	Mandatory	Sundermann and Pugh, 2008; Nason, 2011[36]
Brazil	Cattle and water buffalos	Trial	UHF		Swedberg, 2010 [38]
Canada	Cattle	Currently approved tags; UHF research project	LF	Mandatory As of July 1, 2010 all cattle must be tagged with an approved Radio Frequency Identification (RFID) transponder prior to moving from their current location or leaving their farm of origin.	Baerg and Farmer, 2011; [15] RFID World Canada, 2010; [23] Sundermann and Pugh, 2008 [36]
Columbia	Cattle	Start tagging Feb. 2011	LF		S.n. RFID news, 2010 [27]
Denmark	Cattle		LF	Mandatory	Swedberg, 2012 [40]
Denmark	Pigs		UHF		Swedberg, 2012 [40]
Europe	Sheep		LF	Mandatory (not mandatory for sheep which are intended for slaughter within 12 months of age)	Council Regulation (EC) 21/2004 (amended by Commission Regulation (EC) No 759/2009 and Commission Regulation (EC) 506/2010) [18]

Malaysia	Cattle, expansion to e.g. goats possible later	Trial with 80,000 cattle			S.n.,RFID News, 2009 [27]
Malaysia	Pigs		Implant		S.n., RFID News, 2011 [30]
NZ	Cattle Deer	01/07/2012 01/03/2013	LF	Mandatory	Nason, 2011 [23]
NZ	Deer, sheep and cattle	Trials	UHF		Sundermann and Pugh, 2008;[36] Cooke et al., 2010 [17]
Spain	Cattle	300,000 animals as part of trial			Sundermann and Pugh, 2008 [36]
USA (USDA, NAIS)		Aim was 70% of cattle by 2009	LF, + 1 UHF tag approved	Voluntary	Swedberg, 2010 [39]
Uruguay	Cattle	Sept. 2006 pilot started	LF	Mandatory	Swedberg, 2008 [38]

5.5 Use of EID in animal transport and handling

It is essential that accurate records of animal movements, journey structures and routes and animal identification are coupled in order to underpin traceability, improved food safety and animal health and adherence to regulations relating to prescribed limits for journey times, feeding intervals, movement restrictions (e.g. in older cattle) and standstill periods. Such concerns apply to commercial animal transportation and to all research relating to these issues. The European Commission is considering the introduction of EID for cattle and this will play a future role in the monitoring of commercial transport practices throughout the EU. The Commission suggests it would be premature to make electronic identification mandatory throughout the EU but it has proposed that whilst Regulation (EC) No 1750/2000 should be amended to enable electronic identification to be used this should involve a voluntary regime with flexible local interpretation and implementation. Clearly introduction of EID (including UHF systems whose advantages are described below) would allow more accurate monitoring and enforcement of the transport Regulation EC 1/2005 in terms of automatic correlation of individual animals and their origins with specific journey parameters and details particularly if, in future, electronic journey documentation is introduced (e.g. the eAML system currently in use for pigs). Many of the advantages and issues relating electronic identification of cattle have been discussed in the final report of the Food Chain Evaluation Consortium submitted to the European Commission Directorate General for Health and Consumers in 2009. Great Britain has a registered herd of over 8 million cattle spread over 90,000 registered holdings and in 2010 13.5 million movements of cattle were reported. Obviously more automated systems facilitating rapid identification and monitoring of such a large number of animal movements would be extremely valuable. EID is of particular benefit in the animal transport research sector as readers may be installed in multiple locations thus acquiring identification details and any other stores information at a number of locations upon each journey. Thus, readers at the farm and upon the vehicle can record identity, loading time and total loading period (as required under EC 1/2005). The information can be linked to GPS data from the vehicle and an electronic clock. Arrival time for every component of the journey e.g. control posts on long journeys, at the slaughterhouse or other destinations is recorded and then the unloading times and sequences may be recorded by the truck reader and an additional reader at the destination. Information gathered in this way is reliable and accurate and facilitates detailed retrospective analysis of journeys allowing correlation of animal based data with identified individuals and journeys. Frequently research studies on animal transportation will employ electronic monitoring of individual animals e.g. parameters such as heart rate and deep body temperature may be continuously monitored by radio-telemetric devices attached or implanted in to animals several days or weeks before the journey. Data may be collected for an extended period after study journeys or up to the point of death in slaughter animals. It is, of course, vital that such electronically harvested data are directly associated with a specific identity and animal history, health status and production details. The current study is investigating the use of ultra-high frequency transponder technology (UHF). These UHF EID transponders are proposed to possess a number of advantages when compared to LF systems. Read-range is claimed to be much higher (in the order of metres read range). This makes UHF more adaptable to reading identifications under commercial conditions in locations such as auction marts, abattoirs, animal transport vehicles etc. The transponders themselves are capable of storing information as opposed to simply containing a unique identification code. This is possible as data transfer rates of

UHF systems are orders of magnitude faster than LF alternatives. UHF technology implements anti-collision as “standard” and multiple transponders can be read simultaneously which facilitates their use under commercial conditions.

5.6 RFID in cattle management

Low frequency (LF) RFID is already widely used in cattle management. Especially in dairy farming this technology is used for a multitude of applications, such as electronic feeding gates, milking robots, weigh scales etc. However, LF RFID and UHF RFID do not affect each other in any way. In both trials, the beef and the dairy trial, cattle were equipped with LF RFID at the same time as the experiment was running. In the dairy trial, cows were wearing LF RFID button tags as well as UHF ear tags. In the beef trial, we did use dual purpose tags with UHF and LF integrated in one ear tag (Figure 4). The LF RFID was used to operate HOKO feeders. There were no problems reported regarding interference or any other problem due to the two technologies run in parallel in any of the trials. This finding is in accordance to the literature and technical knowledge and the reading rates of the working UHF transponders packaged into plastic ear tags were as expected from literature.

Figure 15: Dual Tag produced by ScotEID for experimental purposes.

6 FOCUS GROUP MEETINGS

6.1 First Meeting

An industry focus group comprising representation from farmers, livestock hauliers, abattoirs, ScotEID, NFUS was held on 16th May 2012 at UA Mart, Stirling. To augment the findings from the initial focus group the research team also conducted a small *ad-hoc* focus group during SRUC's Hill and Mountain Research Centre Open Day at Kirkton and Auchtertyre on 24th August 2012 with representation from QMS, NFUS, SRUC Research and Consulting, and 8 hill suckler cow farmers.

The purpose of these focus groups was to present the research teams objective review of UHF transponder technology and discuss their suitability across the beef supply chain and particularly their potential for replacement of cattle passports.

6.1.1 Key Findings

Discussions among focus groups suggest that the industry would welcome EID in cattle, providing the system is not mandatory. In addition, during the initial phases at least, the industry would prefer that UHF transponder systems were compatible with existing manual systems. This would allow a default position where damaged UHF transponders that were unreadable electronically to be manually read.

The UHF technology was generally well received by all stakeholders who could see the benefits of longer read ranges and the ability to read multiple transponders simultaneously, without having to handle animals. Thus, UHF is considered to have the potential to be an effective management tool particularly within larger farms for - e.g. reading transponders batches of calves being sent to auction / slaughter, etc. without need for over handling of the animals (thus reducing stress and minimising Health and Safety risks for workers). Other on farm benefits identified were the ability to auto-shed animals at target weights knowing their ID and pedigree breeders being able to store details about lineage, etc.

Close handling of animals can lead to stress in the animals and therefore lead to reduced meat quality [46]. It was specifically commented that, being able to read UHF transponders from distance in an automated system would be of significant benefit in both auction marts and abattoirs thus reducing risks to the health and safety of workers and reducing stress in the animal which has the potential to improve meat quality. It was reported that in livestock markets and abattoirs, there is a considerable amount of time (and money) currently spent verifying animal IDs, either manually for cattle or with LF readers in sheep. Human error in reading ear tags leads to problems in marts and abattoirs. Abattoirs in particular undertake a significant degree of cross checking between passports - tags and the BCMS database ascertain that an animal can be slaughtered for the food chain. The marts and abattoirs both specifically mentioned that read range benefits and the ability to read multiple transponders would mean that UHF ear tags would likely to be more beneficial than LF ear tags for their cattle handling.

The usefulness of UHF technology for the haulage sector was discussed. Whilst the principles of mounting readers, etc. on wagons appear sound and would benefit farmers moving cattle on and off farms, the practicalities would be very difficult due to the significant wear and tear all electronics face on livestock wagons, particularly salt damage. As a consequence high maintenance time and costs would likely prohibit their use as hauliers would not bear the cost.

However, the main point raised by farmers was whether the passport information was actually required to be held on the transponder given the unique identifier number could be linked directly to the BCMS database. Thus there remain questions in many farmers' minds regarding the logic for the transponder to contain the passport information if the central (BCMS) database is fully functional. Moreover, the logistics of initially putting cattle passport data on a UHF tag was also a key concern from a farmer's point of view. An example was given:

- It is easiest to tag new born calves (especially in suckler herds compared to dairy where calves are in pens). If the farmer had to register the birth and wait for a UHF ear tag to arrive with passport information then it would mean tagging a calf at maybe 10 days old, which is much less convenient/easy. If the farmer was responsible for coding the transponder then human error could play a major role that may result in cross compliance breaches and loss of SFP, or if wrong sex inputted then at slaughter there could be problems. The solution discussed by the research team would be for the UHF ear tag to be put in without passport data, as per existing ear tags, and the farmer register the number with CTS who would send electronic passport information which could then be securely written to transponder first time it came into contact with reader/writer.

If the passport data was to be added as per the above solution it (a) assumes there is internet connectivity (b) assumes farmer is IT literate, (c) would add another function the farmer has to undertake (with potential for error) and, importantly (c) assumes that all cattle farmers have UHF readers and writers. These concerns lead the industry to be weary of using full passport data in UHF ear tags and if adopted they stressed that protocols for using UHF and uploading information need to be “fool proof”.

Concerns were raised by farmers that if the system is made compulsory then farmers are likely to proportionately face the highest cost and receive the least benefit. Farmers stressed the need for any EID system adopted not to act as a barrier for small cattle producers, as this could potentially force them out of business if it is too complicated. Farmers were surprised that UHF ear tags would likely be cheaper than LF counterparts and when they understood that fixed readers were not essential due to the presence of relatively cheap hand held readers (currently an android phone reader will cost about £199) they saw more potential for the technology. It should be noted however that such approaches would require that readers were authenticated and trusted in order for the system to operate effectively.

One farmer pointed out that many of the older generation of farmers are technophobic and automatically be wary of new technology compared to the younger generation who are more likely to see the benefits of adopting UHF systems. It was observed that a lack of understanding of the workings and capabilities of the UHF technology by the focus group farmers may be prejudicing their views on UHF. Inability to visualise the practical processes and perhaps understand the terminology (e.g. reading/writing to transponders and connection to database, the fact that writing to a transponder is bespoke to specified animals, the fact that reader bandwidth can be narrowed to be more targeted, etc.) are therefore problematic. It is therefore suggested that practical demonstration of these processes (e.g. writing passport information to transponder, reading information from specific animal using hand held reader, reading and writing to multiple animals simultaneously, etc.) would significantly aid farmers to make informed decisions about the technology. ScotEID’s practical demonstrations are a good first step in delivering this.

In contrast to farmers QMS, the livestock markets and abattoir representatives all felt that containing the passport data on the transponder would be beneficial to their business and the wider supply chain. In particular this would remove the need to constantly cross-reference the BCMS database and hence speed up the process of moving cattle through marts and to slaughter without loss in rigour. The key issue here is that the process should be able to facilitate the end user function. A secure system, as described earlier, would still be valid in this context.

The longevity of UHF ear tags/transponders was raised as a concern as farmers do not want to have to regularly replace ear tags due to loss of functionality (may be additional window for errors to be made). It was suggested that the manufacturing process of the UHF ear tag could create stress on the transponder and damage it in the process and studies on the degradation of data and transponder performance ought to be completed in field trials before considering uptake of the technology (it was highlighted that the USDA have approved UHF ear tags [38] that have been tested). Therefore it was suggested that should the UHF technology be introduced then international quality assurance standards be adopted (for both the plastic tag and the transponder components) to ensure the ear tag life is not compromised. There was anecdotal evidence provided by farmers of longevity issues with LF tags from those that know farmers that have used the technology for a period. However, ScotEID reported that an indication was found that read rates decrease with time by about 3 % over 600 days [47]. Farmers reported that somewhere around 12 years durability would be required for cattle.

Whilst it was acknowledged that there are already errors in the manual system, representatives from the farming sector suggested that if UHF EID was to be made compulsory and the read rate of the technology is not 100 % then it could cause cross compliance issues and the Government would have to introduce a degree of flexibility which currently is not particularly evident in the inspection regime. Stakeholders asked that the limiting factors regarding read rates be identified.

Discussion about what other information could be held on the transponder (e.g. veterinary medicine treatments that require standstill). Whilst this could be seen as a benefit there was reticence that information would need to be double stored (e.g. on office paper system and also on transponder - and potentially electronic database). It was highlighted by the research team that the process should be seen by farmers as complimentary and would allow quick (in-field) identification of animals that had previously received treatments. Some farmers also expressed that automatically date stamping cattle movements at critical control points which could then be read and downloaded automatically into BCMS database automatically would be of considerable benefit, particularly regarding time spent on paperwork.

A key message was that if UHF ear tags are to be used then it should be as simple and fool-proof as possible. Whilst the supply chain may like the passport data on a tag (e.g. it would instantly give age, sex, farmer, location, breed, etc.) that could follow carcase through the supply chain for use as a marketing tool without need to access a database it was expressed by some farmers that UHF runs the risk of potentially trying to be too smart and therefore potentially problematic for farmers. Farmers particularly resent external pressure to adopt new technologies unless it performs an essential function and/or eases their daily operations. A potential intermediate route to implementation which considers voluntary adoption may be more appropriate.

There was much discussion in relation to the current cattle movement database and the need for all databases across the UK and EU to be joined up[3]. It was suggested that Interaction with the database is essential for EID to work properly and even with UHF technology the database should be the driver of the UHF ear tags. Thus any cattle information/updates should go to the database first before being written on to the transponder. The UHF technology needs to be field tested to ensure updating/synchronisation with the national database is simple, effective and not a burden to farmers. There would also need to be systems put in place for farmers not connected to the internet/mobile communications that may have to use the technology if adopted on a compulsory basis.

One farmer made a very salient point in that the cattle EID system that Defra adopt may be the overriding factor as farmers trading cross border are likely to be resistant to different system being implemented across UK (see UK Parliaments comments on latest EU bovine EID proposals [48]).

6.1.2 Questions raised

Some farmers questioned the premise that UHFs long read range is better. This related to concerns that the read range may mean that tags on animals you did not want read could be mixed with those you were wanting read. This led onto discussions about the possibilities of narrowing the detection beam and would it be possible to add laser style pointer so you could use very narrow beam to read/write to specific animal. The research team explained that narrowing the UHF detection beam to identify individual animals is possible by reducing the power of the reader.

Farmers wish to know if tissue masking affects the read/write rate of the technology, particularly for young calves at foot. The research team suggested multiple readers in a critical control point would likely overcome this problem, plus very young calves and mothers are invariably transported in a different manner than, for example, steers. Overhead positioning of readers appears best.

As transponders have a limit on the number of movement stamps that can be stored on them, farmers expressed that could be an issue for cattle who are moved more than a dozen times (e.g. show animals). The research team highlighted that as the technology

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[3] It should be noted that under the latest EU proposals the central database is key. "In addition, the proposal recognised the administrative burden involved with animal passports, and the extent to which computerised databases ensured the traceability of domestic movements of cattle, by stipulating that passports would in future be required only for intra-EU trade (though this requirement would also be removed once exchanges of data between national computerised databases had come into force)": http://www.publications.parliament.uk/pa/cm201213/cmselect/cmeuleg/86ii/86ii10.htm

develops transponder memory will likely increase and again discussed how all lifetime movements need not be stored in the transponder, as if movements were recorded then these could be read and synchronised with the national database. This means that movement date stamps could be overwritten in the future. This again highlighted the need for a central database but also for testing any proposed movement date/location stamps and the synchronisation with the central database with vigour. The haulage representative suggested that date and location stamps may lead to difficulties for hauliers due to strict driver and animal transport regulations.

Farmers suggest that the Scottish Government need to consider a bovine EID implementation plan carefully and whatever technology be adopted it be introduced on a voluntary basis initially. This would allow teething problems to be resolved, unforeseen problems overcome, etc.

Some farmers questioned the EU’s commitment to UHF given their focus on LF RFID systems. They stressed that intercommunity beef trade issues may occur if Scotland was the only country to adopt UHF (assuming it is approved). This raised concerns about the additional costs of using dual tags (which the research team estimated to be 30 p extra per ear tag). The stakeholders felt that there was a need for the EU Commission (and Defra) to be invited to see the UHF trails/demonstration in action and to discuss and highlight the potential benefits of UHF and show them alternatives to LF. NFUS said they would be happy to facilitate this. The project field trials aimed to test dual tags.

Some stakeholders felt that there should be a comparison of performance of flat transponders versus pin transponders as producers need to have choices and options.

Stakeholders asked what the costs to the industry would be to convert to UHF or dual systems.

Whilst there is a good understanding of the technological flows the stakeholders suggested that it would be useful to produce a flowchart of the UHF system from a farmer’s engagement perspective. This would help farmers understand the benefits more clearly.

Data integrity was only briefly discussed but was still highlighted as a concern for farmers. In particular the security of encrypted data was essential if passport data was to be stored in a tag to ensure malicious altering of passport data could not occur and render the animal economically worthless. Farmers were also keen to fully understand who could read the data (anyone with a reader?) and could the information they see be limited by any means.

6.2 Second Meeting

An ‘end of project’ focus group took place in the Dingwall and Highland Marts. The focus group was preceded with a practical on farm demonstration of UHF ear tags in cattle on Auchmore Farm, Muir of Ord. The project team would like to express our thanks to Stephen Mackenzie of Auchmore Farm for hosting this practical demonstration. The demonstration and focus group was attended by 9 beef farmers along with representation from ScotEID.

The purpose of this demonstration and focus group was to allow the participants to observe the technology working on a commercial farm where the practicalities of different UHF tags and readers could be observed and discussed. The subsequent focus group discussions centred on the practical farm management uses of the technology, along with opportunities to use the technology for official traceability and identification purposes - an alternative to paper cattle passports.

6.2.1 Key Findings

As with previous groups, this focus group largely welcomed the technology and the potential benefits that bovine EID may bring to their herd management. In particular the greater read range of the UHF ear tags (compared to visual inspection and LF), the ability to store more data on the transponder, to read and write data to the transponder, to read multiple animals at once, and the ability for handheld readers to be adjusted to narrow the beam to identify single animals in a group were all seen as positives for the technology.

There was some resistance to bovine EID *per se*, and comments were made to the effect that there would be very limited benefit to individual farmers (particularly those with small herds) in adopting the technology. The concern was that additional technology would simply add a further level of bureaucracy and be an additional cost to the primary producer. Some within the group felt that, even if there was no benefit to the primary producer, given that the cost was minimal (an additional £0.40) it would still be worthwhile using the technology for the benefit of the wider supply chain, including auction marts, finishers, abattoirs and retailers. This led to an interesting discussion as to why should the primary producer bear a cost while the benefit was in the main to others in the sector. There was an indication that an underlying fear of the technology becoming mandatory leads to a resistance to accepting the technology and its potential benefits.

One farmer expressed the view that beef farmers need to embrace this new technology and help its development so that the industry can influence policy makers within Scotland and Europe from an informed position, rather than wait until a technology (i.e. LF RFID) is enforced on them in a top-down manner, as occurred with sheep.

The suckler farmers that made up the majority of the group were strongly against any mandatory adoption of EID in cattle (using LF or UHF technology) preferring a voluntary adoption that would enable the “early adopters” to showcase the benefits of UHF RFID in cattle to the wider industry. It should however be noted that a beef finisher amongst the group made a very valid point that a mandatory adoption of UHF EID would be the best method for the finishing sector to be able to effectively use the technology as a herd management tool since, with voluntary EID, finishers will likely be buying in calves with different tag types (LF, UHF and non-RFID tags). Consequently benefits from UHF would be restricted.

A practical demonstration showed how simple it was to put cattle passport data onto a transponder using a handheld integrated barcode scanner and UHF reader/writer. This led to the discussion about whether it was sensible for the actual passport data to be stored on the ear tag. Some farmers felt that it would be beneficial to have all the passport information on the transponder if the technology was to be adopted, whereas others felt that purely identifying each animal’s unique ID would be required, with farm management software linking to passport data. The latter position is probably the only realistic approach given that space will be limited if the system is to be securely implemented and furthermore, the system will require a robust central repository in order to protect against tag failure. As with the previous focus groups, the logistics of putting the cattle passport data onto the UHF ear tags was an issue raised by farmers. If the passport data was not required on the ear tag then the whole process becomes simpler and it is more likely that farmers would adopt the technology. Cattle from those farms could then be used downstream. However, if passport data was a mandatory requirement on the UHF ear tags then that would put a significant burden onto farmers, meaning they would all need to invest in readers to (a) write the data onto the transponders once the passport information had been released by BCMS, and (b) check that the information written is accurate to ensure the farmer is not penalised due to human or technological errors.

During the practical demonstration of the handheld reader the importance of being able to alter the range, by reducing the strength of the reader (the demonstration showed this in action), was pointed out. The farmers could see the practical benefits of reading calves and cows from a distance but wanted assurances that you could read a specific individual at close range without fear of picking up other animals, etc. Another important point made was that the handheld readers would have to be robust enough for day-to-day life on a farm and must be able to withstand being dropped, getting wet or covered in mud/slurry, etc. Some raised concerns that the readers on demonstration would not be robust enough and that reader manufacturers should be consulted about designing “rugged” versions.

The physical design of the UHF ear tags was discussed as there was a feeling that the USDA approved eTattoo ear tag is too long in the neck and too big for calves (but would be good for cows) compared to the smaller Zee ear tags, widely used at Scottish farms, which it was felt would be ideal for calves.

The farmers expressed that for adoption of any technology there has to be benefits that outweigh the adoption costs. Therefore, since they are unlikely to be the biggest beneficiaries of putting statutory passport information on the ear tags the technology has to be sold to beef (and dairy) farmers as an important herd management tool. Some of the herd management benefits identified by the group include:

- With a UHF handheld reader and integrated barcode scanner, the farmer is able to barcode scan medicines, record the animals treated and then download that information to the medicines book / farm management software
- Standstill dates could be written onto the transponders to ensure animals are not moved off the holding in breach of the regulations
- Calving date could be written onto the transponder
- Using a fixed reader to monitor calves entering a creep feeder enables the farmer to establish an alert system (e.g. by light/or SMS) if one fails to enter in a specified time period
- Using a fixed reader to monitor the frequency of cows taking water at water-trough throughout the day. An alert could be generated if a cow is drinking too frequently or not enough (both may be signs of illness).
- UHF tags would speed up cross compliance inspections considerably (especially for large herds) if animals can be read in batches with handheld reader / or using fixed reader at a fixed point (e.g. a gate, shed entrance, race, etc.)
- Whether a cow should be culled or sold once dry (e.g. frequent mastitis, calving difficulties, temperament, etc.)
- Improved time efficiency when weighing calves, meaning more frequent weighing can be undertaken and therefore improve feed efficiency and revenue.
- Improved time efficiency and elimination of human error during veterinary tests for BVD and TB, etc. (there could be an added benefit if the blood vial barcodes can also be scanned alongside the UHF ear tag to ensure accurate matching of cattle and blood sample)

- The ability to read an entire batch without putting it through a crush is a big benefit in terms of time, but also reduces the animal's stress when animals are moved.

6.2.2 Questions raised

A number of questions were raised by the focus group – for example, could voluntary adoption of the UHF technology be incentivised by the wider beef supply chain? If auction marts offered reduced commission rates and finishers and abattoirs offered a small premium for cattle with UHF RFID containing the passport data (or at least each animal's unique ID which can be electronically matched to the central database) then this may facilitate more rapid uptake of the technology by the suckler breeders. Once farmers adopted the UHF technology they may start to identify and investigate herd management benefits that the technology may bring, as has been seen in the sheep sector following mandatory EID.

Farmers also raised a concern about the potential for another technology to displace UHF. However, our view is that this is unlikely given that UHF is widely used throughout other industrial, distribution and retail sectors. The scale of use of UHF globally means that the technology is constantly improving (e.g. transponder memory capacity is improving) whilst costs are continually falling (e.g. for the transponders, antennae and readers, etc.).

A concern was also raised in relation to tag retention for UHF ear tags. Tag retention is an important consideration for all cattle farmers as it is time consuming and often awkward to replace broken or missing ear tags depending on location of the animals. ScotEID reported that tag retention was much the same as standard plastic ear tags, with Stephen Mackenzie reporting some UHF RFID tags were still in animals and functioning after 5 years. The project team reported that there were little problems during the short trials with ear tag retention and felt that the longevity of the UHF ear tags is more of an issue in the long run.

Farmers were keen for assurances that if they adopted the technology that they would not have to frequently replace dead tags. The longevity of UHF cattle ear tags is largely unknown, due to the relative infancy of the use of the technology in this environment. However, improvements are constantly being made to the design and production of these UHF ear tags as more countries run trials and/or approve UHF ear tags for commercial use. The project team discussed how there had been a problem with the first batch of

UHF ear tags trialled due to the design causing the antennas to crack or break away from the chip. However, the two of the UHF ear tag types used in the trials did not show any signs of breakage throughout the trial period. It is imperative therefore that transponder and ear tag manufacturers collaborate effectively to produce a robust component.

A question was raised with respect to the cost implications and how UHF compares with LF. Farmers are cost conscious, particularly where they have invested in LF readers for sheep flocks. Ironically at this moment the fixed readers are cheaper than the handheld readers and ScotEID reported fixed readers to currently retail at about £800. One benefit from UHF over LF is that each reader can have multiple antennas (up to 8 ports) meaning only a single computer is required for multiple fixed antennas. This is not the situation for LF where each antenna must be connected to a computer, therefore making it more expensive (particularly in places like auction marts / abattoirs and large farms). Some farmers felt that the handheld readers were not prohibitively expensive and could see the benefits very quickly outweighing the costs, particularly if support was obtained through SRDP's Land Manager's Options, Option 4: Modernisation through electronic data management for Agriculture.[4]

During the recruitment of farmers to the focus groups a couple of farms explained that they had recently invested quite a lot of money in LF RFID systems for cattle and wondered about the compatibility. Unfortunately the technologies are different, meaning in such cases new equipment would have to be purchased if UHF was to be adopted.

7 REPORT SUMMARY AND RECOMMENDATIONS

This study has examined the issues associated with the adoption of UHF transponders within the beef and dairy supply chain, primarily as a means of replacing cattle passports. It is established that there are a wide variety of UHF RFID transponders that have technical capability to perform the functions of animal tracking and the dual purpose of an animal passport. These tags are manufactured to global specific standards and consequently there is little to choose between them in terms of technical specification. We have evaluated experimentally a subsection of the tags that were considered appropriate according to the following:

- size (such that they are not intrusive);

[4] Support is available for 40% of the actual cost up to a maximum of £1000 and support for individuals for up to 40% of their share of the actual cost of equipment and software, up to £1000, is available when the purchase is made in collaboration with one or more individual businesses.

- polarisation orientation (to minimise angular sensitivity)
- user memory availability (to be compatible with a passport).

From the above, the range of available transponders was narrowed to around 6 for a first pass evaluation. This is not an exhaustive list but will be representative of the performance that is generally available. Preliminary evaluation of these tags (in a laboratory) has been undertaken. This has identified a range of tags the Herdstar eTatto, Invengo, UPM Web, UPM Frog 3D and Avery Dennison AD203, all of which can be read at ranges appropriate for cattle passports. However within those only the UPM transponders were writeable at ranges in excess of 2 m. Furthermore, it was demonstrated that the eTattoo and the Invengo tags could be corrupted during the write process at the edge of their range. This is due to the transponder that they contain.

A wide range of readers are available on the open market. There are a limited number of manufacturers and all of them produce readers that conform on paper to standard specifications. With this in mind, two readers have been selected for potential evaluation. These are those manufactured by Impinj and Alien. These readers will therefore be used in the experimental evaluation of the above tags. Preliminary assessment of these has shown the Impinj reader to be more user friendly however it should be noted that the Alien reader used in the present set of experiments is several years old not necessarily representative of current reader performance.

A previous review into UHF tags undertaken by ScotEID had evaluated a subset of the tags that are selected above. This study used a reader manufactured by Deister [14]. This is different from the readers that we have selected and therefore compliments the measurements made here. In broad terms the results are comparable and demonstrate that read ranges appropriate for cattle monitoring are obtainable. No measurements of write range had been previously available.

The UHF ear tags tested in the beef trial were produced by ScotEID and had limited longevity. The writing performance of the functioning transponders was good and there are was sufficient for livestock management and as cattle passport replacement. The UHF ear tags in the dairy trial showed a read rate of over 99 % for all three types of UHF tags. The Herdstar eTattoo tag and a second variant of ScotEID tag (Size 5) performed well. The Hana tag indicated was prone to failure and transmitted erroneous EPC numbers. This could cause confusion in animal identification.

- Read rates are acceptable, however, antenna locations and number of antennae are important for high read rates.

- Transponder longevity can be an issue. However, if transponder manufacturers and ear tag manufacturers work together, it should not be a problem. Herdstar is an example for a well working UHF ear tag.
- A central trusted data base that regulates access and validates tag write procedures is essential for delivering a secure system.
- Larger memory is desired, for security and management.
- The technology is not well understood within the farming sector and a significant amount of education will be required to enable farmers to make informed judgements.

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