

**Investigation into the Effect of
Acoustic/Mechanical Interference
on Radio Frequency Identity (RFID)
Systems used to Identify Animals
Electronically**

(copy 1 of 2)

for

Scottish Government

Document number 2528CR1

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Change History Sheet

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Appendix 1 Desk Based Research – Report 2433CR1

Appendix 2 Study of Acoustic Interference – Report B179CR1

Appendix 3 Study of Vibration Interference – Report 100802TR1

Appendix 4 Study of Modulation/Metallic Interference – Report 2527CR1

List of terms and abbreviations

AC	Alternating Current
CENELEC	Comité Européen de Normalisation Electrotechnique
CISPR	Comité International Spécial des Perturbations Radioélectriques
COTS	Commercial Off The Shelf
DC	Direct Current
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EID	Electronic Identification
EUT	Equipment Under Test
FAR	Full Anechoic Room
FFT	Fast Fourier Transform
g	Acceleration Due to Gravity (a Constant)
OATS	Open Area Test Site
PC	Personal Computer
RF	Radio Frequency
RFID	Radio Frequency Identification
RMS	Root mean square
SG	Scottish Government
UKAS	United Kingdom Accreditation Service
YES	York EMC Services (2007) Ltd

Executive summary

The Scottish Government have commissioned York EMC Services (2007) Ltd to evaluate the effect that acoustic and mechanical interference has on electronic identification (EID) reader performance.

Desk based research was performed in order to identify any existing work that has been performed in this area and to gain technical information on the methods of operation of EID tag reading systems. This research showed that work performed in this area is extremely limited in both academic research and detailed studies.

Various EID reader manufacturers and distributors were approached in order to participate in this study in order to provide readers for testing and characterisation. EID readers were extremely difficult to be procured and with much effort, a total of 4 units were obtained for this study.

Site surveys for the characterisation of mechanical and acoustic interferences in auctions marts and abattoirs were performed in order to derive suitable test levels for laboratory testing. A total number of four sites were surveyed. The results show that the mechanical environment in these locations consists of random vibration of moderate level with short duration, but frequent bursts of high acceleration shocks. The acoustic environment consists of short duration, high intensity sounds that have considerable frequency content, extending to the ultrasonic range.

Laboratory testing for the acoustic study shows that loud sounds do affect tag readers such that their performance is degraded or completely inhibited. The study also shows that it is possible to design EID systems that are immune to acoustic interference as measured in auctions marts and abattoirs.

Laboratory testing for the vibration study shows that the all tested samples were affected by the vibration and shocks during the testing, with degradation varying substantially between samples.

All EID readers tested recovered fully and automatically on removal of both acoustic and vibration interference.

Laboratory testing for the study of the performance of the EID readers when used in non-metallic and metallic environment shows that the magnetic field amplitude can be reduced from 30% to 80% depending on the reader and demonstrates that metallic structures such as tubular fencing or kiosks (such as that used in the study) do greatly impact on the reading distance of the EID readers. The study demonstrates both experimentally and theoretically that the presence of metal has little effect on the quality factor of the EID system. It is also shown that EID readers have a limitation on the maximum read of individual tags at any pass, to a maximum of 6 in the EID readers tested.

Finally, the results obtained during the research could not be developed into a Code of Practice due to the build quality standard of the commercially available equipment that was under investigation for the use of EID systems in markets and abattoirs. Further research will be required to validate engineering concepts in order to propose suitable mitigation measures.

1 Conclusions of the Overall Study

The following conclusions can be drawn based on the results obtained during this project:

1.1 Desk Based Research – Report 2433CR1 – Appendix 1

The report, document number 2433CR1 (Appendix 1) summarises the findings of a desk based research into the subject of acoustic and mechanical vibration and other physical effects on the performance of electronic ID tagging in animals. As detailed in the report, the work performed in this area is extremely limited in both academic research and detailed studies. The limited information available clearly identify that metallic structures affect the functional operation of RFID systems, but without providing any detailed explanation.

1.2 Procurement of RFID Systems for the Study

Various manufacturers and distributors were approached to participate in this study. Only a total numbers of 4 samples could be procured for this study and these samples were obtained from 2 independent distributor/manufacturers.

Test samples were extremely difficult to be procured and manufacturers and distributors were, in general, not interested to participate with this work, despite the clear potential benefits (testing and characterisation of their units, gained experience...).

1.3 Study of Acoustic Interference – Report B179CR1 – Appendix 2

Acoustic conditions in auction markets and abattoirs give rise to short duration bursts of high intensity sound, resulting from steel gates and impacts against steel barriers. This has considerable high frequency content, extending into the ultrasonic range.

Loud sounds were found to affect tag reader systems such that their performance is degraded or completely inhibited. Samples 3 and 4 were affected by sound interference during testing, for both frequency swept measurements (Frequency domain) and impulse measurements (time domain).

For samples 3 and 4, susceptibility occurred at low frequencies, in the order of a few hundred Hertz, and with relatively high levels of sound applied, and also between 25 and 40kHz with 0dBPa applied, and at 80kHz at a relatively low level of –20dBPa. For both these samples, high levels of degradation of performance were measured (ranging from 25 % to 94%).

It is possible to manufacture tag reader systems such that they are immune to sounds of the levels likely to be encountered in auction markets and abattoirs. Samples 1 and 2 were not affected by any levels of sound applied during testing including some additional extra high levels at spot frequencies.

1.4 Study of Vibration Interference – Report 100802TR1 – Appendix 3

The mechanical environment in auction markets and abattoirs consists of random vibration of a moderate level with short duration, but frequent, bursts of high acceleration shock, resulting from steel gates, impacts against steel barriers, operation of machinery and animal movements.

The levels of vibration measured varied from site to site but were typically in the range between 2g and 10g RMS, although at times levels considerably in excess of this could be experienced for short periods.

The high level shocks present were typically of short duration (<1ms) but could have amplitudes from 50g to as high as 500g dependent upon the mechanical configuration of the site.

The variation between sites of the level of mechanical vibration and shock measured indicate that considerable care will need to be taken in selecting a location in which to install RFID reader systems.

It is possible for vibration and shock to affect tag reader systems such that their performance is degraded or completely inhibited. All samples were affected by vibration and shock during testing, with degradation varying substantially between samples. The level of vibration at which these effects start to occur is typically less than 1g RMS, and so is well within the envelope of conditions likely to be encountered in auction markets and abattoirs.

All samples tested were sensitive to shocks of the type found in auction marts and abattoirs and exhibited degraded performance under these conditions, ranging from 88% to 64% of full performance.

All readers tested recovered fully and automatically on removal of vibration and shock.

There was significant variation in performance between the four reader systems tested. The best, Sample 1, operated at levels as much as ten times higher than the levels at which the other readers ceased to function.

The readers have clear sensitivity to stimulation of their inherent mechanical modes of vibration. Within the scope of this study it was not possible to fully explore the nature of this sensitivity but further work in this area would help in understanding the potential problems that will be faced by trying to install and operate these kinds of systems in environments such as abattoirs and auction markets.

The site measurements made demonstrate that random vibration is a more realistic form of stimulus to be used to validate operational performance of reader systems than sinusoidal vibration.

Three of the readers were extremely sensitive to the proximity of metal that could readily disrupt their function. This sensitivity was not confined to magnetic materials as they appeared also to be affected by materials such as aluminium alloy.

1.5 Study of Modulation/Metallic Interference – Report 2527CR1 – Appendix 4

Four RFID systems have been assessed for their physical performance when used in a non-metallic and metallic environment. The following specific studies have been performed:

1. Characterisation of the magnetic field distribution in X, Y and Z-axes (magnetic field axes)
2. The maximum distance for tag readability
3. The bandwidth at the magnetic field frequency (134.2kHz) and the derivation of its Q-factor
4. The effect of the number of tags within the field at any one time.

The first study shows that each case, the magnetic field amplitude of all four samples is affected when the antenna is mounted on the kiosk. Sample 1 magnetic field amplitude was reduced by approximately 30%, sample 2 by approximately 40%, sample 3 by 70 to 80% and finally sample 4 by 70 to 80%.

In addition, all of the three-dimensional plots indicate distortion of the field to some extent due to the presence of the metal kiosk.

The measurements show that there are slight variations in the magnetic field around the centre line but generally the field produced by each of the sample appears quite planar within the limited area of measurement, thus contributing to consistent tag reading within that area.

The second study shows that the effect of the kiosk on the tag read distance was significant in all samples but extreme in Samples 3 and 4 to the extent that no significant read distance could be obtained.

The third study shows that the presence of metal has little effect to the Q factor of the RFID system. Theoretical analysis supports this conclusion.

The fourth study shows that for Sample 1 and 2, there appears to be a maximum read number of 6 individual tags at any pass. The effect of the kiosk was to reduce the ability of the antennae to read the tags primarily due to the reduction in the amplitude of the magnetic field.

Similarly with Samples 3 and 4, there appears to be a maximum read number of 4 individual tags at any pass. The kiosk reduced the amplitude of the magnetic field to such an extent that no read was obtainable at the test distance.

1.6 Code of Practice

During the meeting between the representative of York EMC Services (2007) Ltd (YES Ltd) and Scottish Government on 20th March 2008, it was agreed by the project steering committee that the results obtained during the research could not be developed into a Code of Practice for the use of EID systems in markets and abattoirs as specified in the contract.

The results required to develop a Code of Practice were not obtained due to the build quality standard of the commercially available equipment that was under investigation, and not in any way related to the scientific quality of the work carried out by YES Ltd. In light of this the steering committee agreed that YES Ltd should not be bound to produce a Code of Practice.

Further research will be required to validate engineering concepts in order to propose suitable mitigation measures.

Appendix 1 Desk Based Research – Report 2433CR1

**Report on Research and Identification of
Relevant Work Related to Project
CR/2007/01**

(copy 1 of 2)

for

The Scottish Government

Document number 2433CR1

Project number 4046

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LIST OF TERMS AND ABBREVIATIONS

CE	European Community
CENELEC	Comité Européen de Normalisation Electrotechnique
CISPR	Comité International Spécial des Perturbations Radioélectriques
DEFRA	Department for Environment Food and Rural Affairs
DSL	Digital Subscriber Line
DTI	Department of Trade and Industry
ECT	Electronic Cattle Traceability
EDT	Electronic Data Transfer
EID	Electronic Identification
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test
FCC	Federal Communication Commission
GTEM	Gigahertz Transverse Electromagnetic
FDX	Full Duplex
HDX	Half Duplex
IEC	International Electrotechnical Committee
IEE	Institute of Electrical Engineers
IEEE	Institute of Electrical and Electronic Engineers
ITE	Information Technology Equipment
ITT	Invitation To Tender
JRC	Joint Research Council
LVD	Low Voltage Directive
OATS	Open Area Test Site
OFCOM	Office of Communications

1 INTRODUCTION

This document forms the report of a desk based research into the subject of acoustic and mechanical vibration and other physical effects on the performance of electronic ID tagging in animals. This report provides a focussed summary of the key findings performed as part of this desk based research.

The desk based research is aimed to identify existing work that has been performed in this area and to gain technical information on the methods of operation of tags readings systems. The knowledge gained as part of this research will be used to define test types and methods that will be used to investigate tag reading operations under acoustics and mechanical interference.

The potential physical sources of interferences were considered independently and the desk based research aimed the answer the questions as follows:

Acoustic: Can acoustic interference affect the functional operation of EID systems and if so under which specific conditions (local environment, design features...).

Mechanical: Can mechanical vibrations due to the movement of livestock and/or mechanical resonance of metallic structures affect the functional operations of EID systems.

Modulation/metallic: Can metallic structures present in the local environment affect the functional operation of the EID systems and which aspect of the EID system is being affected.

2 METHODOLOGY

The desk based research was performed in three distinct phases as described below:

Search for information relevant to the project: The search for information primarily focussed on findings published in engineering/scientific articles relevant to the project. The search was performed using an access management system (Athens) developed by Eduserv, which provides access to a wide variety engineering and scientific journals, reports and standards. Furthermore, a web based research was also performed using typical search engines like Google and Yahoo.

Review and analysis of the information: A review and detailed analysis of the key relevant articles, reports and standards was then performed. In a large number of cases, references of the reviewed articles led to further articles thus providing a more in depth analysis.

Reporting of the relevant information, this is provided in this document.

3 UNDERSTANDING RFID SYSTEMS – BASICS

3.1 Working principles (Extract of [1])

An inductively coupled transponder comprises an electronic data-carrying device, usually a single microchip, and a large area coil that functions as an antenna. Inductively coupled transponders are almost always operated passively. This means that all the energy needed for the operation of the microchip has to be provided by the reader (Figure 1). For this purpose, the reader's antenna coil generates a strong, high frequency electromagnetic field, which penetrates the cross-section of the coil area and the area around the coil. Because the wavelength of the frequency range used (<135kHz: 2400m) is several times greater than the distance between the reader's antenna and the transponder, the electromagnetic field may be treated as a simple magnetic alternating field with regard to the distance between transponder and antenna. A small part of the emitted field penetrates the antenna coil of the transponder, which is some distance away from the coil of the reader.

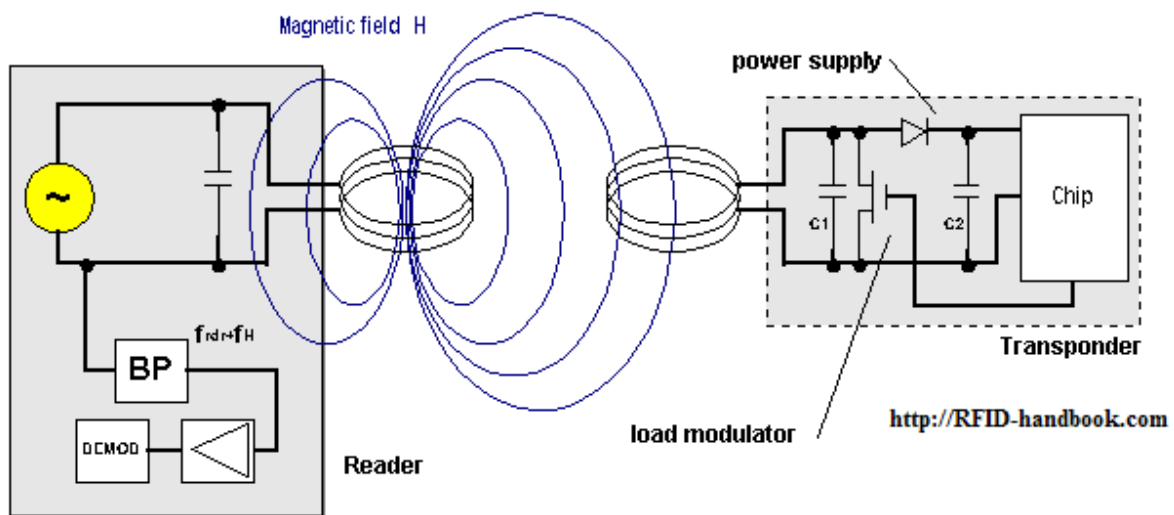


Figure 1: Power supply to an inductively coupled transponder from the energy of the magnetic alternating field generated by the reader

A voltage U_i is generated in the transponder's antenna coil by inductance. This voltage is rectified and serves as the power supply for the data-carrying device (microchip). A capacitor C_r is connected in parallel with the reader's antenna coil, the capacitance of this capacitor being selected such that it works with the coil inductance of the antenna coil to form a parallel resonant circuit with a resonant frequency that corresponds with the transmission frequency of the reader.

Very high currents are generated in the antenna coil of the reader by resonance step-up in the parallel resonant circuit, which can be used to generate the required field strengths for the operation of the remote transponder. The antenna coil of the transponder and the capacitor C_1 form a resonant circuit tuned to the transmission frequency of the reader. The voltage U at the transponder coil reaches a maximum due to resonance step-up in the parallel resonant circuit. The efficiency of power

transfer between the antenna coil of the reader and the transponder is proportional to the operating frequency f , the number of windings n , the area A enclosed by the transponder coil, the angle of the two coils relative to each other and the distance between the two coils. As frequency f increases, the required coil inductance of the transponder coil, and thus the number of windings n decreases (135kHz: typical 100–1000 windings, 13.56MHz: typical 3–10 windings).

3.2 Key functional parameters/variant

The information in this sub section is derived from [2].

3.2.1 Antenna performance

The reading range of an antenna is dependent on many variables. These include, for example;

- the quality of the earth ground connection
- the antenna size
- the tag size
- the tag's orientation with respect to the transmitting antenna
- the antenna location with respect to other materials
- the ambient electrical and magnetic noise within the band of interest

3.2.2 Low frequency transmission

Classical theory states that radio transmission is comprised of a combination of an electrostatic field and a magnetic field component. These fields are depicted as orthogonal vectors that propagate a transverse electromagnetic (TEM) disturbance that can be received at a distance from the source. Although Low Frequency RFID Tags are generating TEM waves their magnetic component becomes most the significant source of energy transfer for the link of the near field.

As the energy is coupled from the Radio Frequency Module (RFM) to the antenna, magnetic flux waves extend into the space surrounding the coils. Similar to a transformer coupling energy from its primary winding to its secondary winding, the expanding field from the transmitter antenna coils can induce a voltage in a second coil in its proximity, such as an antenna coil within an RFID tag present in the field. The induced voltage in the tag's coil is utilized to charge a capacitor. Acting as a temporary battery, the capacitor then powers a chip that provides the data and intelligent protocol for transponding back to the RFM.

The ratio of turns between the RFM antenna coil and the RFID transponder coil determines the maximum voltage that can be induced by this transformer action. By increasing the turns ratio of the antennas it may increase the induced voltage linking in one direction but decreases the induced voltage linking in the opposite direction. Just

adding more turns to the RFM antenna does not increase performance. In fact it may decrease the performance.

3.2.3 Antenna size

Reading performance does not necessarily increase when using a larger antenna. Although larger loops tend to yield wider coverage areas for the transponder tags, received noise from the environment may result in obtaining a worse "Signal-To-Noise Ratio" at the receiver. A careful balance must be attained between the coverage area required and the reliability of the reception. A 6dB difference between signal and noise levels must be maintained.

3.2.4 Antenna types

Antennas come in all shapes and sizes. When selecting the antenna type that will optimize the performance, it is necessary to take into account;

- Size
- Shape
- Proximity to other materials
- Field pattern
- Cost

and perhaps a number of other concerns. Also, consider utilizing a multiple array of smaller antennas that may operate better than one larger antenna.

3.2.5 Loop antennas

Small RFM antennas have less area than large antennas to transmit and capture energy. By increasing the number of windings of the smaller antenna more energy can be captured. However, as mentioned previously, the induced voltage at the RFID transponder is dependent on the turns ratio between transmitter and tag coils. More turns on the transmitter coil induce a stepped down voltage at the tag. Also, as the distance between the coils increase, less lines of flux are available to cut through each other. The loss of voltage due to the step-down ratio and loss of field lines can be offset by increasing the "permeability" of the core of the couplings.

Also, the number of turns of the loop is determined by the overall size of the antenna and how tightly the wires are packaged together. The optimum number of turns for maximum range is also affected by the proximity of metal. Metals having different magnetic permeability will exhibit different achievable ranges.

3.2.6 Resonance

In order to transfer maximum energy from the RFM to its antenna system the antenna circuit (tank) should be tuned to resonate at the carrier frequency of 134.2kHz. At resonance the capacitance of the circuit is balanced out by the inductance of the antenna coil. Antennas having a nominal inductance of 27 μ H are ideal for standard low frequency RFMs. On-board variable tuning components should properly resonate antennas having inductance ranging from 25.5 μ H to 28.5 μ H.

3.2.7 Quality factor – “Q”

Dimensionless figure of merit called the "Quality Factor", or simply "Q" represents the relationship between effective impedance caused by the inductance of the coil at the frequency of transmission and the resistance of the antenna wire. The lower the resistance of the conductor - the higher the value of Q.

A high Q antenna not only transfers maximum energy at resonance, it also has a narrow bandpass limiting out-of-band interference. Keeping the resistance of the coil approximately 0.3 Ohm will yield a Q typically near 100; offering increased performance and maximum immunity to noise.

3.2.8 Proximity to metals

Altered performance of the RFID system can be expected when the radiating antenna is in proximity to metal objects. Proximity to metals effectively lowers the antenna's inductance. Lower inductance causes an increase in resonant frequency and also a reduction in "Q". Designers may consider starting with a higher-than-needed "Q" in the initial stages, expecting it to be lowered when installed in its intended location. External capacitance may be required to tune the modified antenna system back to resonance. These types of situations can be experienced around conveyor belt structures and also embedding antenna loops on concrete driveways where metal re-bar absorbs some of the radiated energy.

3.2.9 Skin effect

"Skin Effect" is the tendency of alternating currents to exist in the area of a conductor approaching the surface, rather than in the entire cross-sectional area of the conductor. At radio frequencies the moving charges in the conductor cause a self-induced magnetic field, which in itself generates a counter voltage. This self-inductance is greatest at the centre of the conductor and thus limits the current in that area. Electrical currents move toward the outer surface of the conductor where the counter electromagnetic force (EMF) is a minimum. To limit losses due to skin effect the conductors chosen should have a maximum surface area in relation to volume. Multi-stranded, insulated, fine wire has more surface area than does a single solid wire of the same overall gauge.

3.2.10 Antenna arrays

Multiple antennas may be desired to cover a larger area or to alter the polarization characteristics. Multiple loops may simply be directly connected together or "multiplexed" through intelligent antenna switches and matching networks to alter the tag detection patterns. An analogy can be realized by connecting audio speakers to a stereo amplifier. Caution must be taken when attaching "+" and "-" leads to be sure the sound produced by each speaker is "in-phase" with the other.

If parallel antenna loops are connected "in-phase" a strong field is produced between them. This field is ideal for operating tags that are oriented parallel to the loops. If they are connected "out-of-phase", also referred to as "anti-phase", the field is rotated and is ideal for a tag oriented at right angles to the loops. Anti-phase connection is used where noise reduction by phase cancellation is required. Consideration must be given to the effective inductance of two individual loops connected in parallel. Note: Two 54 μ H loops connected in parallel will have a combined inductance of 27 μ H.

3.3 Technical Characteristics of Electronic Identifiers and Readers

The Joint Research Council has recently published a set of 3 technical guidelines for the Council Regulation No.21/2004 [3] of 17/12/2003:

- Part 1: In Field aspects: application of identifiers, their reading and recovery, which described recommended practices for the application, reading and recovery of electronic identifiers [4].
- Part 2: Electronic Identifier and Reader Specifications, Test Procedures, Acceptance Criteria, and codification of identifiers which describes the technical characteristics of electronic identifiers and readers, the test procedures and acceptance criteria for the equipment to be used in the Members States in conformance with Regulations 21/2004 [5].
- Part 3: Common glossary, data dictionary and communication standards [6].

In the case of this project, the information provided in Part 2 of the technical guidelines are extremely relevant and are to be considered as part of the work to be performed, and key information is provided in the following sub-sections.

3.3.1 Principles of Operation of the Radio Frequency Identification (RFID) System

The transponder consists of a plastic or glass package containing an integrated circuit fitted with an air or ferrite coil antenna (Figure 2 and Figure 3). An identification number is encoded in the integrated circuit. A reading device emits an alternating magnetic field, which transfers energy to the integrated circuit via its coil antenna, exploiting the physical phenomenon of inductive coupling. Once energised, the transponder sends its identification code back to the reader, and reverts to its passive state. The identification system is depicted in Figure 4 below.

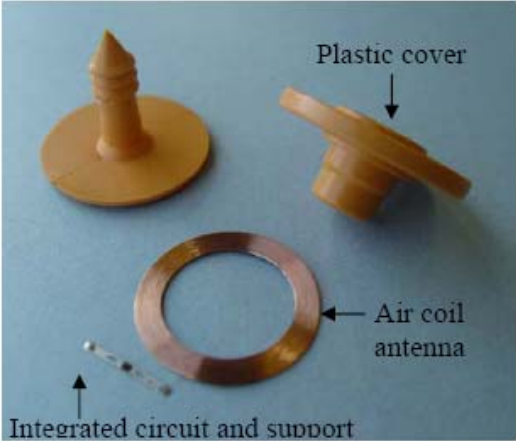


Figure 2: RFID – Passive transponder in ear-tags

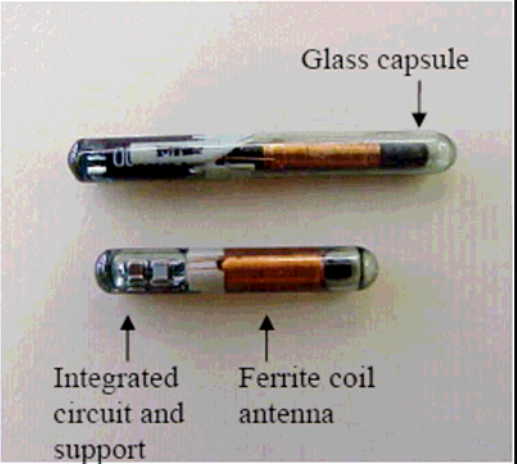


Figure 3: RFID – Passive transponder in injectables or boluses

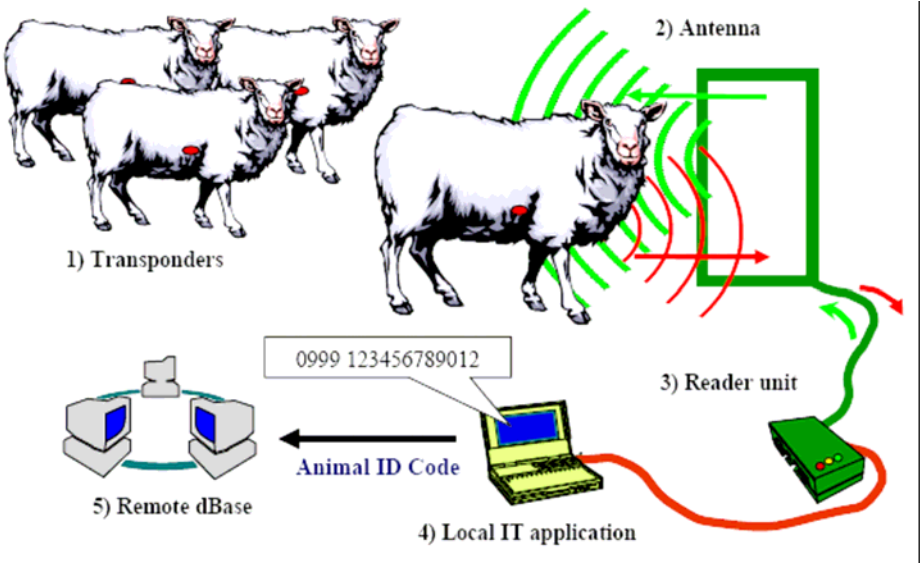


Figure 4: RFID – The complete electronic identification for sheep and goats

ISO has reserved a range of frequencies centred at 134.2kHz for animal identification; and has defined two protocols for data transmission between transponders and readers in the ISO11785 standard [7].

3.3.2 ISO 11785 Full Duplex (FDX-B) Protocol

An FDX-B transponder (hereinafter abbreviated to FDX) coupled to the activation field transmits its code during the activation period (the reader actually emits the magnetic field in pulses of fixed duration). The FDX transponder emits an amplitude modulated (AM) signal whose side-bands (129 - 133.2kHz and 135.2 - 139.4kHz) encode the binary 0's and 1's of the identification code. A measured FDX signal spectrum is presented in Figure 5 below:

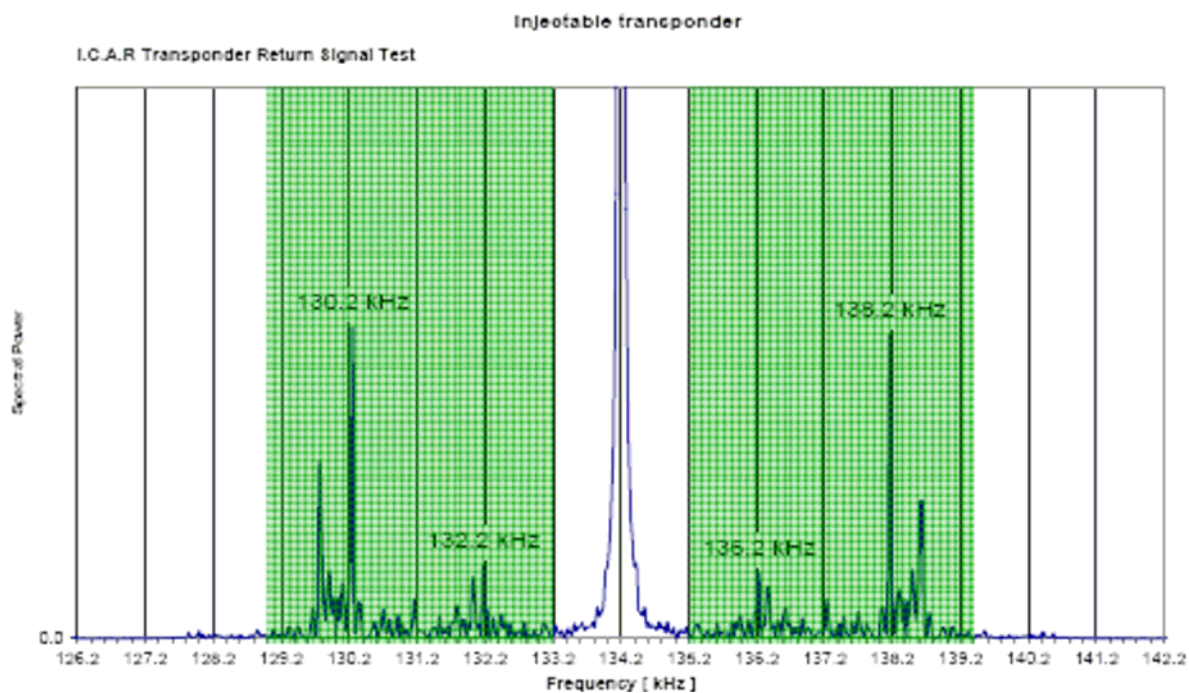


Figure 5: Return Signal modulation of a FDX transponder

According to ISO11785, the Full Duplex (FDX) is equivalent to the method of information in which the information is communicated while the transceiver transmits the activation field.

3.3.3 ISO 11785 Half Duplex (HDX) Protocol

An HDX transponder coupled to the activation field accumulates energy during the activation period, and transmits its code during the intervals between successive activation pulses. The HDX transponder replies between 1ms and 2ms after a 50% (3dB) reduction of the activation pulse. The HDX transponder uses frequency modulation (FM), where $124.2 \pm 2\text{kHz}$ represents a binary 1, and $134.2 \pm 1.5\text{kHz}$ represents a binary 0. A measured HDX signal spectrum is shown in Figure 6.

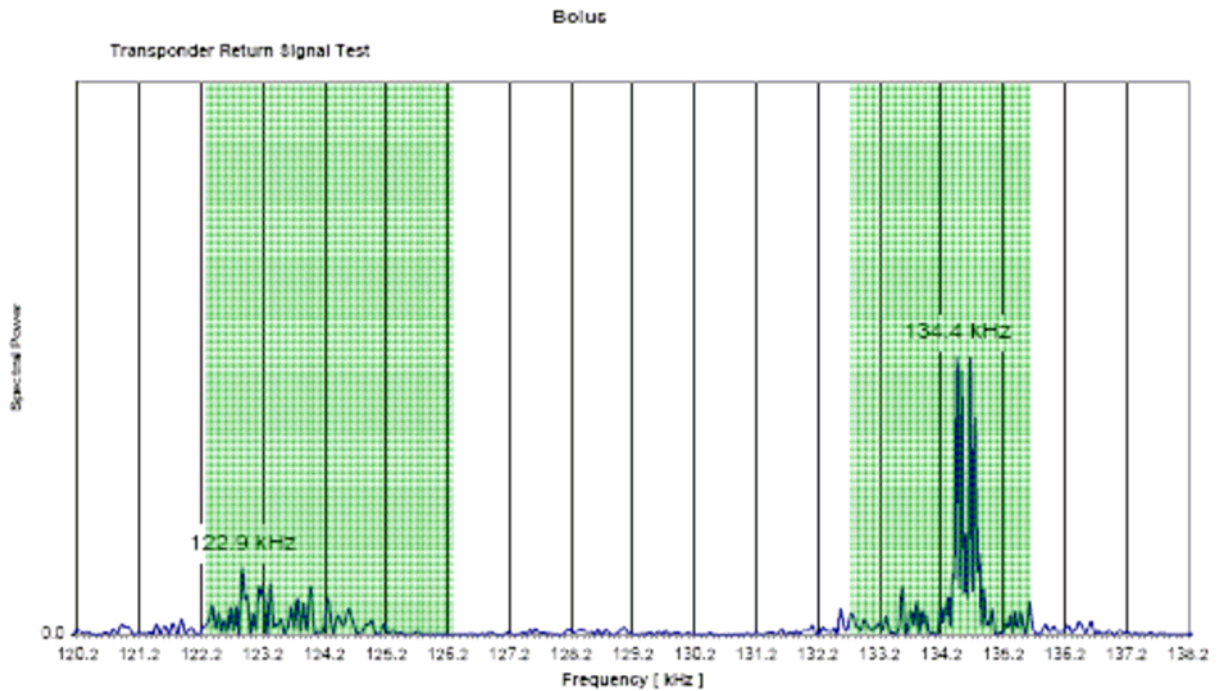


Figure 6: Return signal modulation of a HDX transponder

According to ISO 11785, the Half Duplex (HDX) is equivalent to the method of information exchange in which the information is communicated after the transceiver has stopped transmitting the activation field.

3.3.4 Compatibility of Readers and Electronic Identifier

Commercial-off-the-shelf (COTS) readers are available (both hand held and stationary) which using one or both of the data transmission protocols defined in ISO 11785:

- HDX readers only read HDX transponders and not FDX-B transponders
- FDX-B readers only read FDX-B transponders and not HDX transponders
- ISO compliant readers read both HDX and FDX-B transponders.

Reader-transponder interoperability is summarized in Table 1:

Reader technology	Transponder technology	
	HDX	FDX-B
HDX	Read	No read
FDX-B	No read	Read
ISO	Read	Read

Table 1: Reader-transponder compatibility

Regulation 21/2004 accepts two transponder technologies (HDX and FDX-B) for use in the identification of small ruminants, yet acquisition of electronic identification codes has to be assured. This may only be achieved by mandating the use of ISO compliant readers.

3.3.5 Mandatory Requirements for Identifiers and Readers

The requirements laid down in Regulation 21/2004 are based on laboratory tests and field experience (in particular from the IDEA project). Electronic identification equipment shall have the following technical characteristics:

1. Identifiers shall incorporate passive, read-only transponders, using the HDX or FDXB data transmission protocols defined in ISO 11785;
2. Electronic identification codes shall comply with ISO 11784;
3. Readers shall be capable of reading both HDX and FDX-B transponders complete code in accordance with the ISO 11784 code structure;
4. Readers should be capable of displaying the transponder's country code, the individual identification code, the re-tagging code and the user information field (e.g. species code);
5. For hand held readers, the minimum mandatory reading distances are 12cm for eartags and 20cm for boluses. These reading distances are measured under standard test conditions;
6. For stationary readers, the minimum mandatory reading distance is 50cm under standard test conditions.

Regulation 21/2004 defines two different reading distances for hand held readers depending on the type of electronic identifier used (eartag or bolus). The requirement for eartags is less than that for boluses because eartags are always visible, and in the worst case the operator can place the reader close to (even in contact with) the eartag if necessary to obtain a reading.

The reading distance requirement for stationary readers aims to assure a minimum of one satisfactory reading when an electronically tagged animal passes in front of the antenna, at walking speed in an appropriate race way (around 40cm width according to the animal size), during dynamic reading in field conditions.

The quality of an RFID system may be quantified in terms of reading distances determined under standard test conditions (achieved in a controlled laboratory environment). However, it is important to note that reading distances may be considerably reduced in field (uncontrolled) conditions. Regulation 21/2004 sets the reading distance requirements appropriate for small ruminants. Specification of greater reading distances would help to protect investments by assuring that the same equipment will also be appropriate for electronic identification of larger animals such as cattle.

4 FINDING OF THE DESK BASED RESEARCH

4.1 Acoustic interferences

The potential effect of acoustic interference on EID systems for animals tagging has been researched and no information could be found on this subject. This likely to be due to the physical nature and extreme complexity of acoustic science.

Acoustics can be defined as the science concerned with the production, control, transmission, reception and effects of sounds. It originates from mechanical vibrations and the transmission of these vibrations through mechanical waves in gases, liquids and solids.

In the case of this project, a mechanical vibration (for example a gate being slammed) will create both a physical vibration in terms of a pseudo oscillatory movement of the gate (and surrounding metal structure) and will create a resultant in the sense of an acoustic wave.

Both the acoustic wave (acoustic interference) and physical vibration (mechanical interference) will occur simultaneously, thus making it extremely difficult to determine which type of interference may predominantly impact on the EID systems.

The work recommended as per of the research proposal will effectively be able to ascertain which type of interference predominantly affects EID systems, since the EID systems under test will be subjected to both acoustic and mechanical interference independently under laboratory conditions.

4.2 Mechanical interference

Environments such as auction marts and abattoirs are known to present high levels of mechanical interference. One could classify these interferences into two types:

1. Direct interference, i.e. in the form of a mechanical shock directly applied to the EID reader (for example a cow kicking the reader panel);
2. Indirect interference, i.e. in the form a mechanical interference that is indirectly coupled to the EID reader (for example, a gate being slammed will conduct mechanical vibration onto the race onto which the EID reader is mounted).

Both of these types of physical disturbances can interfere with the functional operations of the EID systems.

The desk based research led to very limited information regarding the potential effect of mechanical interference onto EID system. In some way, this is not surprising as most of the published evidence relates to the effect of metal structure (which most of the conventional races are being made of) thus making it extremely difficult to dissociate the contribution of the metal adverse properties form the potential mechanical vibration issues.

The JRC technical guidelines [5] commands type approval process in order to provide end-users with assurances regarding the performance, interoperability, and reliability of approved components for animal identification and accordance with regulations 21/2004 [3]. Sub section 3.5 (Type Approval Test Schedule for Electronic Identifiers) and sub section 3.6 (Type Approval Test Schedule for Readers) provide requirements for endurance tests. Readers and identifiers are both subject to swept-frequency vibration test over a wide range of frequency to mimic real life conditions that both identifiers and readers will be subject to during their product life cycle.

Table 8 (for identifiers) and Table 11 (for readers) specify the test sequence. The specifications are exactly the same in both cases, and refer to IEC 60068-2-6 [8] as detailed in Table 2:

Reader type	Standard	Severity testing
Hand held and static (portable)	IEC 60068-2-6	Test Fc– Vibration (sinusoidal); Frequency sweep 10 Hz – 2000Hz; 0.75mm displacement / 10 g peak accel., crossover at 60Hz; sweep rate 1 octave / min; 10 cycles
Static	IEC 60068-2-6	Test Fc– Vibration (sinusoidal); Frequency sweep 10 Hz – 2000Hz; 0.75mm displacement / 10 g peak accel., crossover at 60Hz; sweep rate 1 octave / min; 3 cycles

Table 2: Endurance test sequence

The technical guidelines mandate that at the end of each test, the reader (or identifier) be subjected to a visual inspection, functional verification and a performance check. However, it is not mandatory to perform functional verification during and after each test, as the guidelines specify the following [5]:

“Functional verifications during **and / or** after each test shall confirm the capability to correctly acquire identification code from FDX and HDX transponders’.

The proposed research will investigate whether EID systems are more prone to error while being subjected to mechanical interference: in this instance, an environmental site survey will be performed to ascertain the levels and frequencies of mechanical vibrations present in typical abattoirs and auctions marts, and the conditions monitored during the site survey will then be repeated in a laboratory under control conditions.

4.3 Modulation/metal interference

4.3.1 Published relevant research evidence (academic)

An academic literature review performed between 1991 and 2005 was recently published in 2007 [9] and showed that various challenges are facing the RFID industry, one being a clear understanding of the physical limitations of the technology. The paper highlights that, material effects on antenna power, tag antenna orientation affecting radio reception for example are some of the challenges that the industry does need to address.

In 2005, L. Syndanheimo published an article on the effects of size and shape of metallic objects on performance of passive radio frequency identification [10]. The

article investigates the effect of metallic object in the case of ultra high frequency (UHF) spectrum passive radio frequency identification (RFID) systems. Although, this project does not deal with UHF passive RFID system, most of the issues raised still remain valid.

It is reported that:

- Metallic surface or object in the vicinity of an antenna changes radiation pattern (or local field distribution pattern), input impedance, radiation efficiency and resonant frequency;
- Changes depend on the size and shape of the metallic object;
- Changes depend on the distance from the antenna from the object;
- Incident electromagnetic wave will be reflected from a metallic surface with a change in contribution from both E and H field component (-1 for E field and +1 for H field);
- Local reflection (due to metal) change of the local field distribution pattern.

In [11], a study was performed using an RFID system, GrowSafe, to investigate the feeding pattern of feedlot cattle. It is reported that the metal fencing was potentially acting as an antenna when the animals were coming within 50cm distance of the fencing and thus leading to antenna errors. Similar measurements were performed at a site where no metal fence dividers are used and results showed no adverse effects.

In an article entitled “Making the “MOST” of RFID technology: a research agenda for the study of the adoption, usage and impact of RFID” [12], it is reported that research is still required to understand the limitations of RFID technology when signal in close proximity of various metal.

4.3.2 Study based evidences

Published evidences of metal affecting the functional aspect of RFID are available on the Web, but the reported evidences are mostly anecdotal with no in depth analysis of the physical reasons why RFID systems are being affected by metal structures.

In a report published by DEFRA [13], it is reported in page 10 of the document, that;

”within markets and abattoirs, equipment is not able to handle anomalies (e.g. animals not carrying identifiers) at speed without interrupting procedures. Reading equipment suffers from electromagnetic interference from the physical structure (i.e. metal) of the premises around it”.

Later on in the report (Page 11), it is reported that;

“Of particular concern was the high level of interference found in both markets and abattoirs because of the presence of metal in the physical structure of the

premises. The majority of UK markets contain only metal pens and races because they are easily cleaned and disinfected, leading to better biosecurity. The JRC's Technical Guidelines recommend avoiding placing the reading antennae in direct contact with metal fencing".

Later in the document (Page [13]), starting points for improvement are recommended, and it is stated that;

"Systems need to be developed that work in a physical environment that contains large amounts of metal and other electromagnetic disturbances, which effectively deal with non-reads and which retrieve boluses for destruction"

and in Page 18, it is reported that;

"Devices and/or equipment performed poorly when incorporated with metal farm and market infrastructure".

Similarly, in the part 1 of Technical Guidelines [4], the JRC states in page 13 of the document that;

"Avoid placing reading antenna in contact with any electrical conductors (e.g. metal fencing)".

Various web sites (similar to [14] and [15]) report the effect of detuning when installed (or used) in close proximity to metal fencing;

"Metal can also detune both reader and tag antenna, causing added parasitic capacitance (which means energy drain caused by the electromagnetic "friction" from the metal) and reduced system performance. Finally, at some frequencies the energy reflected by metal creates interference between the tag and reader. RFID in heavy metal environments can mean reductions in actual read and write rates, ranges and reliabilities far below those experienced in the clean lab environments of RFID pilots".

5 CONCLUSION

The report has summarised the findings of a desk based research into the subject of acoustic and mechanical vibration and other physical effects on the performance of electronic ID tagging in animals. As detailed in the report, the work performed in this area is extremely limited in both academic research and detailed studies. The limited information available clearly identify that metallic structures affect the functional operation of RFID systems, but without providing detailed explanation.

The proposed project [16] will be able to provide answers to the above issues as each type of interference (acoustic, mechanical and modulation/metallic) will be assessed independently under laboratory conditions.

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Appendix 2 Study of Acoustic Interference – Report B179CR1

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**A Study of the Susceptibility of
Animal Tag Reading RFID
Equipment to Interference from
Acoustic Signals Present in the
Abattoir and Auction Market
Environments
(copy 1 of 2)
for
Scottish Government**

Document number: B179CR1

Project number: 4046

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CHANGE HISTORY SHEET

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LIST OF TERMS AND ABBREVIATIONS

Pa	Pascal (unit of sound pressure equal to 1 Newton per square metre)
dB	Decibel
HP3561A	Hewlett Packard dynamic signal analyser, type 3561A
Hz	Hertz (frequency) (1 Hertz = 1 cycle per second)
kHz	kilohertz (frequency) (1 kHz equals 1000 Hz)
RFID	Radio Frequency Identification
EUT	Equipment Under Test
FFT	Fast Fourier Transform
SG	Scottish Government
YES	York EMC Services (2007) Ltd

EXECUTIVE SUMMARY

The Scottish Government have commissioned York EMC Services 2007 Ltd to investigate certain aspects of the functional reliability in service of RFID Tags and their readers when used for identification of farm animals and includes immunity of the whole system to certain external disturbances.

This report describes the investigation into whether RFID systems are immune to levels of acoustic disturbance likely to be found in areas where animal tag reading is expected to become commonplace, such as cattle markets and slaughterhouses.

Four samples of RFID tag reader were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. The study was conducted on an anonymous basis such that the identity of equipment manufacturers is protected.

A preliminary investigation was conducted into the need to extend the measurement of sound level into the near ultrasonic frequency band. It was concluded that frequencies up to 80kHz should be considered. Appropriate measuring equipment was sourced and calibrated.

Surveys were conducted at four sites to measure the acoustic levels experienced close to where the animals would be identified.

The site data were analysed to enable the definition of appropriate immunity levels and disturbing signals for an acoustic immunity test system.

Acoustic conditions in auction markets and abattoirs give rise to short duration bursts of high intensity sound, resulting from steel gates closing, and impacts against steel barriers. This has considerable high frequency content, extending into the ultrasonic range.

An immunity test system was assembled capable of providing sound of the appropriate intensity and covering the appropriate frequency range identified from the site data. Tests were performed with both frequency based and time based sound sources. For frequency based tests, the sound source was continuous to enable easier detection of susceptibility of the test samples. For time based tests, use was made of sound signals which replicated the actual sounds present at the sites visited.

Immunity testing was performed on the four RFID tag reader systems supplied. The results were analysed and showed that it is possible for loud sounds to affect tag reader systems such that their performance is degraded or completely inhibited. The results of the study show that samples 3 and 4 were affected by sound interference during testing.

The results also show it is possible to design a system to be completely immune to the levels applied during the tests. Sample 1 remained unaffected under all conditions.

1 INTRODUCTION

1.1 Background

The Scottish Government have commissioned York EMC Services 2007 Ltd to investigate certain aspects of the functional reliability in service of RFID Tags and their readers when used for identification of farm animals (ovine and bovine). This includes immunity of the whole system to certain external disturbances.

As detailed in the Tender document 2333CR1 (York EMC Services (2007) Ltd) [1], there are various physical sources of interference that may cause a reduction in tag reading efficiency, which this study intends to address. These are as follows:

- a) Acoustic High levels of acoustic noise in the environment, for example, due to slamming of steel gates which form the animal pens in markets.
- b) Vibration Vibration of the structure (often metallic) to which panel antennas are fixed, for example, shock and vibration transferred via steel fencing.
- c) Modulation Modulation/modification of the magnetic field produced by the tag reader antenna or detuning of the system due to the presence of ferromagnetic material (typically fencing) or multiple tags in the field. This effect can also be an indirect cause of either a combination of acoustic and/or mechanical vibration.

This report describes the investigation into whether RFID systems are immune to levels of acoustic disturbance likely to be found in areas where animal tag reading is expected to become commonplace, such as cattle markets and slaughterhouses.

1.2 Test samples

Four samples of RFID tag reader were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. As this study is not intended to identify specific products or manufacturers, the samples are referred to only as Sample 1, Sample 2, Sample 3 and Sample 4 throughout this report.

Some photographs of the test setup include views of one or more parts of the tag readers. Care has been taken to blank out any identifiable parts from photographs.

1.3 Test methodology

The following steps were considered for the acoustic investigation:

1. Perform a preliminary investigation into the need to extend the measurement of sound level into the near ultrasonic frequency band.
2. Prepare and source measurement equipment capable of recording the levels of sound intensity and the frequency range required.
3. Survey a number of actual sites where sheep and cattle would regularly be present, and where it would be necessary to identify the animals by their tags. Make measurements there of the acoustic levels experienced close to where the animals would be identified.
4. Analyse the site data. Define appropriate immunity levels for an immunity test system. The site data contains information in both the time domain and the frequency domain. It was considered important that the analysis should include both aspects, and that an immunity test system should be capable of taking this into account.
5. Assemble an immunity test system capable of providing sound of the appropriate intensity and covering the appropriate frequency range identified from the site data.
6. Perform immunity testing on the four RFID tag reader systems supplied. Analyse the results and present the findings and our conclusions.

2 PRELIMINARY INVESTIGATIONS AND ON-SITE MEASUREMENTS

2.1 Test Equipment

Measurements of sound pressure were made using a Brüel and Kjær Type 4136 measuring microphone. This, coupled to a type 2633 preamplifier and powered from a type 2804 power supply unit will accept sound pressure levels up to +78 dBPa with less than 3% distortion, and is calibrated for frequencies up to 80kHz. It also provides a good indication (un-calibrated) of sound pressure in the frequency range 80kHz to 100kHz.

Explanatory note:- A sound pressure of 0dBPa (or 1 Pascal) is subjectively loud, but not deafeningly so. The quietest sound humans can hear is about -94dBPa. The dB scale is a logarithmic scale. A 20dB increase equals 10 times the sound pressure, a 40dB increase equals 100 times the sound pressure, a 60dB increase equals 1000 times the sound pressure etc. Sounds louder than +24dBPa are likely to cause permanent hearing damage.

This relationship can be expressed as an equation that relates the level in Pascals to the level in dBPa (dB Pascals) as follows:

$$\text{Level in dBPa} = 20 \log_{(10)} (\text{level in Pascals})$$

The microphone signal was fed to a Hewlett Packard dynamic signal analyser, type HP3561A. This will capture a signal from the microphone and make measurements on it. The HP3561A has the ability to perform a Fast Fourier Transform (FFT) on the captured signal, and display the result in the frequency domain. (It displays a graph of frequency against amplitude, allowing the level of signal at a specific frequency to be measured.) Calibration constants were entered into the FFT Analyser and the analyser then displayed results directly in dBPa. The HP3561A measures over the frequency range 0 to 100kHz, and has about 80dB dynamic range. For the testing it was set to measure and display sound pressure between +30dBPa and -50dBPa.

Preliminary investigations in the laboratory involved using the above equipment to measure the response to slamming a steel gate on a cattle crush. This showed that there were components of the sound in the ultrasonic region (above 20kHz) but that the sound pressure decreased as the frequency increased, and was at a very low level by 80kHz. This gave some confidence that the measurement system chosen would be adequate for the site measurement task.

In addition to the HP3561A analyser, recordings were made using a PC based data capture system. This, in conjunction with the same Brüel and Kjær microphone and power supply permitted the capture of much longer samples of sound data in real time, and the recording of sound files in .wav format using a laptop computer. The input signals are filtered to restrict the highest recorded frequency to 25kHz, but this does not have a significant effect on the time domain information. It was then possible to replay and analyse the recordings in the laboratory, to identify the durations and profiles of the acoustic disturbances.

2.2 Choice of Test Locations

All movements of cattle have to be reported to the British Cattle Movement Service (BCMS). This organisation operates the Cattle Tracing System (CTS). This is a database where all the movements of cattle registered or imported into Great Britain are recorded

European legislation requires cattle keepers report both the "off" holding and "on" to next holding movements to the database, as well as in their own herd registers. Fast and accurate reporting of movements to the database allows traceability of cattle from birth to entry to the human food chain, and in the event of a disease outbreak. Keepers of cattle are legally obliged to notify movements of cattle within 3 days of the event, and the death of an animal within 7 days.

The following movements of cattle must be reported to BCMS:

- On and off farms
- To and from markets
- To slaughterhouses

There is inherent feedback in the process of reading the ID tag of a single animal on a farm, using a hand held reader. The operator applies the tag reader until a confirmed reading is registered. This process however is not ideal where bulk animal movements are involved, and considerable benefit results from reliable automatic reading of ID tags. Markets and slaughterhouses are therefore the places where the most benefit results, but can also provide a difficult environment for automated reading systems. Field tests were therefore performed at cattle markets and abattoirs.

2.3 Locations and Measurement Dates

Four sites were used to collect research data (2 abattoirs and 2 auctions markets):

- | | | | |
|----|---|------------|----------------|
| 1) | Scotbeef Ltd
Longleys
Bridge Of Allan
Stirling,
Stirlingshire
FK9 4NE | 20/11/2007 | Abattoir |
| 2) | United Auctions Ltd
Stirling Auction Market
Kildean
Stirling
Stirlingshire
FK9 4UB | 21/11/2007 | Auction market |
| 3) | McIntosh Donald Ltd
The Meat Factory
Portlethen
Aberdeen
AB12 4QB | 29/11/2007 | Abattoir |

4) ANM Group Ltd
Thainstone Centre
Inverurie
Aberdeenshire
Scotland
AB51 5XZ

30/11/2007

Auction market

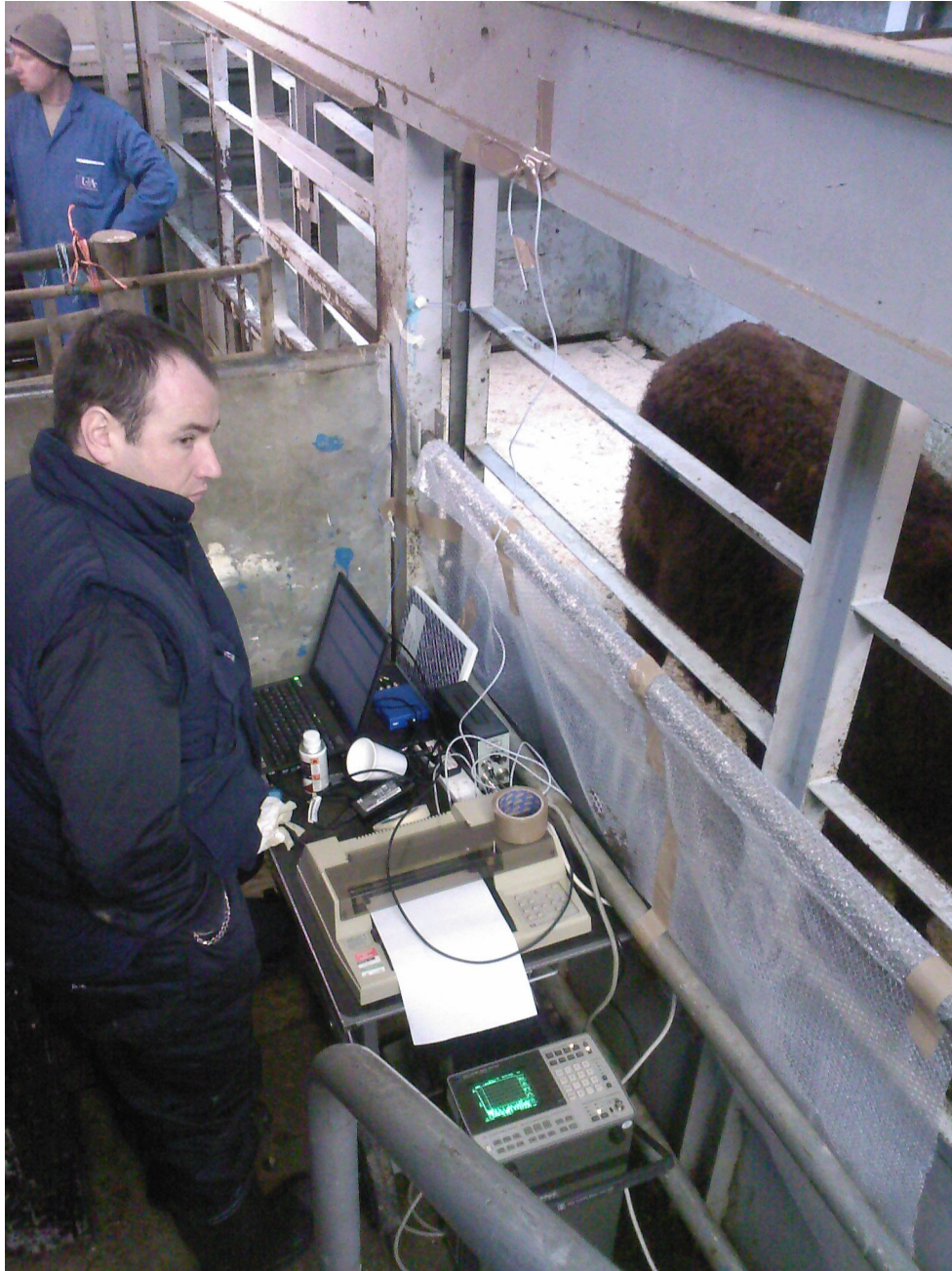


Figure 1: Site data collection at the Stirling Auction Market



Figure 2: Data collection at the Thainstone Centre - Inverurie

3 ANALYSIS OF SITE DATA

Site data were analysed and presented in the frequency domain (seen graphically as plots of sound pressure level versus frequency as in Section 3.1 below)

3.1 Frequency Domain Analysis

Primary raw site data was collected in the form of graphical output from the HP3561A Dynamic Signal Analyser.

A typical measurement graph is shown below:

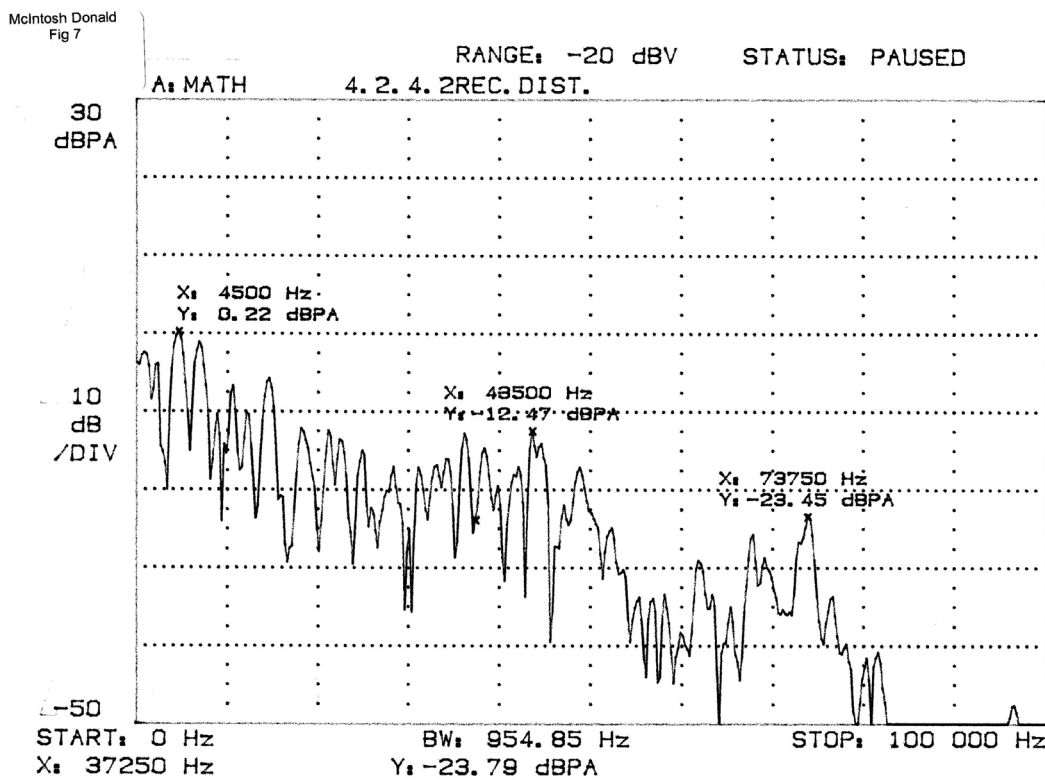


Figure 3: Typical graphical output provided by the HP3561A instrument

The Y axis shows measured sound pressure in dBPa. The X axis is a linear display of frequency from zero to 100kHz, each division being 10kHz wide. Some of the highest peaks have been individually marked for both frequency and sound pressure. Any other peaks of interest can be read from the graph directly, with about 1dB accuracy on the vertical scale and 1kHz accuracy on the horizontal scale.

The microphone calibration is valid at all frequencies up to 80kHz. Above this the microphone loses sensitivity such that at 100kHz the measurement error is 7dB

3.1.1 Typical Peak Sound Levels

In total 58 measurements were recorded of frequency domain information. Measurements were continuously performed throughout the day but only measurements with differing characteristics (frequency or amplitude) were plotted for subsequent analysis. This approach was adopted in order to optimise the analysis process. Analysis was conducted independently for each of the sites and this may be seen in the following sub-sections.

The analysis showed that in virtually all cases the level of sound pressure recorded was highest in the speech band (400Hz to 5kHz). There was however considerable sound pressure evident in the frequency range from 5kHz up to 50kHz and somewhat less in the frequency range from 50kHz to 80kHz.

3.1.1.1 Site of Scotbeef Ltd

19 plots were taken at the Scotbeef site. The first batch of 11 measurements were taken in the cattle area. Two typical results are shown below.

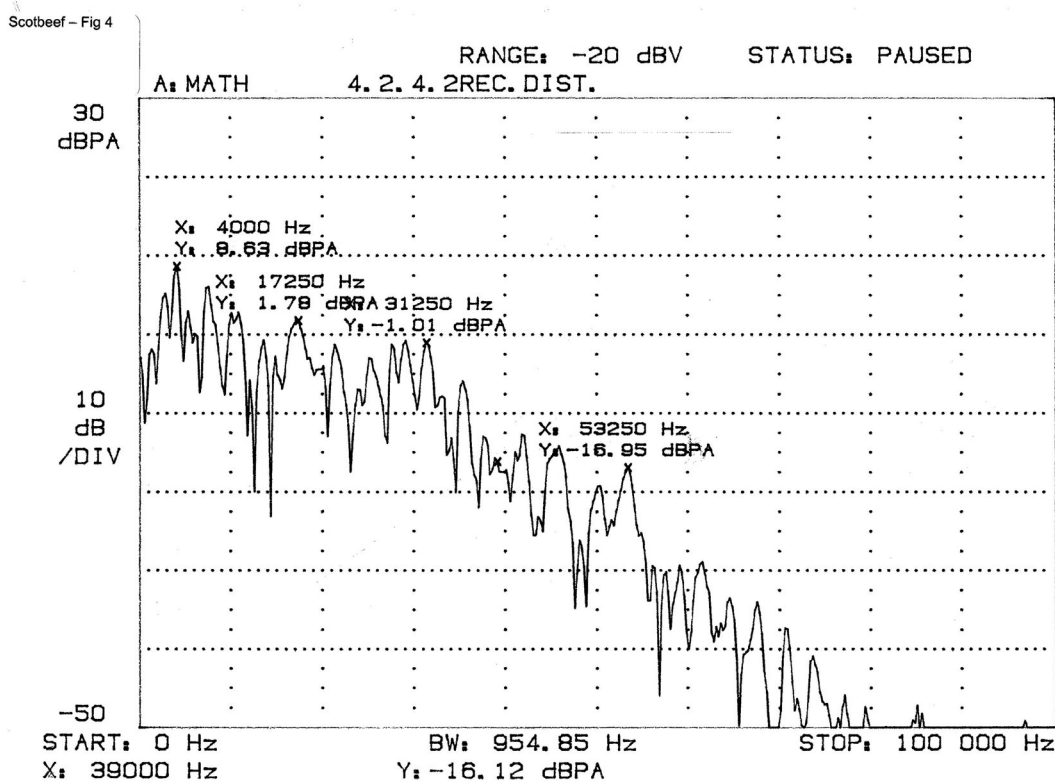


Figure 4: Measurement using the HP3561A instrument at the Scotbeef site

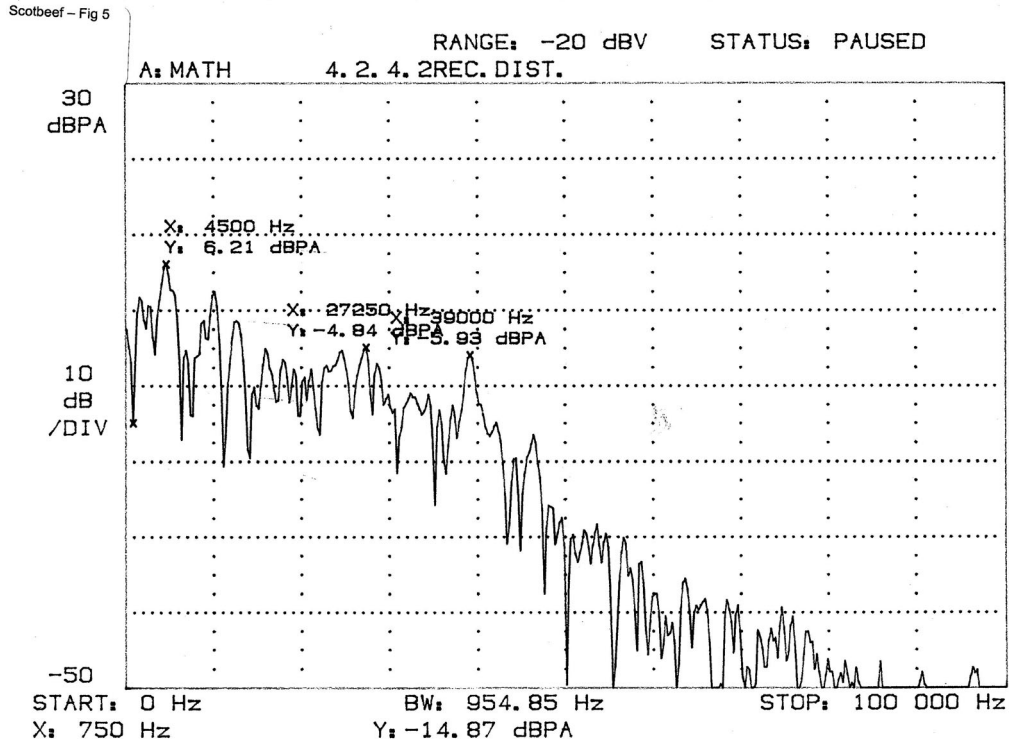


Figure 5: Measurement using the HP3561A instrument at the Scotbeef site

Responses of all measurements made at the cattle run at the Scotbeef site were combined and the overall envelope of frequency components was determined. The graph below shows the resulting limit line.

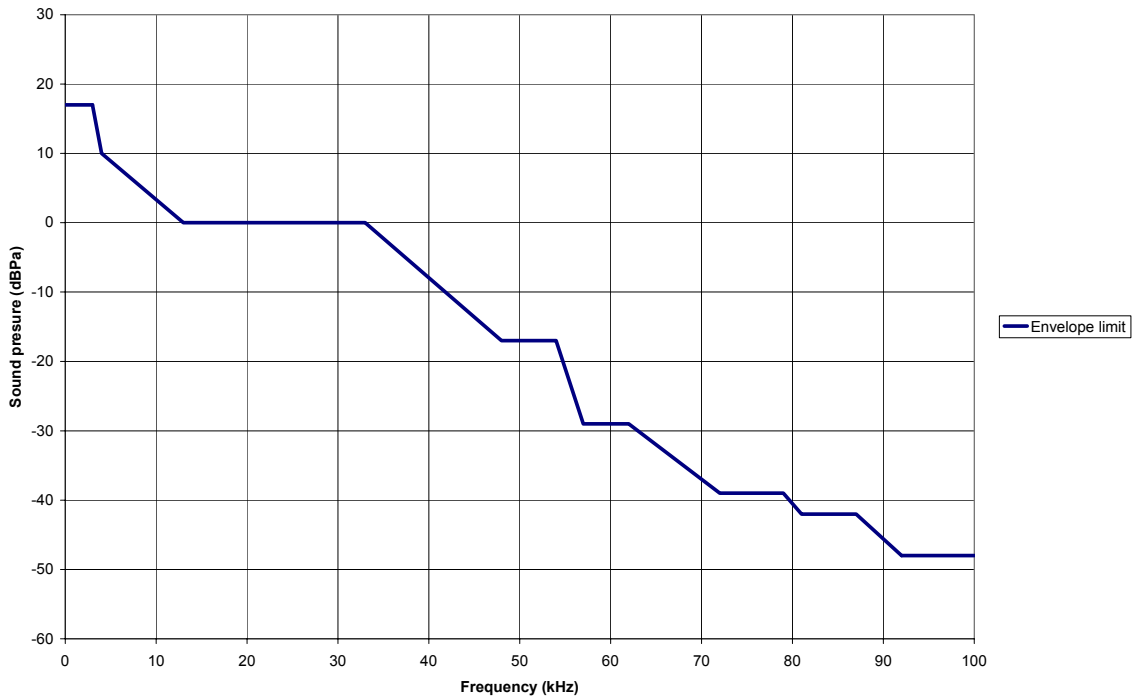


Figure 6: Combined responses of cattle measurements made at the Scotbeef site

In addition to the above, measurements were also made at the sheep run in the same site. Two of the response plots are shown, and again the combined envelope of the measurements has been derived.

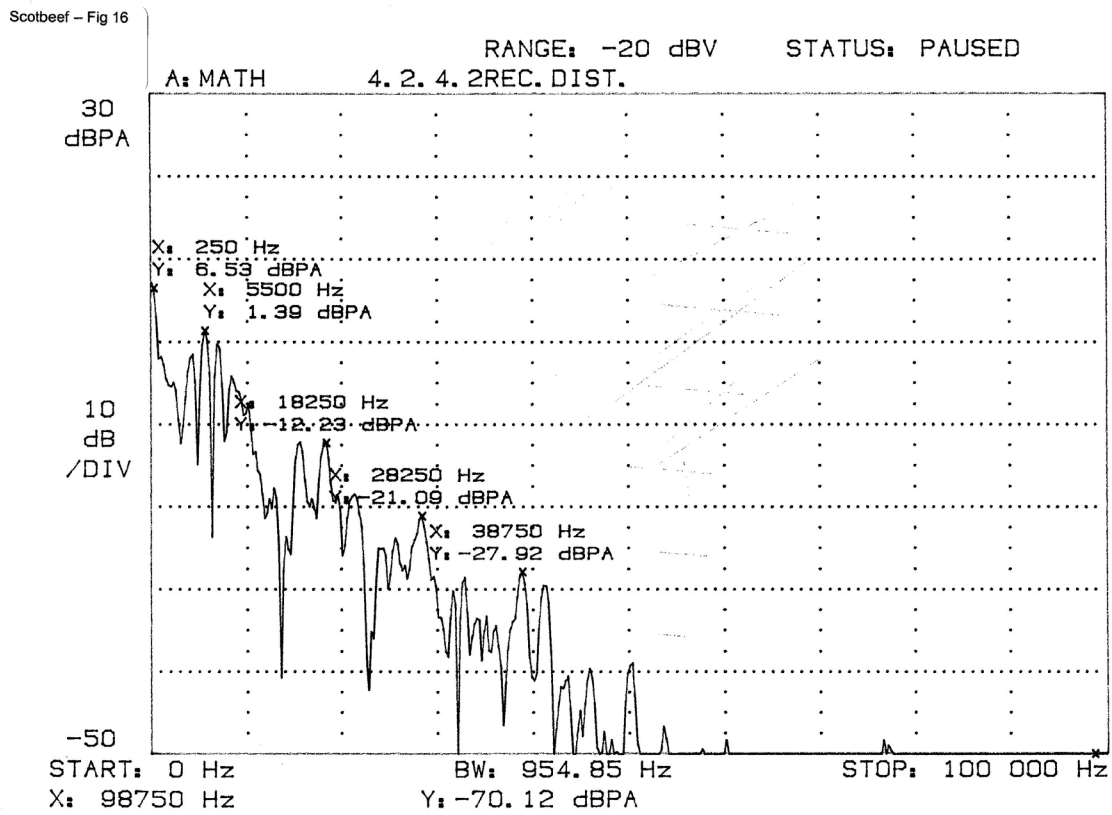


Figure 7: A measurement at the sheep run at the Scotbeef site

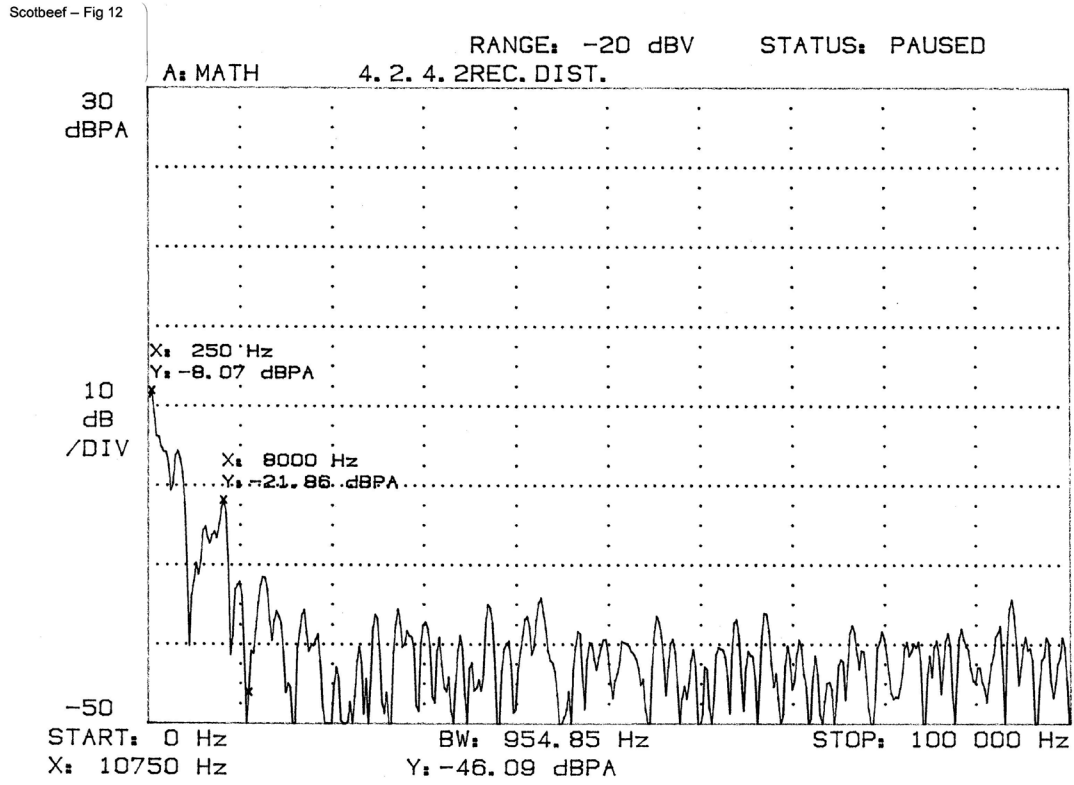


Figure 8: A further measurement at the sheep run at the Scotbeef site

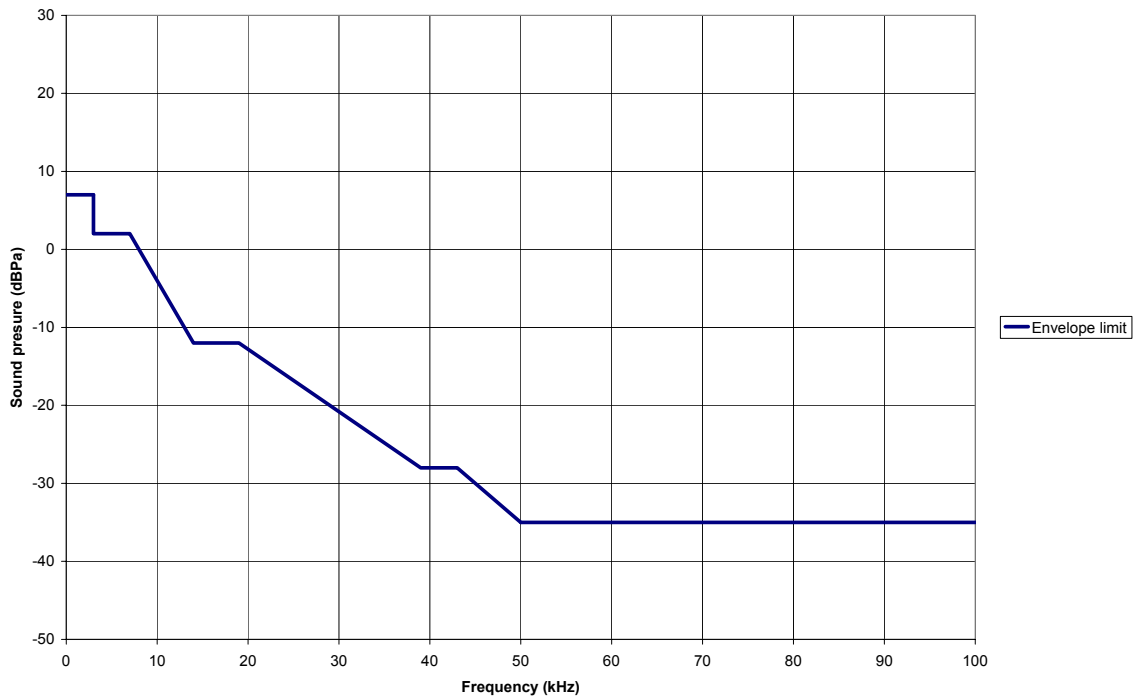


Figure 9: Combined responses of sheep measurements made at the Scotbeef site

3.1.1.2 Site of United Auctions Ltd

11 plots were taken at the United Auctions site. Two typical results are shown below. The responses obtained were similar in their general form to those obtained from the cattle area of the Scotbeef site. The general trend was that most of the acoustic energy was in the lower part of the frequency spectrum.

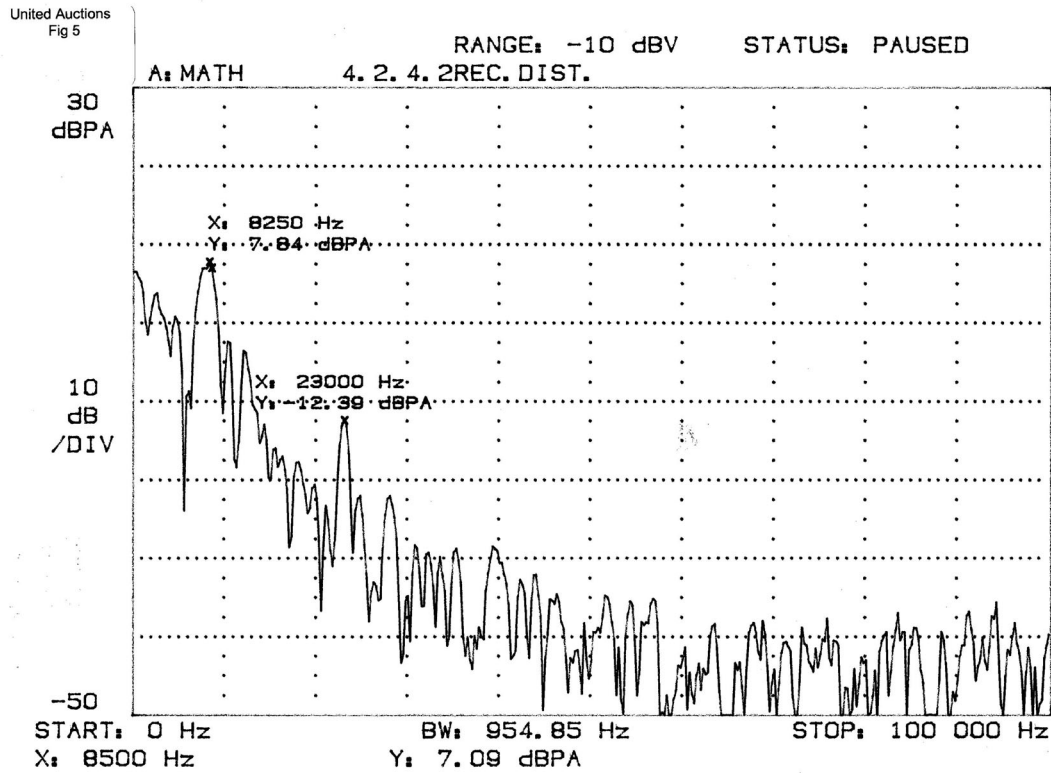


Figure 10: Measurement using the HP3561A instrument at the United Auctions site

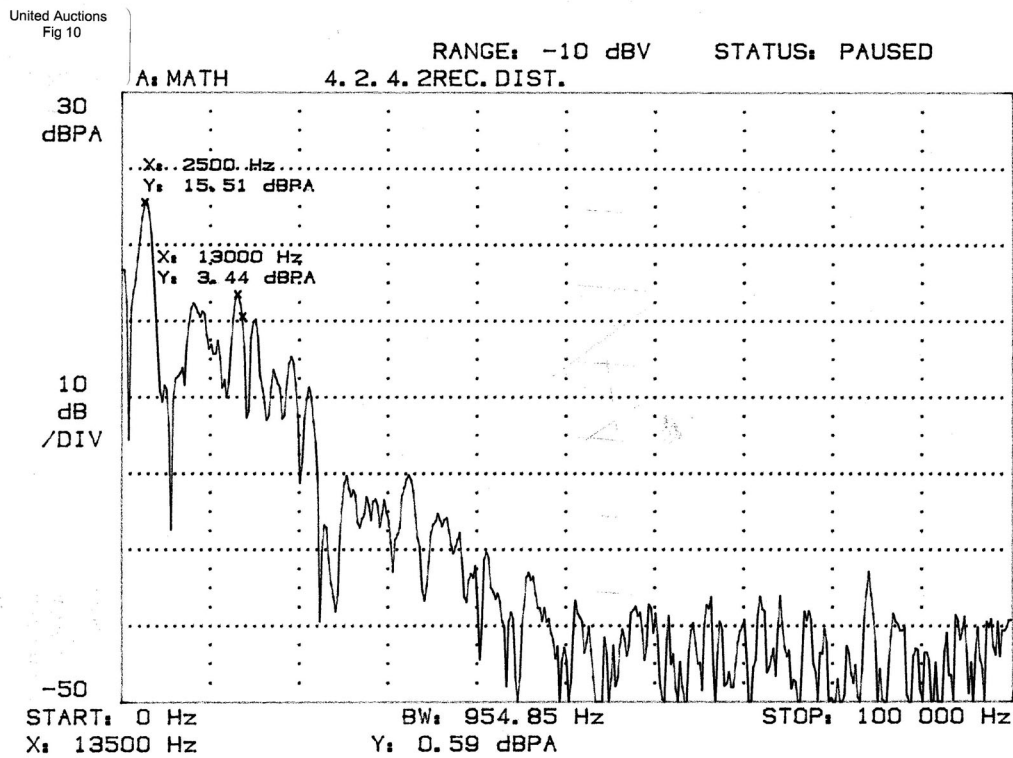


Figure 11: Measurement using the HP3561A instrument at the United Auctions site

Responses of all measurements made at the cattle run at the United Auctions site were combined

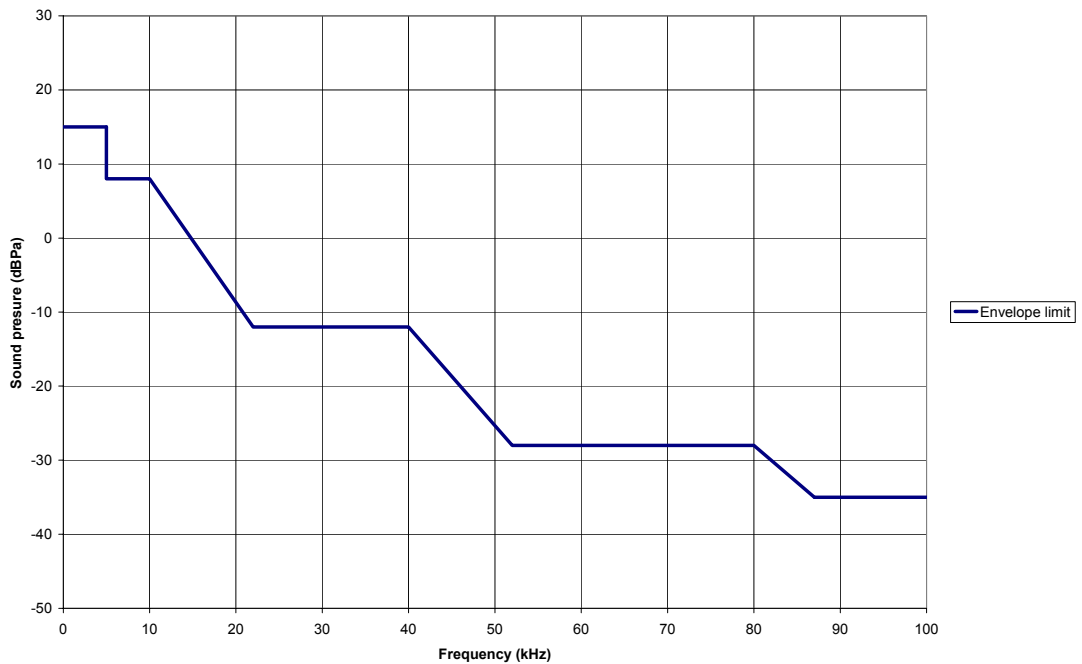


Figure 12: Combined responses of measurements made at the United Auctions site

3.1.1.3 Site of McIntosh Donald Ltd

13 plots were taken at the McIntosh Donald site. Two typical results are shown below. The responses obtained were similar in their general form to those obtained from the cattle area of the Scotbeef site and at the United Auctions site. The general trend was that most of the acoustic energy was in the lower part of the frequency spectrum, with some in the low ultrasonic range.

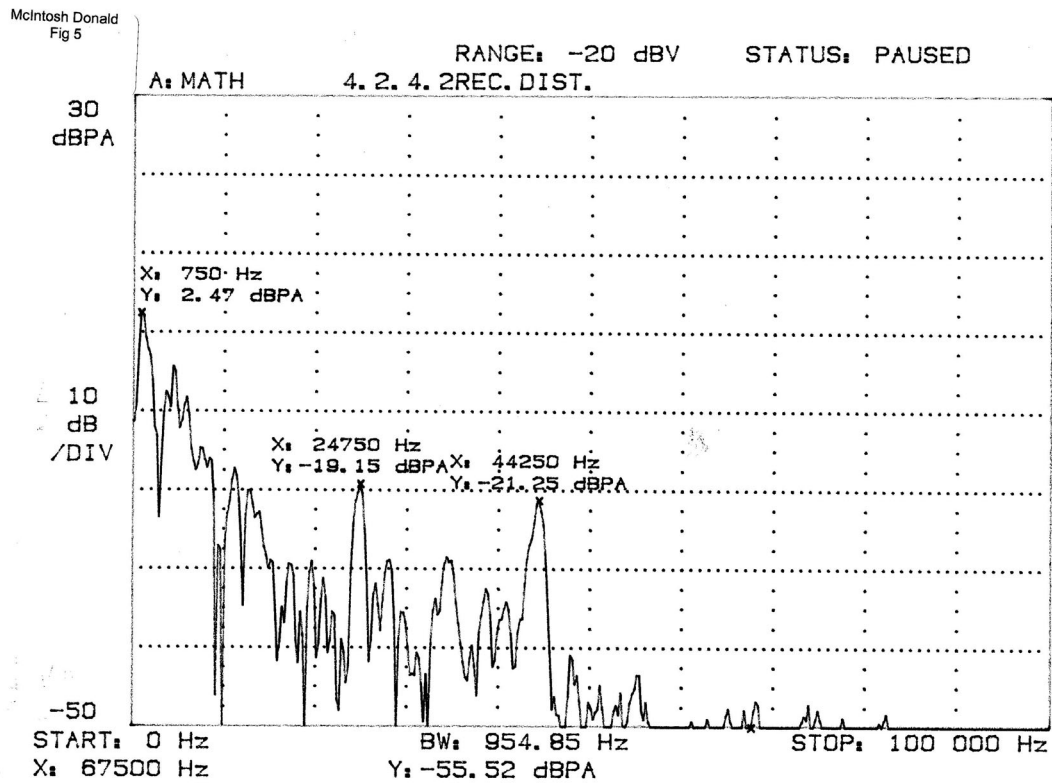


Figure 13: Measurement using the HP3561A instrument at the McIntosh Donald site

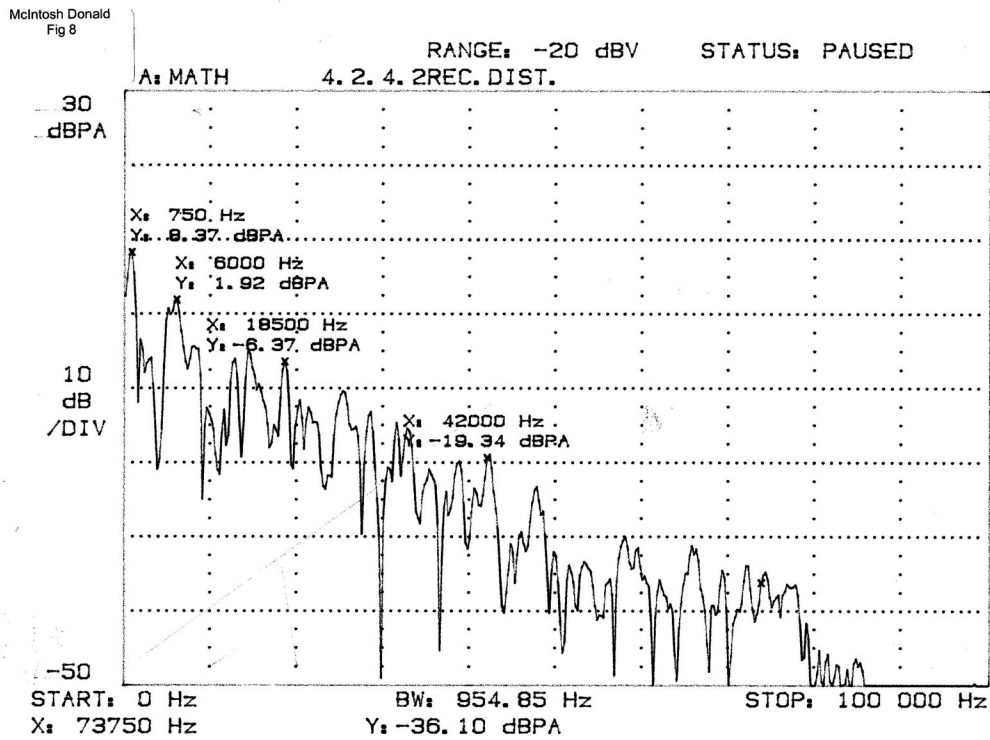


Figure 14: Measurement using the HP3561A instrument at the McIntosh Donald site

Responses of all measurements made at the cattle run at the McIntosh Donald site were combined

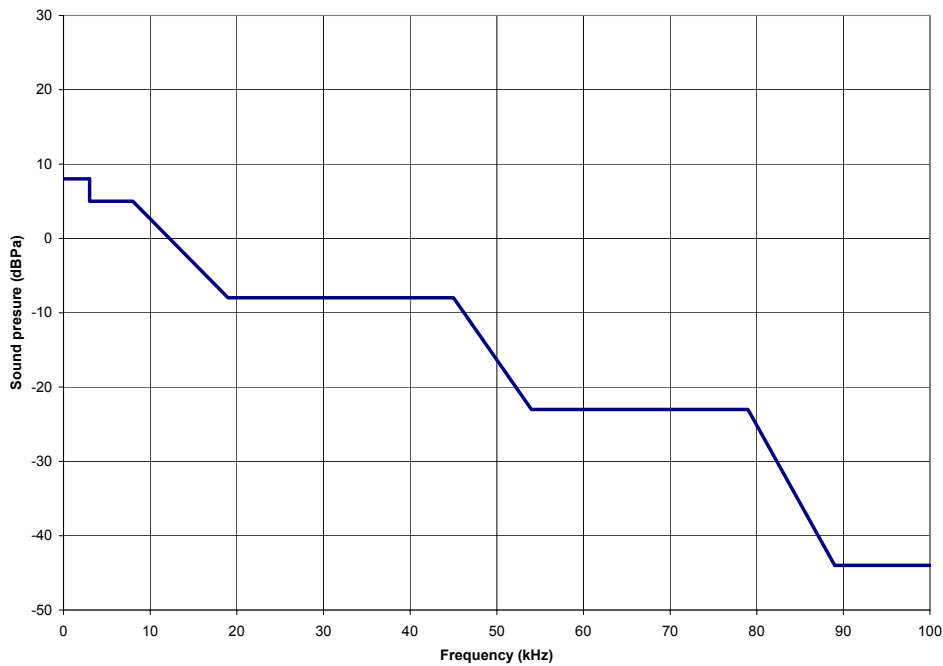


Figure 15: Combined responses of measurements made at the McIntosh Donald site

3.1.1.4 Site of ANM Group Ltd (Thainstone Centre)

15 plots were taken at the Thainstone Centre. Again responses obtained were similar in their general form to those obtained from the previous sites.

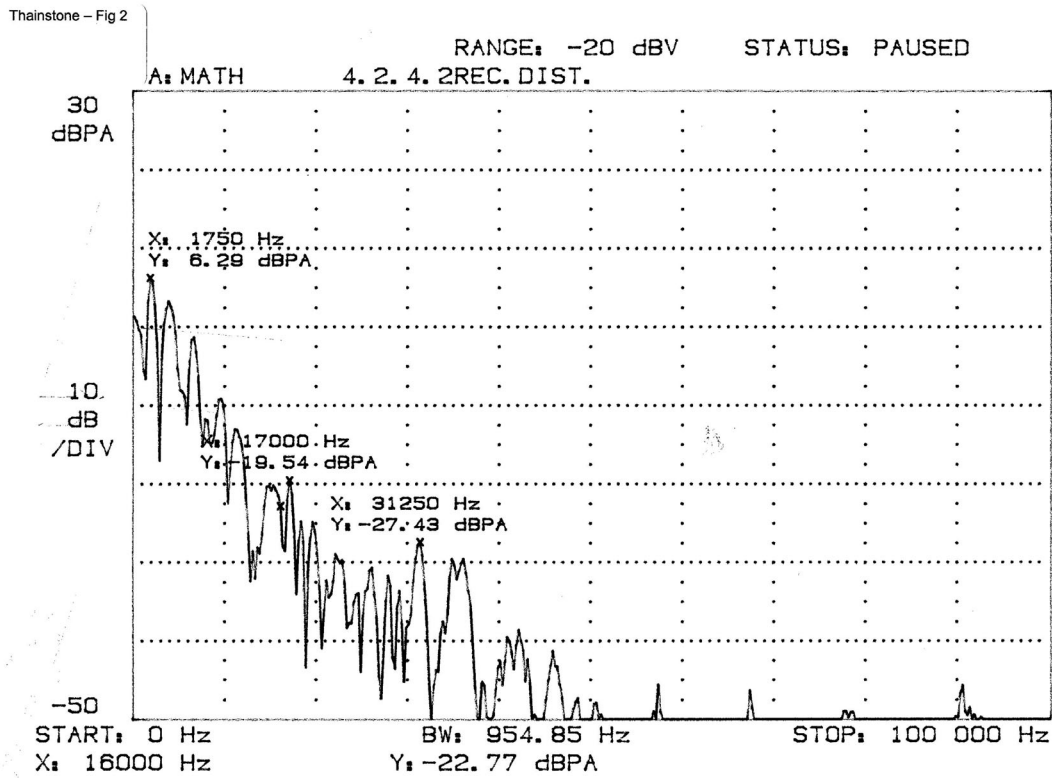


Figure 16: Measurement using the HP3561A instrument at the Thainstone Centre

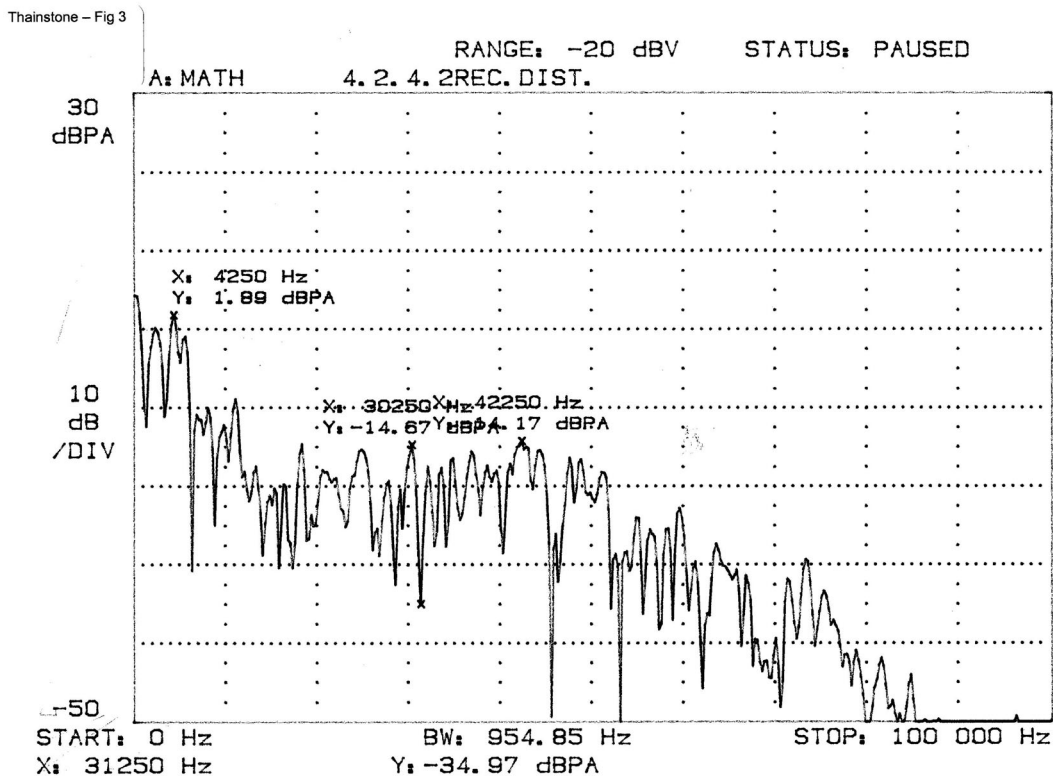


Figure 17: Measurement using the HP3561A instrument at the Thainstone Centre

Responses of all measurements made at the cattle run at the Thainstone Centre site were combined

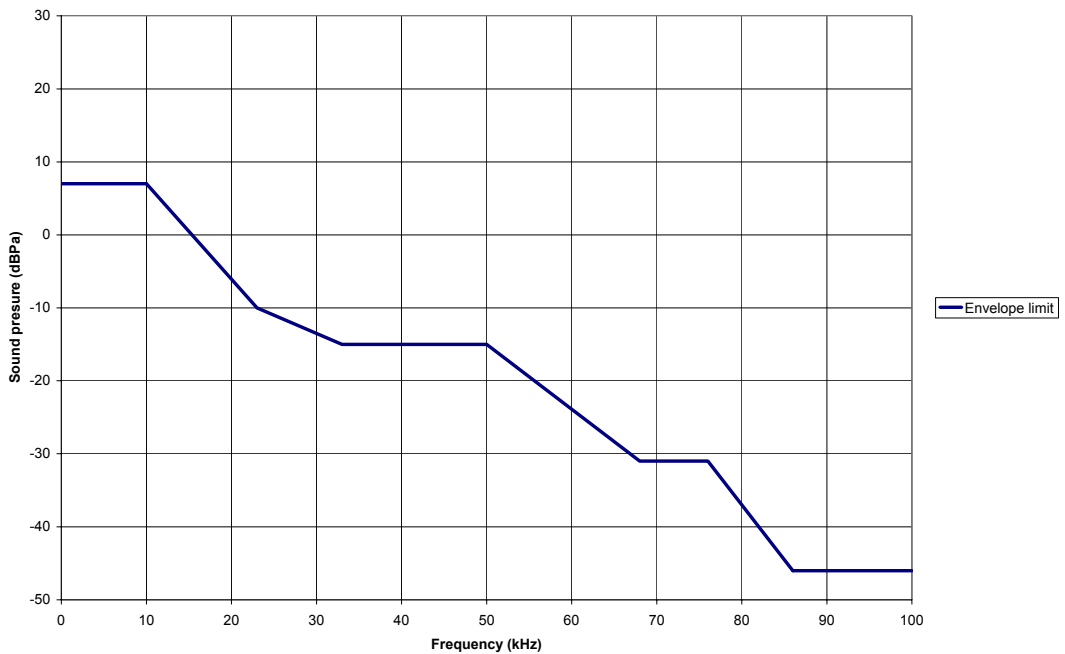


Figure 18: Combined responses of measurements made at the Thainstone Centre

3.1.2 Conclusion

The five graphs of combined responses are shown together in Figure 19 for ease of comparison.

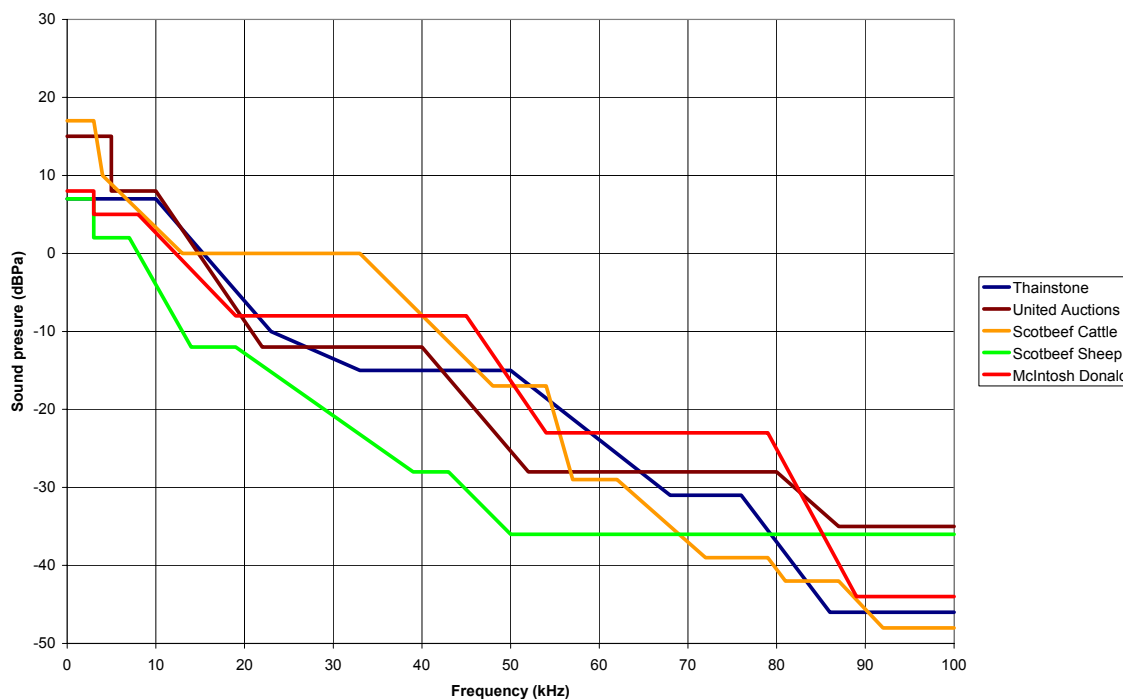


Figure 19: Combined responses of measurements made at all the sites

The trend is clearly visible from the combined responses. The energy of sounds in the environments investigated is mainly contained in the audible frequency band up to 20kHz. There is however some spread of energy into the low ultrasonic range from 20 to 50kHz and a small amount in the higher ultrasonic range from 50 to 80kHz. At frequencies above 80kHz there is very little energy.

The Scotbeef sheep run gave a small number of anomalous results (3 plots) that showed a more linear spread of energy into the higher ultrasonic range. This result could not be replicated at any of the other sites, and most of the results measured at the Scotbeef Sheep run showed the general characteristic of reduced sound pressure at higher frequencies.

Based on the results obtained and shown in Figure 19, a set of test levels was established for an immunity test system, intended to represent the peak levels of sound found to occur at the sites investigated. Sloping limits were avoided to simplify the performance of immunity testing.

	Frequency range	Sound pressure level
1	400Hz to 5kHz	+15dBPa
2	5kHz to 10kHz	+5dBPa
3	10kHz to 50kHz	0dBPa
4	50kHz to 80kHz	-20dBPa

Table 1: Stimulus levels to be applied for acoustic immunity testing

Figure 20 shows this sound pressure stimulus level superimposed on the combined responses shown in Figure 19.

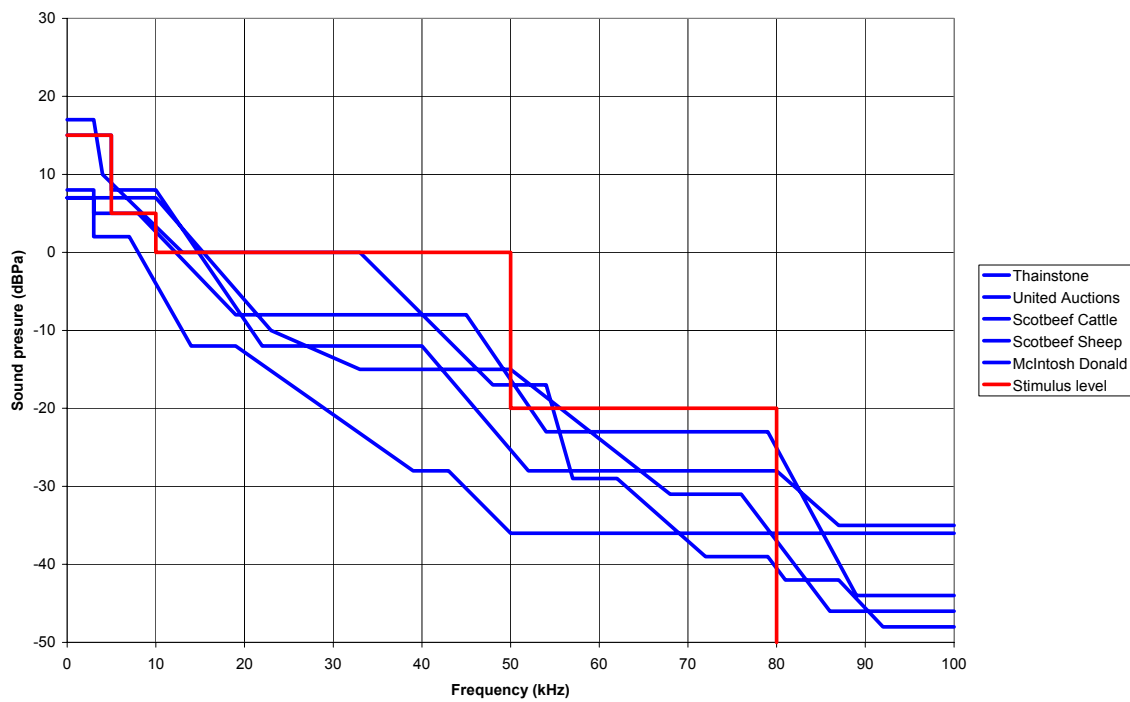


Figure 20: Combined responses and the stimulus level for test system

3.2 Time Domain Analysis

At two sites additional information was collected using the measuring microphone and a PC based data-logger. Although the PC based data-logger had a reduced bandwidth of 25kHz it enabled a timeline to be captured in the form of .wav files. Much longer durations could be recorded and analysed, and sounds could be replayed as well as being displayed graphically. From this it was possible to identify typical background levels of sound intensity and durations of louder sounds, and to estimate the rate of occurrence of loud sound disturbances. Files were viewed using editing software on the PC.

Figure 21 shows a typical sound timeline showing five minutes of recorded sound from the Thainstone Auction market at Inverurie. The peaks in this trace are the sound of metal gates being slammed shut. It can be seen that the level of background noise is very low relative to the peaks. When listening to the associated sound file, occasional voices can be heard, aligning with the low level sounds shown between the large spikes on the graph below. Both the axes on Figure 21 and Figure 22 are linear. The spike marked with an arrow is expanded in Figure 22, and is revealed as being about 0.55 seconds long with three distinct shorter peaks about a tenth of a second apart.



Figure 21: Typical sound timeline (Thainstone Auction market at Inverurie)

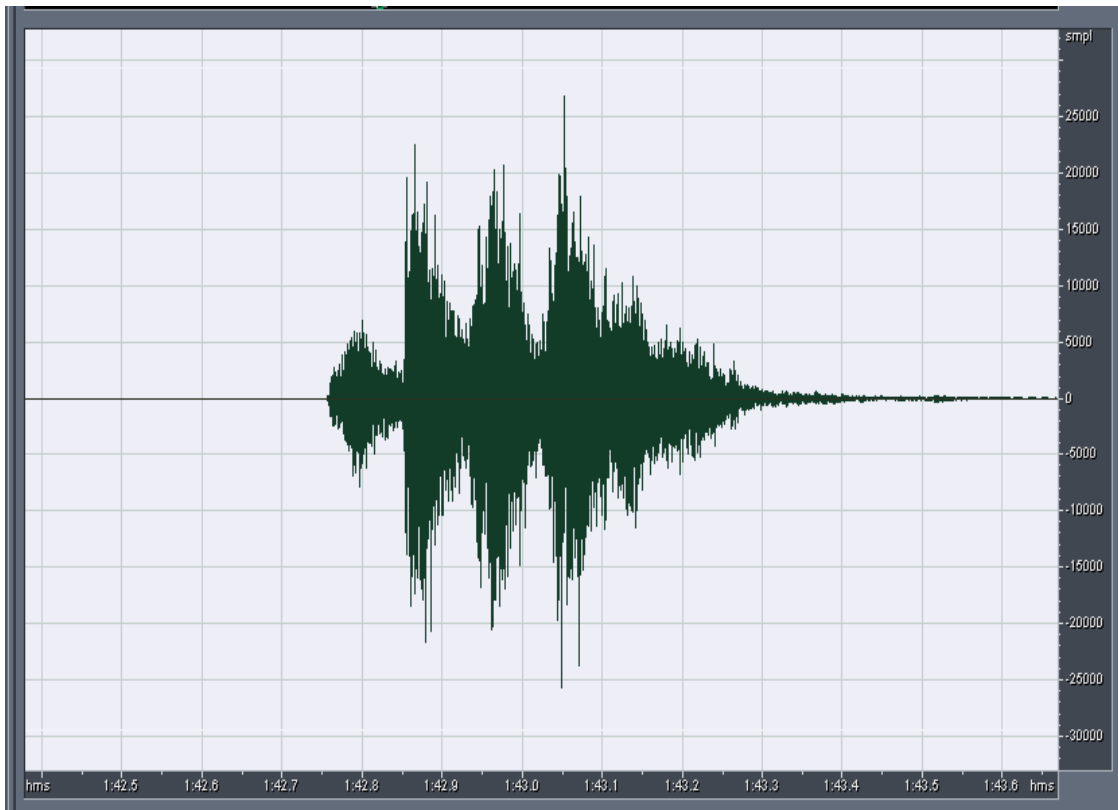


Figure 22: Detailed sound timeline of gate being slammed shut

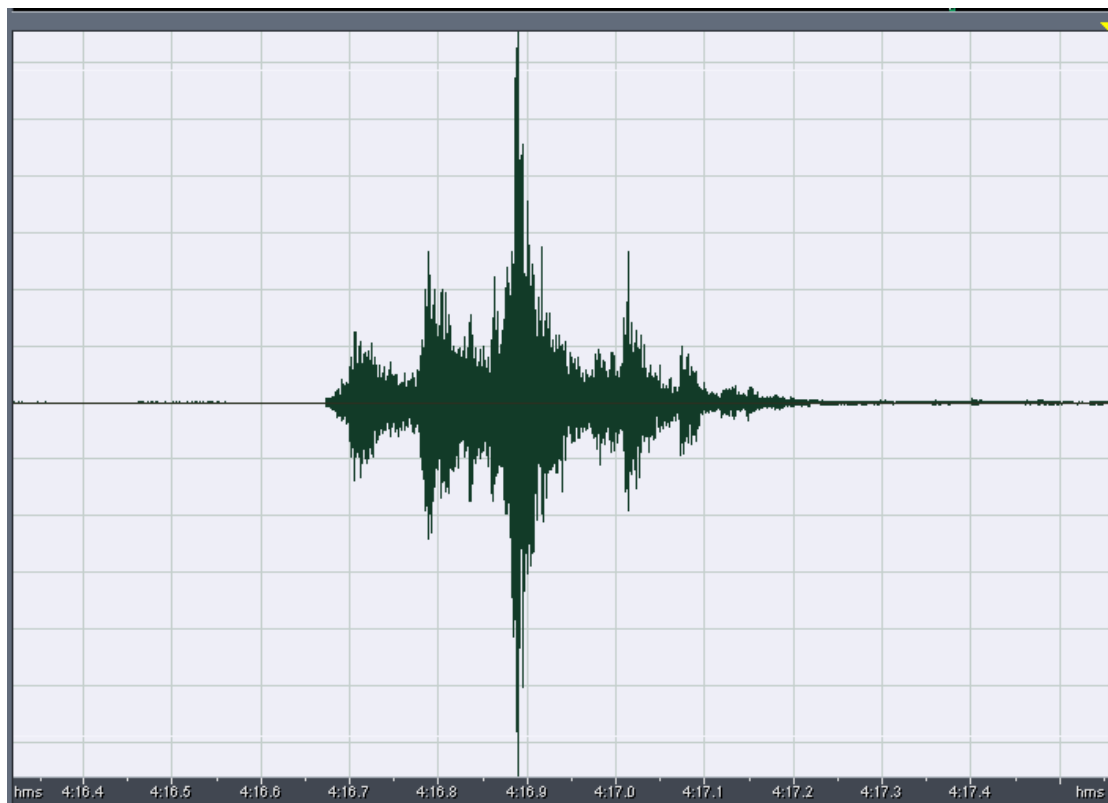


Figure 23: Further sound timeline of a gate being slammed shut

To provide an acoustic stimulus representative of the transient nature of the actual environments encountered, the recording from Figure 21 was edited to remove much of the silence between transients using a sound editing software. The resulting (short) wave file was then repeated several times to create a file of just over 1 minute duration consisting of many closely spaced but otherwise fully representative sound events. This file was used as one of the sound sources in the immunity testing described in Section 4.

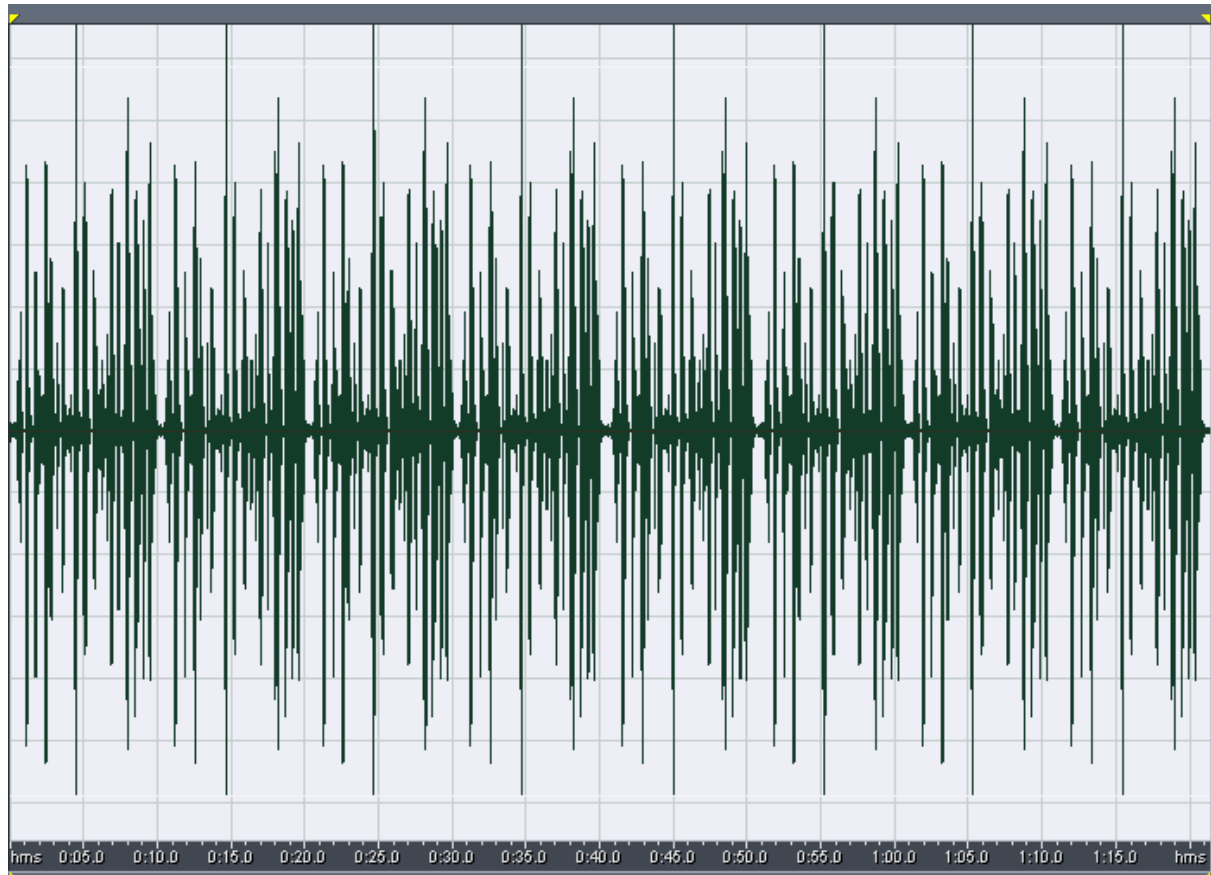


Figure 24: Repeated and condensed timeline of a gate being slammed shut

4 DESIGN OF AN ACOUSTIC IMMUNITY TEST FACILITY

4.1 Frequency Range And Stimulus Levels

Two testing approaches were considered for the acoustic immunity testing:

- Frequency domain: Testing using single frequency signals of known intensity is expected to provide the most information about the susceptibility mechanisms of RFID systems to acoustic stimulus.
- Time Domain: Testing of simulated real life signals are expected to provide better information about the probability of systems being affected by susceptibility to acoustic interference in service.

4.1.1 Frequency domain

The following acoustic interference levels have been derived as described in Section 3 of this report and graphically represented in Figure 20.

Band	Frequency range	Sound Pressure level (dBPa)
1	400Hz to 5kHz	+15dBPa
2	5kHz to 10kHz	+5dBPa
3	10kHz to 50kHz	0dBPa
4	50kHz to 80kHz	-20dBPa

Table 2: Immunity test levels

The interference signals themselves consist of 3rd Octave continuous sine wave signals applied sequentially across the frequency range shown in Table 1.

4.1.2 Time domain

The stimulus signal created from the time domain measurements (Figure 24) is a composite signal, consisting of a complex combination of frequencies and time dependent amplitudes as shown in Figure 21 to Figure 23. Because it is based on the recording of real-life events with the silent periods removed, it represents a more practically based real world immunity test than the application of continuous sine waves.

4.2 Interfering Signal Duration

Figure 21 demonstrates that sound pressure levels of the order of magnitude selected for immunity testing occur in the auction market or abattoir infrequently, and that they appear as noise spikes – high levels of very short duration. To maximise the effect of interference on the systems under test, it was decided to apply the single frequency interfering signals continuously, and measure the degradation in performance in reading the tag data by monitoring the rate at which data is sent.

This method is expected to provide a more severe acoustic environment than one that subjected the equipment to bursts of short duration high intensity sound. However, one of the purposes of the test is to explore whether mechanisms exist which might enable acoustic interference to become a practical problem.

The composite signal method can also be expected to result in a more onerous test than in real-life situations due to the removal of most of the silent periods. It has the advantage however in that the test signal is more representative of the real environment.

4.3 Defining the Degradation of Performance of the Test Samples

The performance of the four RFID systems tested was monitored in each case by setting up a serial communications link from the EUT to a PC, and monitoring the data sent to the PC when a tag is read. When a tag is within range of the sensor antenna, the EUT reads it repeatedly and sends serial data (effectively the tag number) for each successful read operation.

Degradation of the tag reading system performance was monitored by counting the number of times tag data was sent to the PC in a 30 second period. Control sets were taken with no interfering signals present, and any degradation of performance was then expressed as a percentage.

(Example – with no interfering signal a tag is read 25 times in thirty seconds. When interfering signals are present this is reduced to 20 tag readings. The performance result would be shown as 80%.)

4.4 Test Equipment

All tests were performed inside an acoustically shielded room, lined on the walls and ceiling with acoustic absorber. This room is of wooden construction, situated in its own room, remote from test equipment or other noise sources. It provides internal space of 2.2 x 2.5 metres x 2 metres high.

A table, 730mm high, with a 150mm layer of foam rubber on top was placed in the room, opposite the door. The tests were conducted with the RFID tag readers placed in turn on a stand on top of the foam rubber.

Sound pressure levels were monitored from outside the chamber using a Brüel and Kjær Type 4136 measuring microphone located close to the test sensor, the same as used for the on-site testing. This, coupled to a type 2633 preamplifier and powered from a type 2804 power supply unit will accept sound pressure levels up to +78 dBPa with less than 3% distortion, and is calibrated for frequencies up to 80kHz. As with the site measurements, a Hewlett Packard dynamic signal analyser, type HP3561A was used to display the sound pressure level and frequency of the acoustic signal.

The signal source for the single frequency interfering acoustic signals was a Philips PM 5145 wide band signal generator, set to generate a sine wave with output levels up to 5V, continuously variable from the front panel.

The signal source for the compressed composite signal derived from the time domain measurements was a laptop computer. The level was set by replaying the composite signal via the Alto PS4LA active loudspeaker (see below) and adjusting the gain control on the PS4LA amplifier, whilst monitoring the level on the HP3561A dynamic signal analyser.

For high frequency tests (above 10kHz) this was fed into a Harman Kardon stereo amplifier, type HK970, which has a frequency response in excess of 150kHz. This was used to drive an array of ceramic horn tweeters. These have the advantage of being constructed without coils in the drive units, which could otherwise result in magnetic coupling between the tweeters and the RFID tag reader. This meant that the tweeters could be placed close to the sensor board of the tag readers, enabling suitable sound pressure levels to be obtained.

For tests up to 10kHz this method does not give sufficient sound pressure level. Instead a 200W active loudspeaker (Alto PS4LA) was used. This was placed at a distance of 2 metres from the RFID sensor coil. Magnetic field strength follows an inverse cube law for distances from the coil, which are large compared to the coil dimensions.



Figure 25: Immunity test system (test object masked out)

Physical Test Site Layout

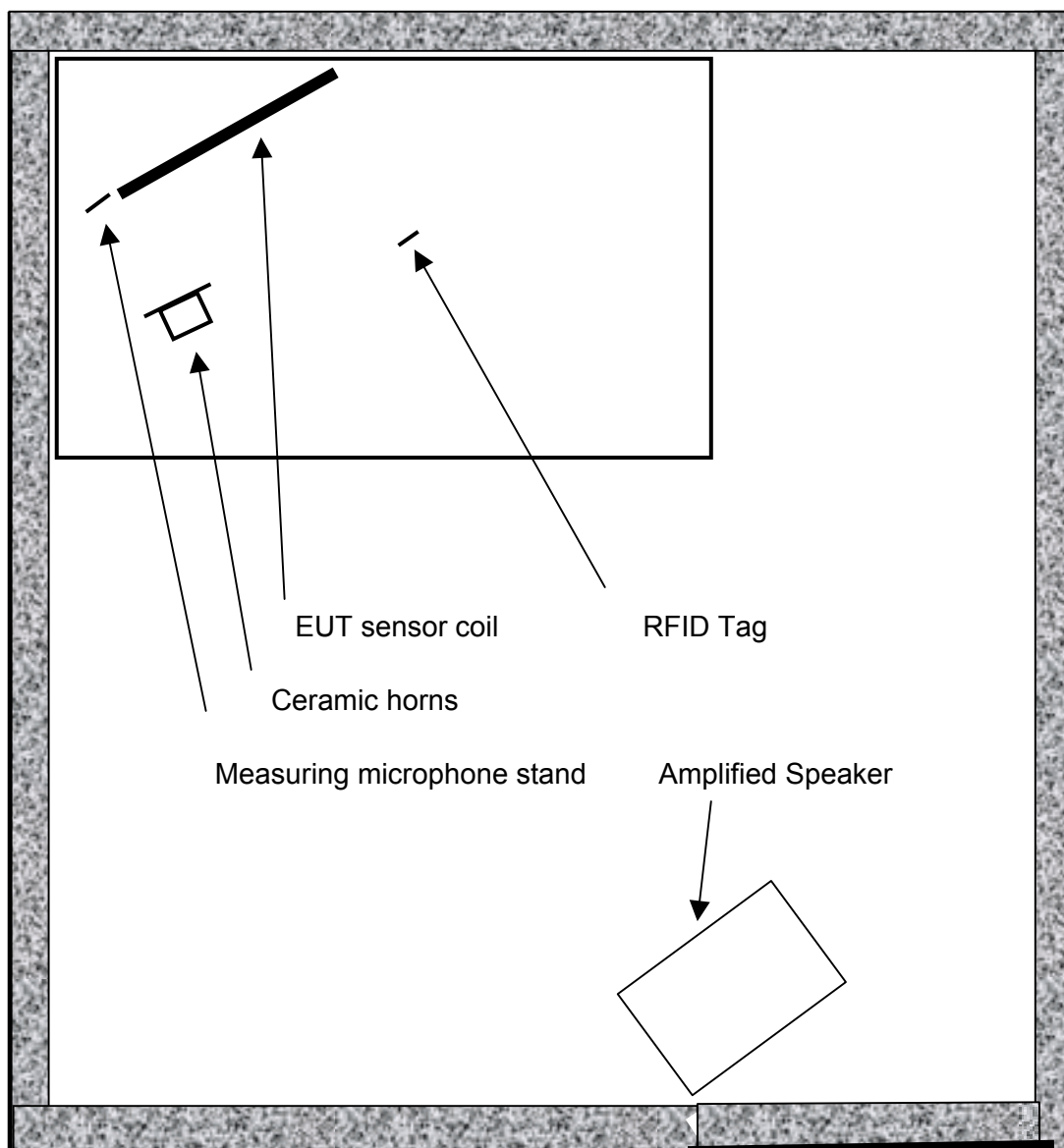


Figure 26: Plan view of the test setup

The RFID tag was placed 400mm in front of the sensor coil. For each coil the pre-test check included ensuring that the tag was reliably detected at this distance. The microphone was positioned close to the edge of the sensor plate.

For the tests using the Alto amplified speaker, the microphone height was set to 320mm above the foam table surface. For tests using the ceramic horn array the microphone height was set to 125mm above the foam table surface such that it was directly in line with the transducers. The Alto speaker was raised 1m from the floor to be directly in line with the sensor plate.

5 ACOUSTIC IMMUNITY TEST RESULTS

5.1 Frequency Domain

Results were recorded for 3rd Octave frequency intervals. For each band, the appropriate level was applied, and it was noted whether the ability to read the tag was impaired at each individual frequency.

In all cases where a degradation in performance was noted, the system performance was observed to recover rapidly when the interfering signal was removed

400Hz to 5kHz with +15 dBPa acoustic signal (Alto amplified Speaker)				
Frequency	Result Sample 1	Result Sample 2	Result Sample 3	Result Sample 4
None	100%	100%	100%	100%
400 Hz	100%	100%	60%	19%
500 Hz	100%	100%	84%	94%
630 Hz	100%	100%	100%	94%
800 Hz	100%	100%	100%	94%
1 kHz	100%	100%	100%	25%
1.25 kHz	100%	100%	100%	100%
1.6 kHz	100%	100%	100%	100%
2 kHz	100%	100%	100%	100%
2.5 kHz	100%	100%	100%	100%
3.15 kHz	100%	100%	100%	100%
4 kHz	100%	100%	100%	100%
5 kHz	100%	100%	100%	100%

Table 3: Results – 400Hz to 5kHz

5kHz to 10kHz with +5 dBPa acoustic signal (Alto amplified Speaker)				
Frequency	Result Sample 1	Result Sample 2	Result Sample 3	Result Sample 4
None	100%	100%	100%	100%
5 kHz	100%	100%	100%	100%
6.3 kHz	100%	100%	100%	100%
8 kHz	100%	100%	100%	100%
10 kHz	100%	100%	100%	100%

Table 4: Results –5kHz to 10kHz

10 kHz to 50 kHz with 0 dBPa acoustic signal (Ceramic Horn Speaker)				
Frequency	Result Sample 1	Result Sample 2	Result Sample 3	Result Sample 4
None	100%	100%	100%	100%
10 kHz	100%	100%	100%	100%
12.5 kHz	100%	100%	100%	100%
16 kHz	100%	100%	100%	100%
20 kHz	100%	100%	100%	100%
25 kHz	100%	100%	95%	97%
31.5 kHz	100%	100%	89%	97%
40 kHz	100%	100%	71%	78%
50 kHz	100%	100%	89%	100%

Table 5: Results –10kHz to 50kHz

50 kHz to 80 kHz with -20 dBPa acoustic signal (Ceramic Horn Speaker)				
Frequency	Result Sample 1	Result Sample 2	Result Sample 3	Result Sample 4
None	100%	100%	100%	100%
50 kHz	100%	100%	100%	100%
63 kHz	100%	100%	100%	86%
80 kHz	100%	100%	58%	61%

Table 6: Results –50kHz to 80kHz

At 80kHz it was also noted that Sample 3 performance dropped to 0% when the acoustic level was increased to -10dBPa. (The ability to read a tag was completely lost in the presence of the interfering signal.)

5.2 Time Domain

The composite signal was amplified and played through the Alto amplified loudspeaker, and degradation of performance was monitored using the same method as for the sinusoidal signals. The test duration was 1 minute for each sample.

Composite signal with peak level of +15 dBPa via the Alto amplified Speaker				
Frequency	Result Sample 1	Result Sample 2	Result Sample 3	Result Sample 4
None	100%	100%	100%	100%
Composite	100%	100%	96%	100%

Table 7: Results –Composite interfering signal

5.3 Summary of immunity testing

5.3.1 Results of Sample 1

None of the acoustic stimuli applied caused any degradation of performance of the tag reader. In addition to the standard sweeps described above, tests were made in the frequency range 300Hz to 5kHz with the maximum sound pressure level achievable from the test system. This varied over the frequency range but was mainly between +20dBPa and +25dBPa. A peak of +27dBPa was recorded at 2kHz. None of these caused any degradation of performance of the tag reader.

There was no degradation in performance noted with the composite recorded signal applied.

5.3.2 Results of Sample 2

There were noticeable effects on the performance of the tag reader during the tests.

5.3.3 Results of Sample 3

There were noticeable effects on the performance of the tag reader when in the presence of an interfering acoustic signal. The following summary can be made, with reference to the table of results.

At 400Hz and 500Hz the tag data being transferred via the serial link slowed when an interfering signal level of +15dBPa was applied, but recovered instantly when the sound source was switched off. At 400Hz the tag reading rate was only 60% of the rate without acoustic interference, and at 500Hz the tag reading rate was 84% of maximum.

The performance was also measurably degraded between 25kHz and 50kHz and at 80kHz. Sample 3 was the only sample to show a degradation in performance with the composite recorded signal applied.

Further exploration of responses revealed that the data transfer fully stopped under the following conditions:

Frequency	Applied level
300 Hz	+11 dBPa
400 Hz	+20 dBPa
2000 Hz	+28 dBPa

Table 8: Further results – sample 3

5.3.4 Results of Sample 4

There were noticeable effects on the performance of the tag reader when in the presence of an interfering acoustic signal. The following summary can be made, with reference to the table of results.

At frequencies up to 1kHz the tag data being transferred via the serial link slowed when an interfering signal level of +15dBPa was applied, but recovered instantly when the sound source was switched off. At 400Hz the tag reading rate was only 19% of the rate without acoustic interference, and at 1kHz the tag reading rate was 25% of maximum.

The performance was also measurably degraded between 25kHz and 40kHz and between 63kHz to 80kHz.

There was no degradation in performance noted with the composite recorded signal applied.

5.4 General Conclusions

Under certain conditions of acoustic stimulus, there was noticeable degradation in performance of two of the four RFID reader systems tested. Care was taken to ensure that it was the acoustic signal causing the observed effect. This included repeating some tests with acoustic foam between the loudspeaker and the EUT. It was found that the observed effects were not present with the sound pressure level reduced in this way, ruling out magnetic or electric coupling as the source of interference.

6 CONCLUSIONS

Acoustic conditions in auction markets and abattoirs give rise to short duration bursts of high intensity sound, resulting from steel gates and impacts against steel barriers. This has considerable high frequency content, extending into the ultrasonic range.

Loud sounds do affect tag reader systems such that their performance is degraded or completely inhibited. Samples 3 and 4 were affected by sound interference during testing, for both frequency swept measurements (Frequency domain) and impulse measurements (time domain).

For samples 3 and 4, susceptibility occurred at low frequencies, in the order of a few hundred Hertz, and with relatively high levels of sound applied, and also between 25 and 40kHz with 0dBPa applied, and at 80kHz at a relatively low level of -20dBPa. For both these samples, high levels of degradation of performance were measured (ranging from 25 % to 94%).

It is possible to manufacture tag reader systems such that they are immune to sounds of the levels likely to be encountered in auction markets and abattoirs. Samples 1 and 2 were not affected by any levels of sound applied during testing including some additional extra high levels at spot frequencies.

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[1] Tender for Investigating The Effect of Acoustic/Mechanical Interference On Radio Frequency Identification (RFID) Systems Used To Identify Animals Electronically, York EMC Services (2007) Ltd, 2333CR1, 4th May 2007.

Appendix 3 Study of Vibration Interference – Report 100802TR1

Issued by SELEX S&AS Environmental Engineering for :-

York EMC Services Limited on the behalf of the Scottish Government.

**A Study of the Susceptibility of Animal Tag Reading RFID
Equipment to Interference from Mechanical Vibration and Shock
Present in the Abattoir and Auction Market Environments for the
Scottish Government**

Prepared by: Graham A. Couser
Function: Environmental Engineering Manager

*Certified that the tests detailed in this report have been carried out as specified with the results shown
The results certified by this report refer only to the items tested
This report is not covered by the laboratory's UKAS accreditation.*

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Change History Sheet

Date	Issue	Page/Para	Description
20.02.2008	draft	-	pre-issue of report
25.03.2008	1		First authorised issue

List of terms and abbreviations

ASD	Acceleration Spectral Density
dB	Decibel
g	Acceleration due to gravity (9.807 m/s ²)
Hz	Hertz (frequency) (1 Hertz = 1 cycle per second)
kHz	kiloHertz (frequency) (1 kHz equals 1000 Hz)
RFID	Radio Frequency Identification
EUT	Equipment Under Test
FFT	Fast Fourier Transform
RMS	Root Mean Square
SRS	Shock Response Spectrum

Executive summary

The Scottish Government have commissioned York EMC Services (2007) Ltd to investigate certain aspects of the functional reliability in service of RFID Tags and their readers when used for identification of farm animals. This includes immunity of the whole system to certain external disturbances.

This report describes the investigation into whether fixed RFID systems are immune to levels of mechanical vibration and shock likely to be found in areas where animal tag reading is expected to become commonplace, such as cattle markets and abattoirs.

Four samples of RFID tag reader were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. The study was conducted on an anonymous basis such that equipment identity is protected.

Surveys were conducted at four sites to measure the mechanical vibration levels experienced close to where the animals would be identified.

The site data was analysed to enable the definition of appropriate levels of vibration and mechanical shock to be used to test the susceptibility of the sample RFID systems to these environmental factors.

The conditions measured in the auction markets and abattoirs consisted mainly of relatively low level random vibration with intermittent superposition of short duration bursts of shock, resulting from steel gates closing, and impacts against steel barriers. The spectral content of these shocks tends to be concentrated in frequencies above 1 kHz and extends beyond this into the range where acoustic coupling of energy can become more significant.

Vibration and mechanical shock testing was performed on the four RFID tag reader systems supplied. The results were analysed and showed that it is possible for vibration and shock to affect tag reader systems such that their performance is degraded or completely inhibited. All samples were affected to various degrees during testing by vibration and shock.

Susceptibility occurred at a range of frequencies across the range tested. The amplitude necessary to produce performance degradation varied from sample to sample but all exhibited some degradation at levels commonly experienced in the environments of a typical abattoir or cattle market.

Some tests were carried out to ensure that the effects seen during testing did result from the direct mechanical stimulus and were not as a result of high acoustic levels which are inevitably present during mechanical testing of this sort.

1. INTRODUCTION

1.1 Background

The Scottish Government have commissioned York EMC Services (2007) Ltd to investigate certain aspects of the functional reliability in service of RFID Tags and their readers when used for identification of farm animals. This includes immunity of the whole system to certain external disturbances. The Environmental Engineering Department of Selex Sensors and Airborne Systems Limited was subcontracted by York EMC to undertake the work relating to mechanical vibration and shock.

As detailed in the Tender document 2333CR1 (York EMC Services (2007) Ltd), There are various physical sources of interference that may cause a reduction in tag reading efficiency, which this study intends to address. These are as follows:

- a) Acoustic High levels of acoustic noise in the environment, for example, due to slamming of steel gates which form the animal pens in markets.
- b) Vibration Vibration of the structure (often metallic) to which panel antennas are fixed, for example, shock and vibration transferred via steel fencing.
- c) Modulation Modulation/modification of the magnetic field produced by the tag reader antenna or detuning of the system due to the presence of ferromagnetic material (typically fencing) or multiple tags in the field. This effect can also be an indirect cause of either a combination of acoustic and/or mechanical vibration.

This report describes the investigation into whether RFID systems are immune to levels of vibration and mechanical shock likely to be found in areas where animal tag reading is expected to become commonplace, such as cattle markets and slaughterhouses.

1.2 Test samples

Four samples of RFID tag reader were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. As this study is not intended to identify specific products or manufacturers, the samples are referred to only as Sample 1, Sample 2, Sample 3 and Sample 4.

Some photographs of the test setup include views of one or more parts of the Tag readers. Care has been taken to blank out any identifiable parts from photographs.

1.3 Test methodology

The following steps were considered for the investigation:

1. Prepare measurement equipment capable of recording the levels of mechanical stimulus over the frequency range required.
2. Survey a number of actual sites where sheep and cattle would regularly be present, and where it would be necessary to identify the animals by their tags. Make measurements there of the vibration levels experienced in locations where it was judged that RFID reader systems would most likely be mounted when in use to identify animals.
3. Analyse the site data. Define appropriate test levels for laboratory vibration and shock tests.
4. Devise a suitable mounting system to enable the performance of the readers to be assessed during conditions of vibration or shock.
5. Perform testing on the four RFID tag reader systems supplied. Analyse the results and make any appropriate conclusions.

2. PRELIMINARY INVESTIGATIONS AND SITE MEASUREMENTS

2.1 Test Equipment

Measurements of vibration were made using a PCB type 356A11 triaxial ICP accelerometer.

This will measure acceleration levels up to 500g with a measurement uncertainty of 5%, and was calibrated for frequencies up to 10 kHz. It also provides a good indication (un-calibrated) of acceleration in the frequency range 10 kHz to 20 kHz.

The accelerometer signal was fed to a 4 channel M+P dynamic signal analyser system. This consists of a 4 channel National Instruments Type 9233 analogue to digital converter connecting via a USB interface to laptop computer on which is run the M+P Smart Office software. This set up enables data to be measured and stored in a wide variety of ways.

During the site measurement programme acceleration signals were generally captured as time histories, although on a few occasions the data was processed as it was captured using a Fast Fourier Transform (FFT) to give Acceleration Spectral Density (ASD) results in the frequency domain.

The system used in any case allows post processing of the data to enable data to be analysed both in the time and frequency domain.

Measurements were made across a number of different frequency ranges up to 25 kHz to enable the environment to be fully evaluated but since mechanical factors are most likely to be significant at lower frequencies, and since vibration test equipment generally only operates up to a few kHz the majority of measurement was carried out in the range 0 to 10kHz.

2.2 Choice Of Test Locations

All movements of cattle have to be reported to the British Cattle Movement Service (BCMS). This organisation operates the Cattle Tracing System (CTS). This is a database where all the movements of cattle registered or imported into Great Britain are recorded

European legislation requires cattle keepers report both the "off" holding and "on" to next holding movements to the database, as well as in their own herd registers. Fast and accurate reporting of movements to the database allows traceability of cattle from birth to entry to the human food chain, and in the event of a disease outbreak. Keepers of cattle are legally obliged to notify movements of cattle within 3 days of the event, and the death of an animal within 7 days.

The following movements of cattle must be reported to BCMS:

- On and off farms
- To and from markets
- To slaughterhouses

There is inherent feedback in the process of reading the ID tag of a single animal on a farm, using a hand held reader. The operator applies the tag reader until a confirmed reading is registered. This process however is not ideal where bulk animal movements are involved, and considerable benefit results from reliable automatic reading of ID tags. Markets and slaughterhouses are therefore the places where the most benefit results, but can also provide a difficult environment for automated reading systems. Field tests were therefore performed at cattle markets and abattoirs.

2.3 Locations and Measurement Dates

Four sites were used to collect research data:

- | | | | |
|----|---|------------|----------------|
| 1) | Scotbeef Ltd
Longleys
Bridge Of Allan
Stirling,
Stirlingshire
FK9 4NE | 20/11/2007 | Abattoir |
| 2) | United Auctions Ltd
Stirling Auction Market
Kildean
Stirling
Stirlingshire
FK9 4UB | 21/11/2007 | Auction market |
| 3) | McIntosh Donald Ltd
The Meat Factory
Portlethen
Aberdeen
AB12 4QB | 29/11/2007 | Abattoir |
| 4) | ANM Group Ltd
Thainstone Centre
Inverurie
Aberdeenshire
Scotland
AB51 5XZ | 30/11/2007 | Auction market |

2.4 Location of Measurement Points

At each site measurements were taken by mounting an accelerometer on an appropriate structure. These were chosen to represent likely locations where RFID readers would need to be positioned to enable stock tags to be read. These can be summarised as follows:

1) Bridge of Allan

- On metal structure of race leading to sheep stun
- On metal structure at entry to cattle kill station (Hydraulic cattle handling system)
- On concrete structure of race leading to cattle kill station

2) Stirling

- On weighbridge support structure at entrance to Cattle Ring
- On weighbridge structure at entrance to Cattle Ring
- On steel fence leading to weighbridge at entrance to Cattle Ring

3) Portlethen

- On steel fence of race leading to cattle kill station
- On structure adjacent to Head Clamp (To enable reading of ear tags)

4) Inverurie

- On upright of gate leading to weighbridge at entrance to Cattle Ring
- On Pen gate upright (At point where ear tags are currently manually read)
- On weighbridge structure at entrance to Cattle Ring

In all cases a triaxial accelerometer was used and measurements were therefore taken in three orthogonal directions (Vertical and two Horizontal axes).

3. ANALYSIS OF SITE DATA

Primary raw site data were recorded in the form of time histories. In some cases these were free running samples lasting typically between 60s and 300s. In other cases a trigger was used to capture short samples of high amplitude events.

An initial analysis of these show that the characteristic signal consists of a relatively low level background level vibration of a largely random nature with irregularly spaced, but at times frequent, high level transient pulses. These latter were observed at the time of measurement to coincide with particular events such as slamming of gates, operation of items of machinery, and the like. A typical measurement period is shown below.

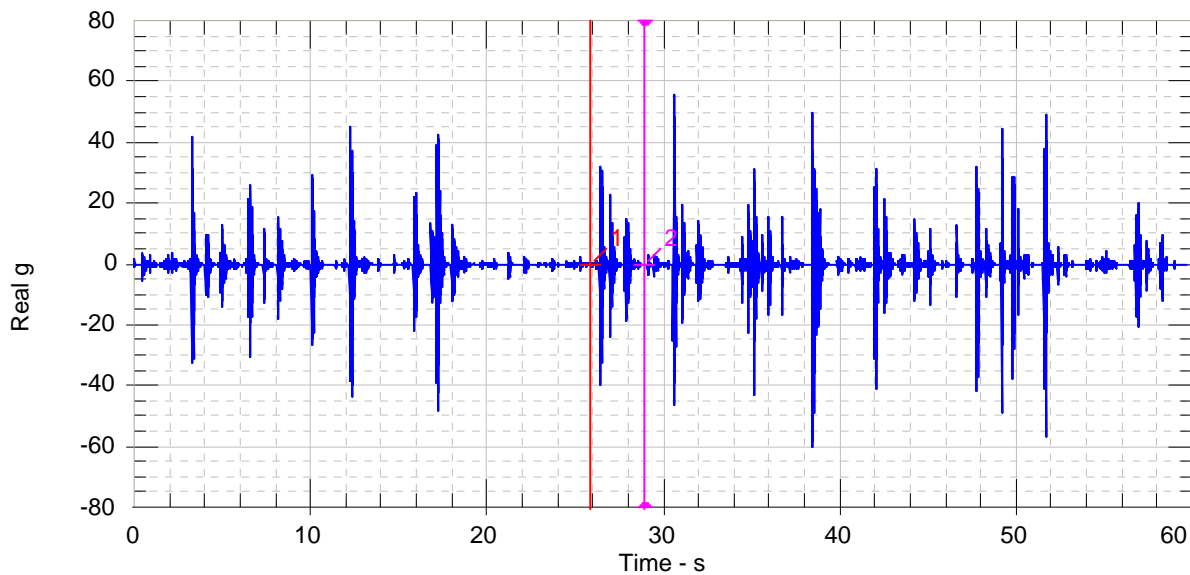


Figure 1: Typical measurement of shock and vibration seen by RFID reader

The section of the measurement between the cursors has been expanded below to show the detail of that event

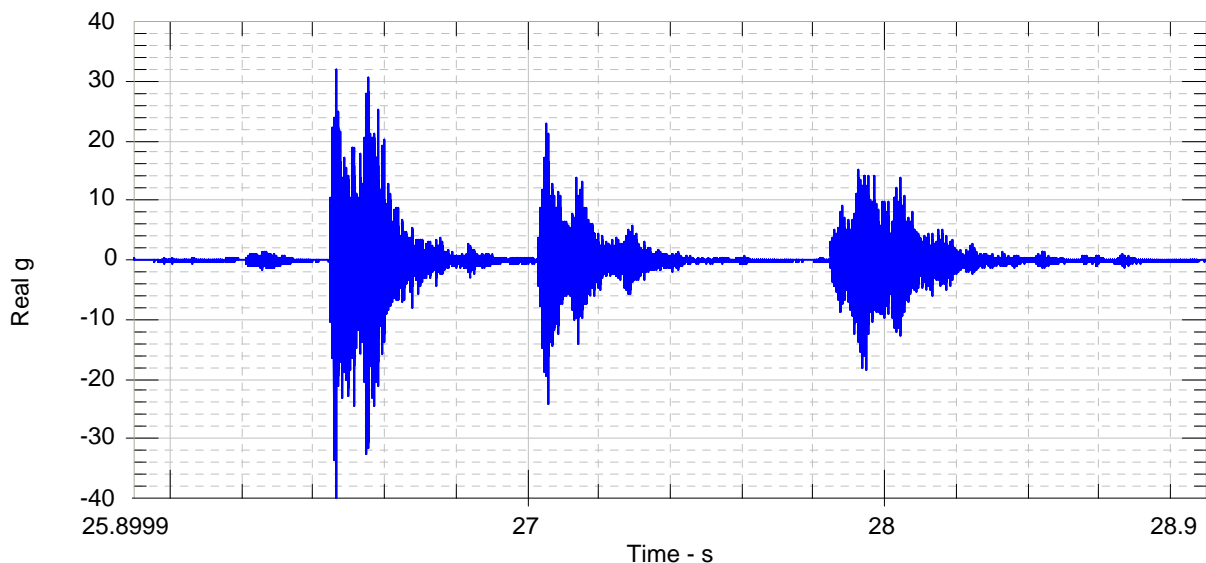


Figure 2: Expansion of Data in Figure 1

Analyses were performed of typical time histories using Fast Fourier Transform (FFT) techniques to give an understanding of the environment in the frequency domain and allow a representative vibration test level to be developed. Figure 3 shows a typical plot.

The Y axis shows Acceleration Spectral Density in g^2/Hz using a logarithmic display. The X axis is a logarithmic display of frequency from zero to 5 kHz.

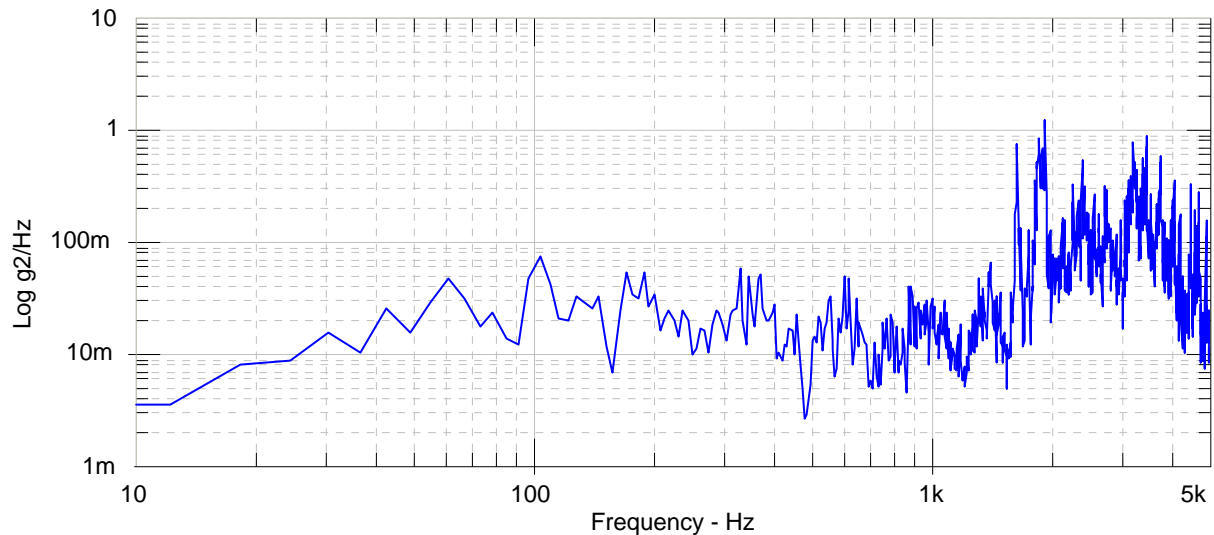


Figure 3: Typical Acceleration Spectral Density Plot of Site Measurement

Although measurements were taken in three axes, it was found that there were only minor differences between the levels measured in each direction. In each position measured one direction would usually tend to show higher levels but this direction was not consistently any one direction and depended upon the local structure and its dynamic characteristics.

The levels of vibration caused by movements of the stock themselves were generally small. There were however exceptions to this when an animal would become agitated and kick or collide forcibly with the structure. These events however tended to cause lower frequency acceleration.

Annex A contains sample sets of graphical results for each of the four locations.

3.1 Typical Vibration Levels

The data summarised in Annex A was further summarised to try to establish a suitable test level to be applied to the RFID reader systems in the laboratory in order to establish their capability to function reliably in an environment such as an auction mart or abattoir.

Two frequency bands were considered, 10 Hz to 1 kHz, and 1 kHz to 5 kHz. Although significant levels of vibration were measured in excess of this range, at these high frequencies there is little mechanical displacement and the effect of such vibration was judged unlikely to be significant on the performance of the system.

Table 1 summarises worst case levels seen at each site. They represent peak hold averages of data taken in a number of positions during normal operation of the site.

Table 1: Summary of Measurements made at All Sites (Peak Hold Average)

Site	Frequency Band			
	10 Hz to 1 kHz		1 kHz to 5 kHz	
	RMS (g)	Mean ASD (g ² /Hz)	RMS (g)	Mean ASD (g ² /Hz)
Bridge of Allan	2.89	0.008	1.75	0.0006
Stirling	12.2	0.15	2.2	0.00096
Portlethen	10.2	0.10	91.0	1.65
Inverurie	4.47	.02	21.47	0.12

There is clearly considerable variation between sites, but the extremely high levels seen for example between 1 kHz and 5 kHz at Portlethen and Inverurie were largely a result of particularly high local resonance of the structure in the area where measurements were made. These could clearly vary substantially from site to site so the approach taken in setting appropriate vibration levels was to set a limit somewhat below these extreme levels.

3.2 Test Procedure

Since the assessment of measurement data demonstrated that the environment likely to be seen by readers when installed consisted of both vibration and short term transients a test programme was designed to test both susceptibility to random vibration and to shock events. In addition a sinusoidal test based on the levels specified in Technical Guidelines for Council Regulations No. 21/2004 of 17/12/2003 was also applied.

3.2.1 Random Vibration Test Procedure

To assess the sensitivity of the readers to random vibration three separate sequences of random vibration were applied. These were applied in two discrete frequency bands so that the sensitivity to lower and higher frequencies could be explored. The upper frequency applied was 3 kHz as the vibration system used to perform the testing could not reliably control frequencies above this.

To give a better assessment of sensitivity to applied level of vibration the amplitude of the applied vibration was gradually stepped up in 3dB increments to full level (0dB). Thirty seconds of vibration was applied at each level.

The following outlines the programme of tests that was applied.

1) Random Vibration Test 1

Frequency: 10 Hz to 1000 Hz
ASD: 0.001 g²/Hz
Overall RMS: 1.0g
Test Axes: Each of three orthogonal axes in turn.

30 seconds vibration was applied at each level from -15dB to 0dB.

2) Random Vibration Test 2

Frequency: 1000 Hz to 3000 Hz
Level: 0.1 g²/Hz
Overall RMS: 14g
Test Axes: Each of three orthogonal axes in turn.

30 seconds vibration was applied at each level from -15dB to 0dB.

3) Random Vibration Test 3

Frequency: 10 Hz to 1000 Hz
Level: 0.01 g²/Hz
Overall RMS: 3.4g
Test Axes: Each of three orthogonal axes in turn.

30 seconds vibration was applied at each level from -12dB to 0dB.

3.2.2 Sine Vibration Test Procedure

To give an additional insight into the frequency dependence of any degradation in performance of the readers under vibration and also to give an assessment against the test levels suggested in Technical Guidelines for Council Regulations No. 21/2004 of 17/12/2003 a sine vibration test was also carried out.

The test level applied was as follows which is half that specified in the referenced document.

Sine Vibration

Frequency: 5 Hz to 2000 Hz
 Level: 5g
 Sweep Rate: 1 octave/minute
 Test Axes: Each of three orthogonal axes in turn.

3.2.3 Shock Test Procedure

Since much of the high amplitude energy measured during the site surveys was of the form of short transient events it was decided to also assess the readers using a shock test method.

To establish a suitable test level, Shock Response Spectra of a number of representative pulses measured during the site surveys were calculated and a test spectrum which enveloped the majority of the spectra of the measured data but ignoring the extreme peaks was developed.

The following plots shows a number of measured spectra compared to the test spectrum

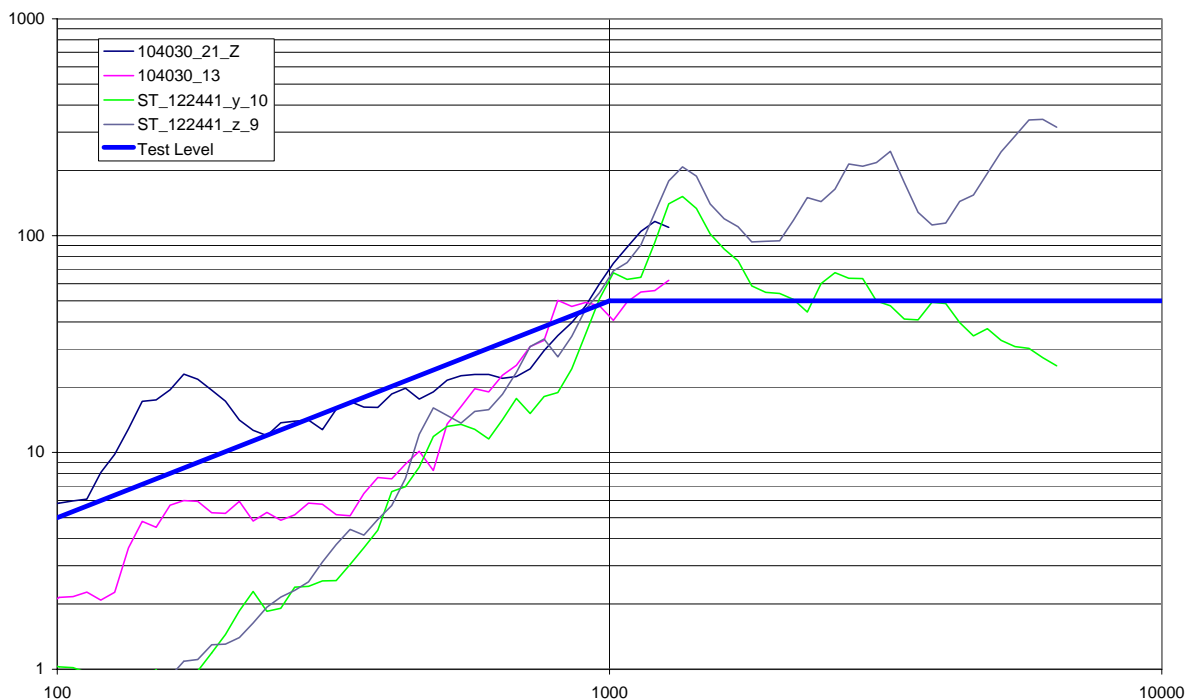


Figure 4: Shock Response Spectra of Measured data compared to test level

Table 2: Shock Test Spectrum

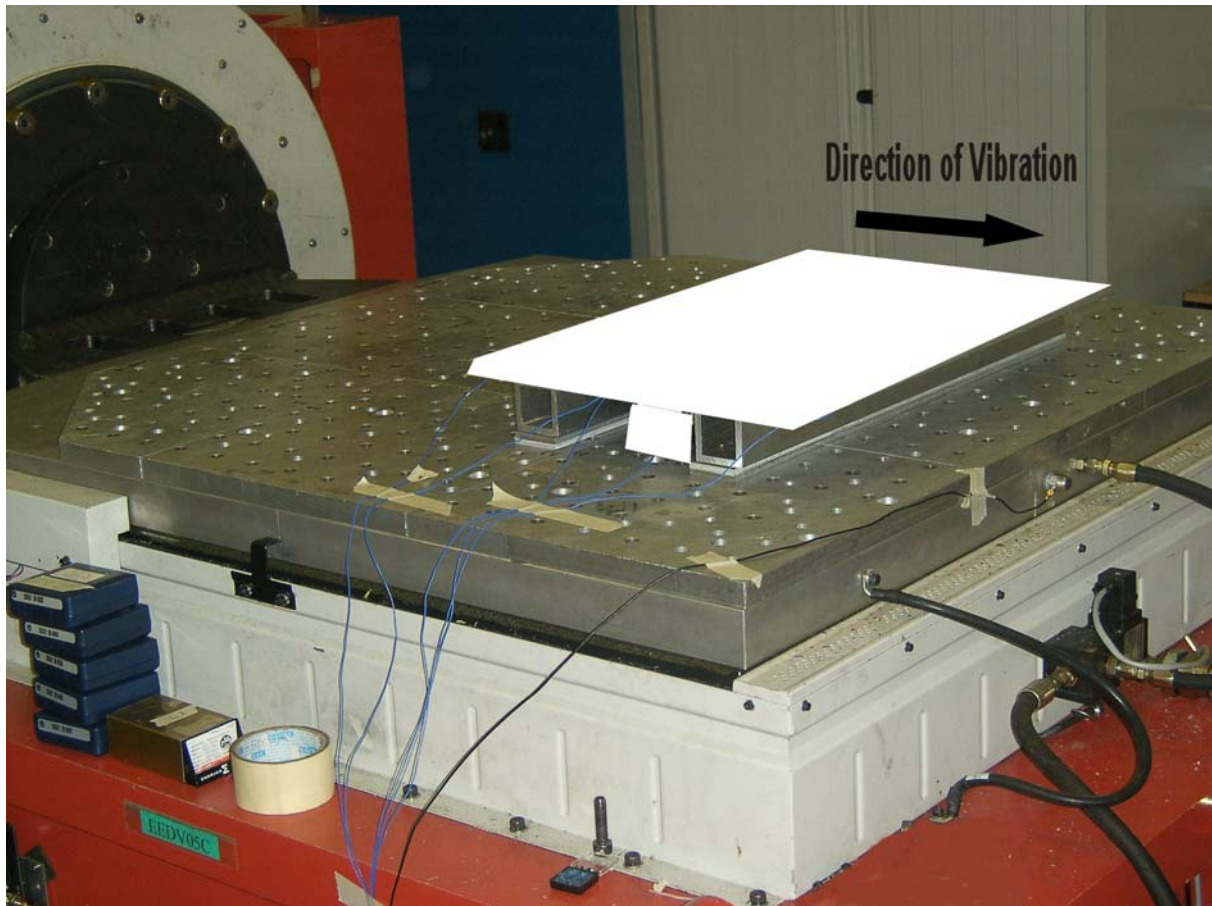
Frequency (Hz)	Acceleration (g) Q=10
10	5
1000	50
10000	50

Shocks meeting this spectrum were applied to each of the readers in one axis (Z – Vertical) only using the SRS synthesis and control mode of the vibration system. Shock were applied at intervals of 2s over a 30s period during which the performance of the readers was measured.

3.3 Vibration Test Configuration

All vibration and shock tests were performed in the Selex test facility at the Crewe Toll Edinburgh site using the equipment listed in Annex B.

Testing was started with Sample 1 mounted onto the vibration table using square section Aluminium tube as shown in Photograph 1 below.



Photograph 1: Vibration Test Set up for Sample 1 in X axis.

The tag to be read was suspended a distance of 20cm above the reader for all RFID systems.

The same approach was initially used for Sample 2, but it was found that the reader would not reliably read in this configuration as it seemed to be unable to deal with the close proximity of the vibration table itself. (N.B. The vibration table is magnesium alloy and is supported on a granite bed so there were no magnetic materials in the immediate vicinity of the reader).

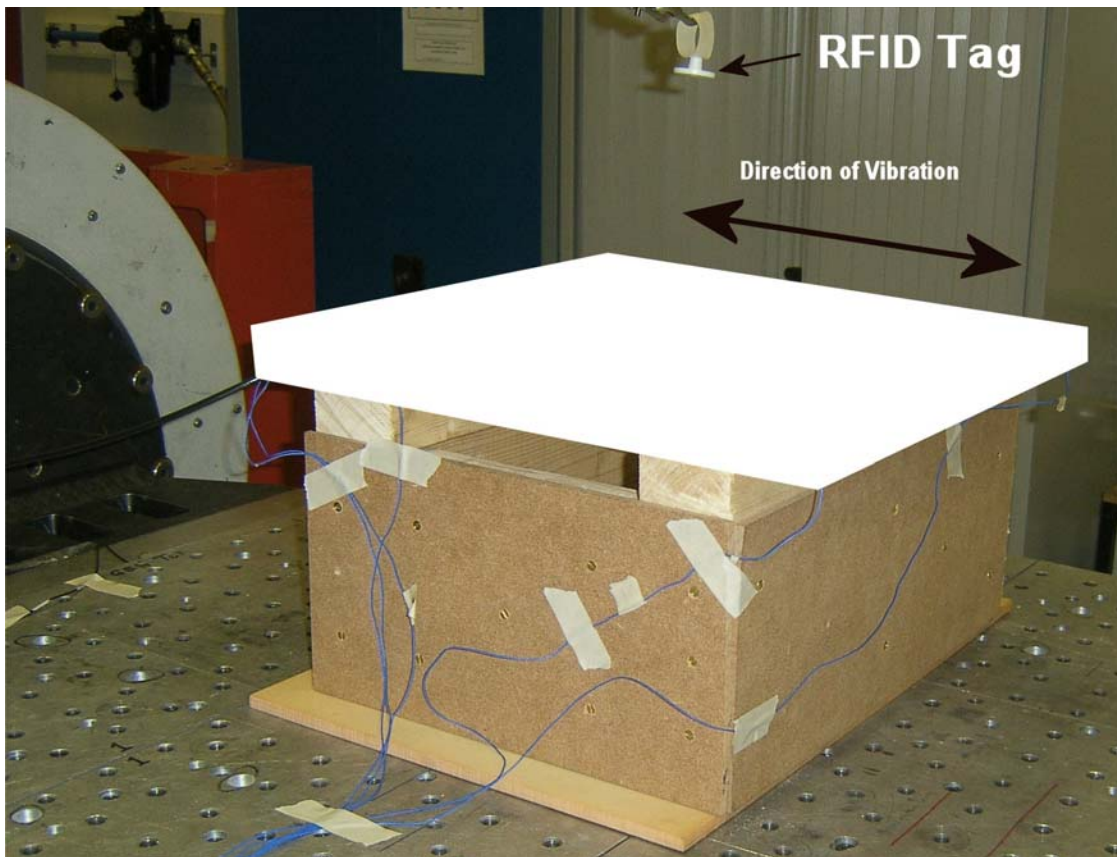
Tests showed that Samples 3 and 4 were even more sensitive to proximity to the vibration table so a fixture constructed from wood and MDF was manufactured (See Photographs 2 and 3). This was used for all vibration testing of Samples 2, 3 and 4 and for shock testing of all four samples.

Measurement accelerometers were mounted on each sample during vibration testing to enable correlation of any changes in performance of the samples with resonant behaviour of the samples.

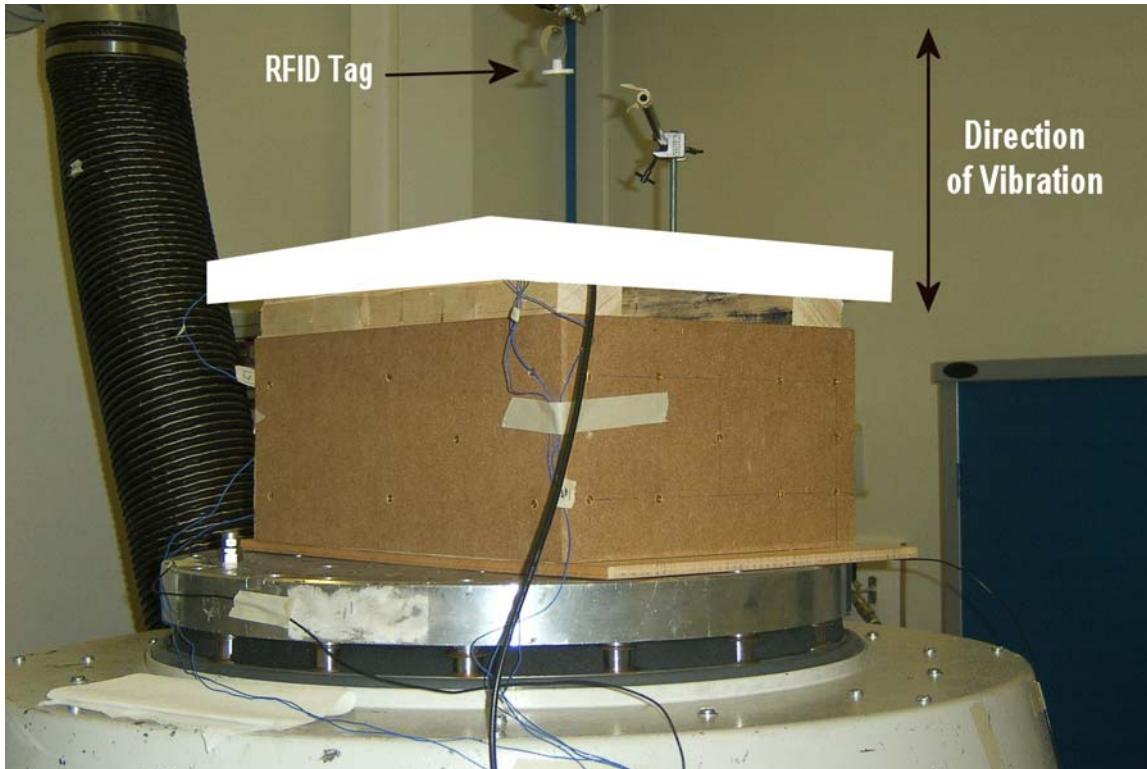
Measurements were taken both in the axis of vibration and in both directions normal to it.

Baseline performance measurements were made on the samples both with the vibration system field energised and without to ensure that there were no effects of this field on the performance of the samples.

Additional checks were carried out with vibration system running as per the high frequency random vibration test but with the samples placed next to the system so that they were not subjected to vibration, but were subjected to the high levels of acoustic noise levels inevitably present during testing of this type. These tests confirmed that the noise itself had no effect on the operation of the samples.



Photograph 2: Test set up for X axis Vibration
(Y axis set up was similar but with test fixture rotated through 90 degrees)



Photograph 3: Test set up for Z axis Vibration

4. VIBRATION TEST RESULTS

During the vibration test programme, the operation of the readers was assessed by placing a tag in a position where it could be continually read by the reader and then timing the time taken to take a number of readings. The exact method used varied from sample to sample dependant on the software available to interrogate each reader. Baseline measurements were taken for each unit in each mounting configuration with no vibration applied. These baselines were used to normalise the data such that 100% represents normal baseline operation. This approach facilitates the direct comparison in the degradation of performance between the various samples.

The results for the four samples are tabulated in the following tables. It should be noted that the results from the two low frequency (10-1kHz) vibration tests have been combined, the test levels being referred to the maximum (0dB) level for the higher level (0.01g²/Hz) test.

4.1 Unit: Sample 1

General information:

Reading rate with no stress applied: 30 readings in 49s ±1.5%
RFID tag placed 20 cm centred away from reader panel
Panel reader fixed with 6 screws

Table 3: Test Results for Sample 1 - Low Frequency Random Test

Frequency range: 10 Hz to 1kHz (Random) – Level 0.01g ² /Hz			
Level – dB	Performance		
	X Axis	Y Axis	Z Axis
-25	100%	100%	100%
-22	100%	100%	100%
-19	100%	100%	98%
-16	100%	100%	83%
-13	100%	100%	55%
-12	100%	100%	43%
-10	100%	100%	29%
-9	100%	99%	17%
-6	100%	98%	0%
-3	100%	93%	0%
0	100%	62%	0%

Table 4: Test Results for Sample 1 - High Frequency Random Test

Frequency range: 1kHz to 3kHz (Random)			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-15	100%	95%	100%
-12	90%	66%	99%
-9	75%	0%	93%
-6	27%	0%	27%
-3	0%	0%	0%
0	0%	0%	0%

Table 5: Test Results for Sample 1 - Sine Sweep Test

Level: 5g (Sinusoidal) 10 Hz to 2000 Hz					
X Axis		Y Axis		Z Axis	
Freq (Hz)	Performance	Freq (Hz)	Performance	Freq (Hz)	Performance
13-16.5	100%	11.44-13.85	97%	10.80-13.02	99%
21-24.5	100%	18.9-23.83	100%	20.22-24.12	100%
54	System stopped reading and recovered at 72 Hz	27.59-32.9	100%	56	0% Recovered at 308 Hz
121-153	93%	43-52.7	89%	396	0% Recovered at 440 Hz
178	0% multiple partial recoveries at 268Hz, 433Hz	62.3	80%	530-600	77%
953-1179	94%	152-186	93%	803-880	100%
1440	0%	233	0% recovered at 250 Hz	1079-978	100%
		436-533	83%	1428-1507	100%
		663-799	97%		
		866	0% recovered at 1079 Hz		

Sample 1 was the least affected by vibration of the four samples tested although it did start to reduce in performance as the level of vibration increased and eventually would stop working altogether. It automatically recovered when vibration was removed.

This sample was most sensitive to high frequency vibration in the Y (longitudinal) axis. In the axis normal to the plane of the reader (Z axis) it was most sensitive to low frequency vibration.

Monitor accelerometers were placed on the sample during test to enable dynamic modes of the sample to be measured. Two example plots are shown in Figures 5 and 6.

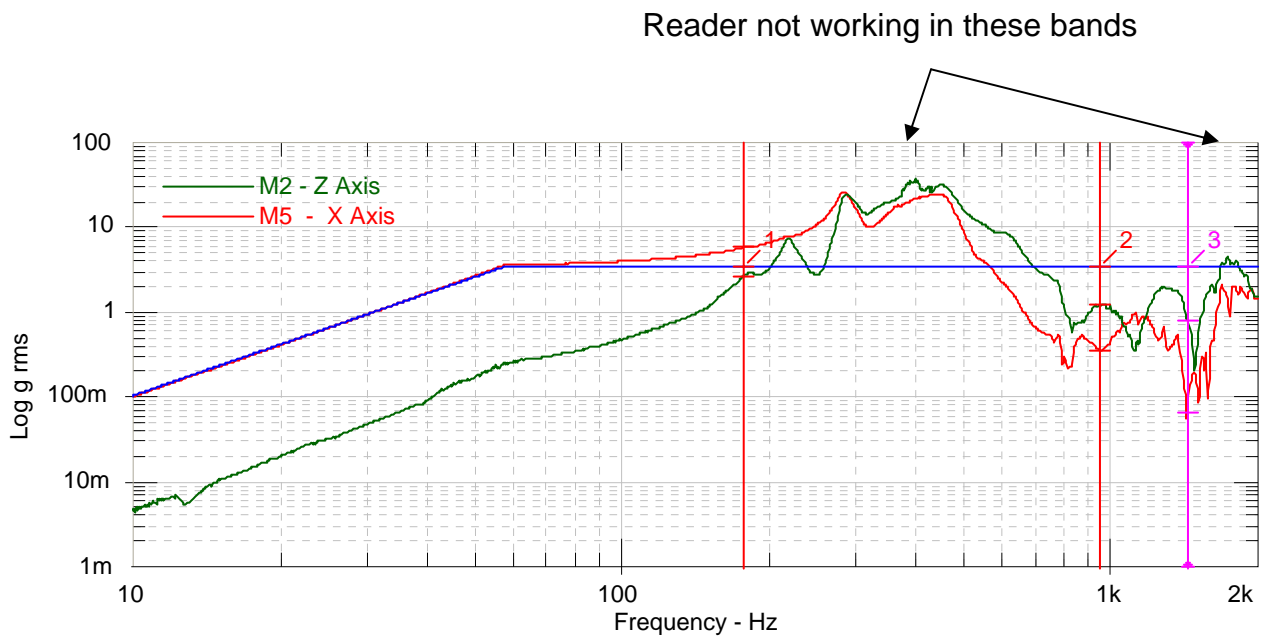


Figure 5: Measured response in X axis for Sample 1 during Sine Sweep test.

It can be seen in Figures 5 and 6 that the frequency bands across which the sample was not reading coincide with measured resonance of the unit.

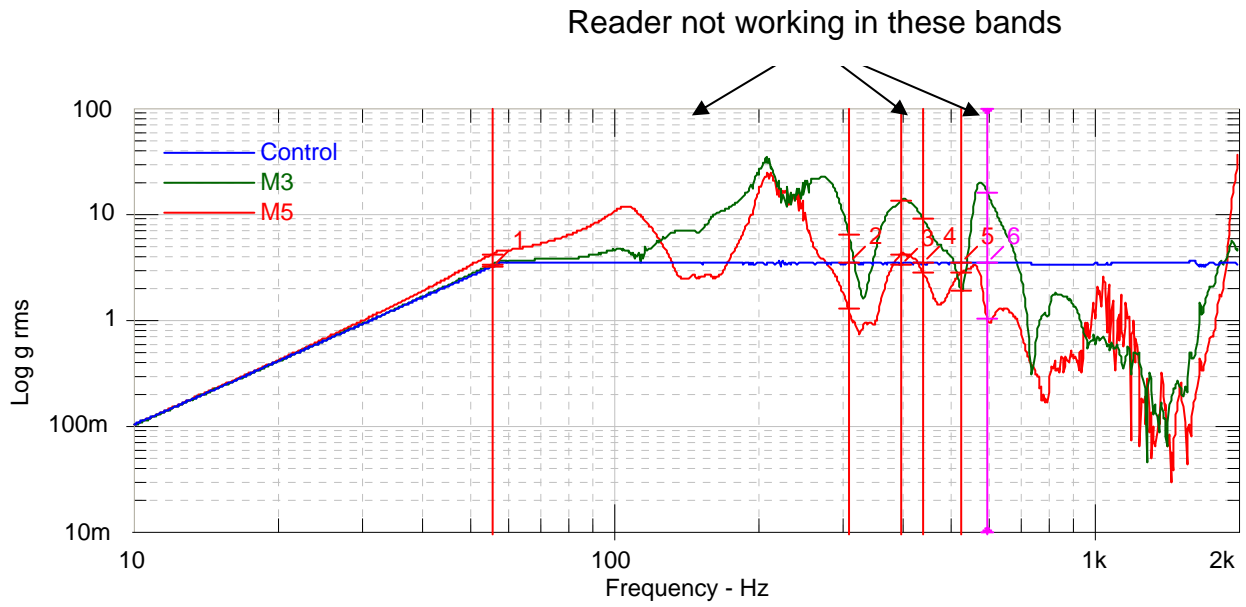


Figure 6: Measured response in Z axis for Sample 1 during Sine Sweep test.

4.2 Unit: Sample 2

General information:

Reading rate with no stress applied: 22 readings in 60s ±5%

RFID tag placed 20 cm centred away from reader panel

Panel reader fixed with 6 screws

Table 6: Test Results for Sample 2 - Low Frequency Random Test

Frequency range: 10 Hz to 1kHz (Random) – Level 0.01g ² /Hz			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-25	91%	100%	91%
-22	64%	82%	91%
-19	36%	64%	77%
-16	18%	64%	50%
-13	N/A	55%	0%
-12	9%	9%	9%
-10	55%	18%	0%
-9	0%	0%	0%
-6	18%	0%	0%
-3	0%	0%	0%
0	0%	0%	0%

Table 7: Test Results for Sample 2 - High Frequency Random Test

Frequency range: 1kHz to 3kHz (Random)			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-15	55%	18%	0%
-12	27%	0%	0%
-9	9%	0%	0%
-6	0%	0%	0%
-3	0%	0%	0%
0	0%	0%	0%

Table 8: Test Results for Sample 2 - Sine Sweep Test

Level: 5g (Sinusoidal) 10 Hz to 2000 Hz					
X Axis		Y Axis		Z Axis	
Freq (Hz)	Performance	Freq (Hz)	Performance	Freq (Hz)	Performance
10 to 15	100%	12 to 16	100%	17 to 24	100%
18 to 25	100%	20 to 27	100%	29 to 1377	0%
28 to 35	68%	32 to 39	76%	1525 to 2000	100%
35 to 235	Not Reading	40 to 1400	Reading slow and intermittent		
235 to 440	Starting and stopping intermittently	1450 to 2000	100%		
480 to 2000	100%				

Sample 2 was much more affected by vibration and began to degrade in performance even at -25dB at low frequency. At high frequency it barely functioned at all giving no better than 55% readings at -15dB and not functioning in Z axis at any level.

Similarly during the sine sweep the unit failed to read across large frequency bands. Figure 7 and 8 below shows responses measured during the X and Z axis sine sweep tests respectively. The correlation of performance with individual resonances is less obvious than for sample 1 but as there are many strong resonances across most of the test spectrum it is likely that many of these are affecting the performance of the reader but the major collapse of measurement in the X axis for example does correlate with the presence of a number of strong resonances in the response (See Fig 7).

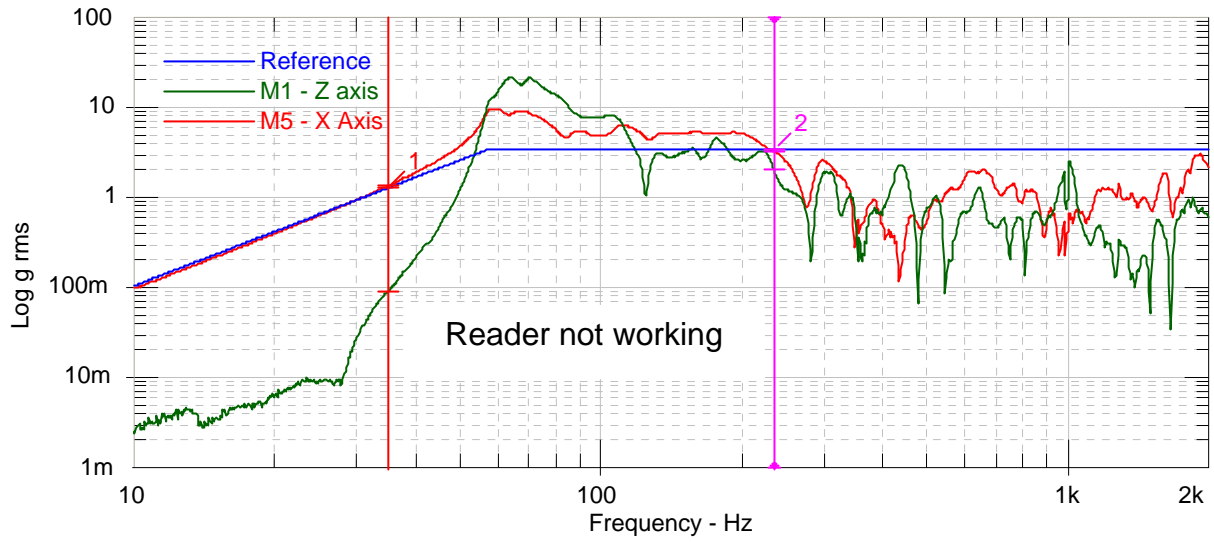


Figure 7: Measured response in X axis for Sample 2 during Sine Sweep test.

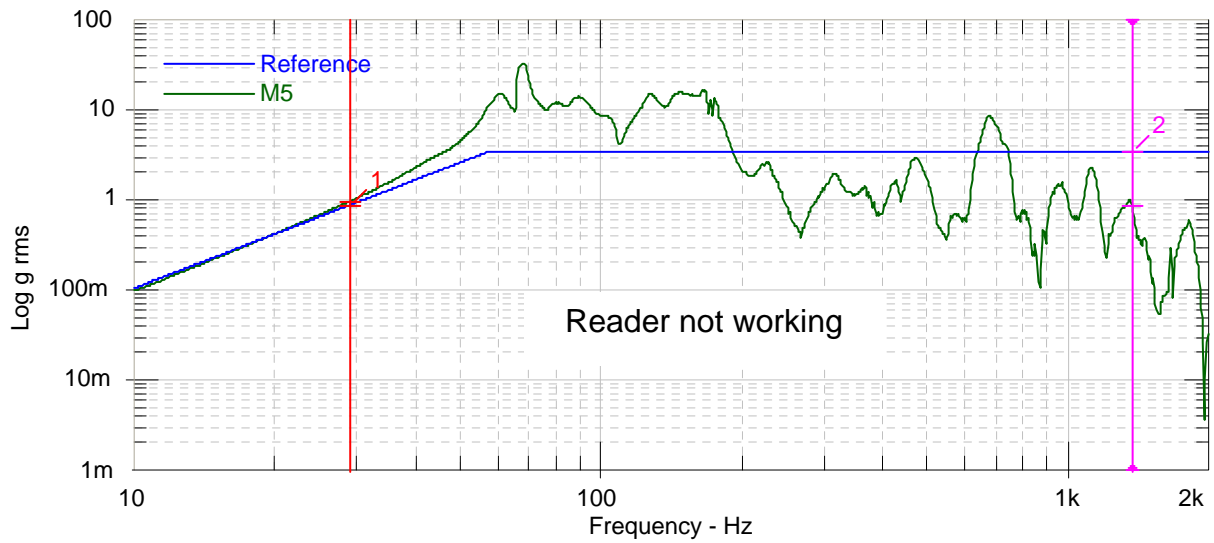


Figure 8: Measured response in Z axis for Sample 2 during Sine Sweep test.

4.3 Unit: Sample 3

General information:

Reading rate with no stress applied: 410 readings in 60 seconds

RFID tag placed 20 cm centred away from reader panel

Panel reader fixed with 6 screws

Table 9: Test Results for Sample 3 - Low Frequency Random Test

Frequency range: 10 Hz to 1kHz (Random) – Level 0.01g ² /Hz			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-25	100%	100%	100%
-22	82%	100%	95%
-19	51%	92%	99%
-16	43%	81%	85%
-15	56%	44%	88%
-13	43%	40%	72%
-12	49%	34%	60%
-10	16%	5%	23%
-9	20%	7%	26%
-6	4%	1%	1%
-3	0%	1%	0%
0	0%	0%	0%

Table 10: Test Results for Sample 3 - High Frequency Random Test

Frequency range: 1kHz to 3kHz (Random)			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-15	10%	29%	20%
-12	4%	9%	2%
-9	1%	1%	0%
-6	0%	0%	0%
-3	0%	0%	0%
0	0%	0%	0%

Table 11: Test Results for Sample 3 - Sine Sweep Test

Level: 5g (Sinusoidal) 10 Hz to 2000 Hz					
X Axis		Y Axis		Z Axis	
Frequency (Hz)	Performance	Frequency (Hz)	Performance	Frequency (Hz)	Performance
11.5 to 16	100%	13 to 18.5	97%	10-31	100%
27.7 to 38	79%	32 to 690	Reading intermittently and very slowly	32-51	Very intermittent readings
50 to 1200	Intermittent readings	1240 to 1910	70%	55	System stopped reading completely
1200 to 1800	9%			480 to 550	Extremely Intermittent
				1750-1870	100%

Sample 3 was significantly affected by vibration from a very low level although it did not stop completely until higher levels than Sample 2. It was more sensitive to the high frequency vibration than the low frequency vibration.

This sample barely functioned at all during the sine sweep test.

4.4 Unit: Sample 4

General information:

Reading rate with no stress applied: 176 readings in 30 seconds

RFID tag placed 20 cm centred away from reader panel

Panel reader fixed with 6 screws

Table 12: Test Results for Sample 4 - Low Frequency Random Test

Frequency range: 10 Hz to 1kHz (Random) – Level 0.01g ² /Hz			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-25	97%	100%	78%
-22	97%	98%	51%
-19	94%	96%	36%
-16	91%	97%	14%
-15	85%	85%	7%
-13	72%	63%	6%
-12	85%	57%	1%
-10	51%	31%	0%
-9	39%	15%	1%
-6	26%	0%	0%
-3	0%	0%	0%
0	0%	0%	0%

Table 13: Test Results for Sample 4 - High Frequency Random Test

Frequency range: 1kHz to 3kHz (Random)			
Level - dB	Performance		
	X Axis	Y Axis	Z Axis
-15	0%	4%	14%
-12	0%	1%	1%
-9	0%	0%	1%
-6	0%	0%	0%
-3	0%	0%	0%
0	0%	0%	0%

Table 14: Test Results for Sample 4 - Sine Sweep Test

Level: 5g (Sinusoidal) 10 Hz to 2000 Hz					
X Axis		Y Axis		Z Axis	
Frequency (Hz)	Performance	Frequency (Hz)	Performance	Frequency (Hz)	Performance
11 to 15.5	100%	12 to 17	51%	10 -13.5	98%
26 to 37.5	83%	25 to 36	44%	25-32	98%
48Hz	Stopped reading	36 to 1350	Stopped and started reading intermittently and slowly at various points	40-55	71%
483 to 1500	Partially recovered (reading slow & intermittent)	1350	Started reading normally	75	Stopped reading and recover at 1391Hz
1800	System recovered fully			1535-2000	83%
Comments: Equipment under test collapses when resonances appears and automatically recovers					

Sample 4 was significantly affected by vibration from a very low level, particularly in the Z axis in which it seemed to be particularly affected by the low frequency random vibration.

This sample again barely functioned at all during the sine sweep test.

5. SHOCK TEST RESULTS

During the shock test programme the operation of the readers was assessed in a similar manner to that used during the vibration test. As the time during which shock is applied is very short compared to the measurement time it was decided in this case to take multiple runs of both the baseline measurements and the “under stress” measurements. In this way any variation as a result of the test methodology could be averaged out.

The results were again normalised and are summarised in the following table.

Table 15: Test Results for All Samples – Shock Test

Sample	Performance under Shock
1	88%
2	87%
3	83%
4	64%

This shows that all units were affected to some degree by intermittent shocks with Sample 4 being most strongly affected.

6. CONCLUSIONS

The mechanical environment in auction markets and abattoirs consists of random vibration of a moderate level with short duration, but frequent, bursts of high acceleration shock, resulting from steel gates, impacts against steel barriers, operation of machinery and animal movements.

The levels of vibration measured varied from site to site but were typically in the range between 2g and 10g RMS, although at times levels considerably in excess of this could be experienced for short periods.

The high level shocks present were typically of short duration (<1ms) but could have amplitudes from 50g to as high as 500g dependent upon the mechanical configuration of the site.

The variation between sites of the level of mechanical vibration and shock measured indicate that considerable care will need to be taken in selecting a location in which to install RFID reader systems.

It is possible for vibration and shock to affect tag reader systems such that their performance is degraded or completely inhibited. All samples were affected by vibration and shock during testing, with degradation varying substantially between samples. The level of vibration at which these effects start to occur is typically less than 1g RMS so is well within the envelope of conditions likely to be encountered in auction markets and abattoirs.

All samples tested were sensitive to shocks of the type found in auction marts and abattoirs and exhibited degraded performance under these conditions, ranging from 88% to 64% of full performance.

All readers tested recovered fully and automatically on removal of vibration and shock.

There was significant variation in performance between the four reader systems tested. The best, Sample 1, operated at levels as much as ten times those at which the other readers ceased to function.

The readers have clear sensitivity to stimulation of their inherent mechanical modes of vibration. Within the scope of this study it was not possible to fully explore the nature of this sensitivity but further work in this area would help in understanding the potential problems that will be faced by trying to install and operate these kinds of systems in environments such as abattoirs and auction markets.

The site measurements made demonstrate that random vibration is a more realistic form of stimulus to be used to validate operational performance of reader systems than sinusoidal vibration.

Three of the readers were extremely sensitive to the proximity of metal which could readily disrupt their function. This sensitivity was not confined to magnetic materials as they appeared also to be affected by materials such as aluminium alloy.

Annex A Site Test Results

Summary data relating to each of the measurement sites is documented in this Annex. Although measurements were taken in 3 orthogonal axes, the data recorded for each was similar with some variation in amplitude. Typical data for a representative axis is presented for each site.

Site 1 - Bridge of Allan

Sheep Line

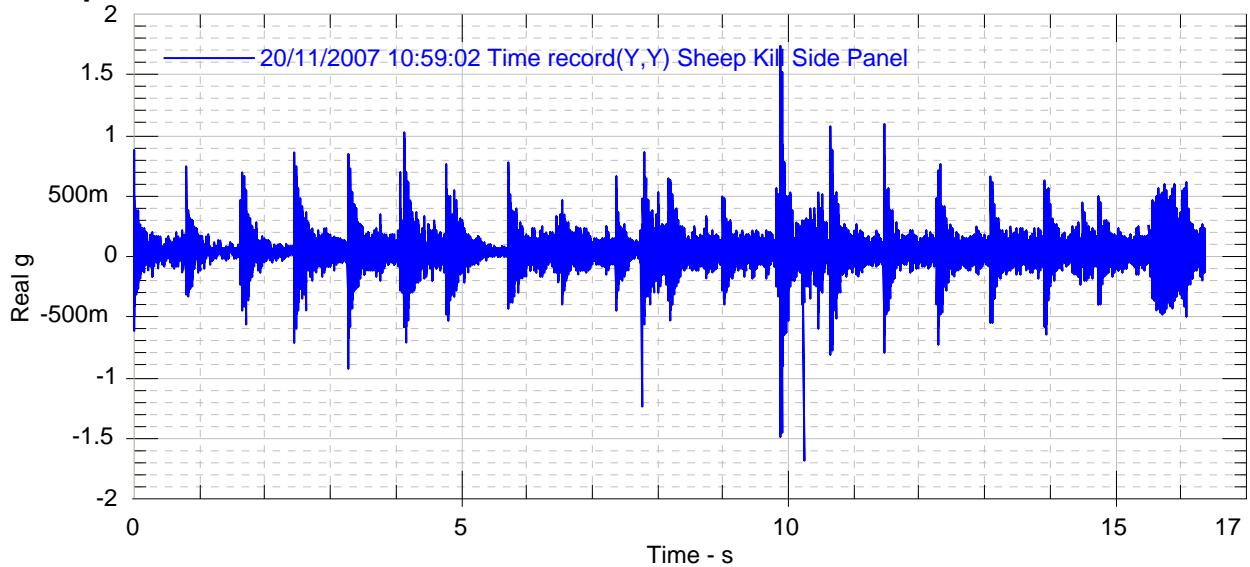


Figure A.1 : Typical data measured at Site 1 in vicinity of Sheep Line

This represents a concatenation of 20 triggered events each of 0.819s captured over a period of approximately one minute. It is typical of the measures made in this location where the environment was relatively quiet and where there were no gates or unduly noisy machinery in the immediate location. Vibration in this area resulted largely from movement of the sheep themselves on the conveyor belt taking them to the stun station and from their contact with the surrounding metal structure.

Analysis of this data in the frequency domain gives the ASD plot shown in Figure A.2. This spectrum has an overall RMS value of 0.16g.

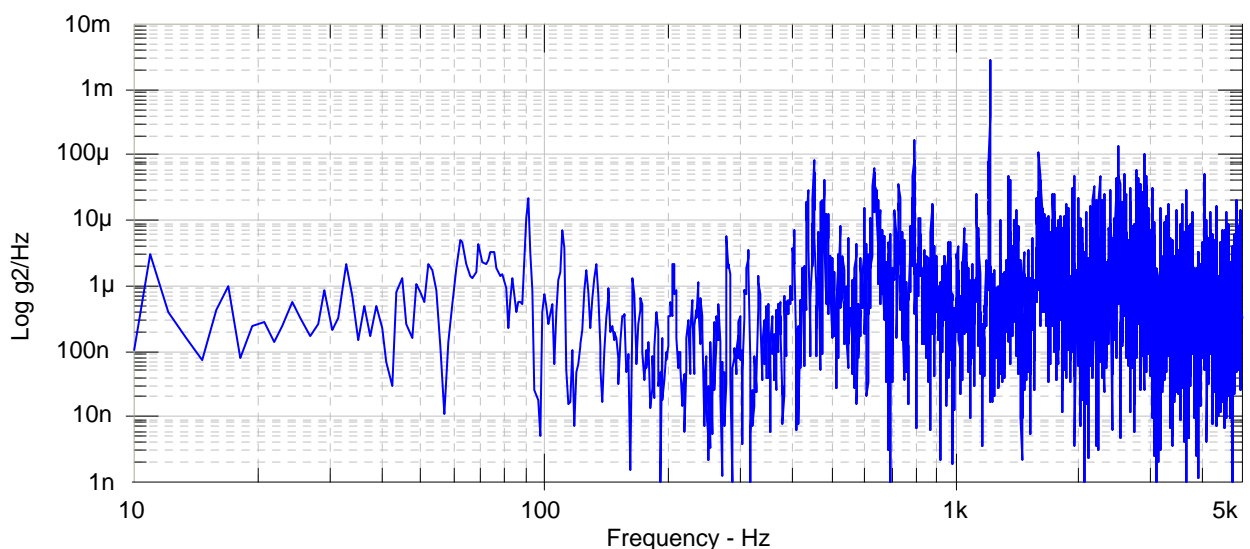


Figure A.2 : ASD of data measured at Site 1 in vicinity of Sheep Line

Cattle Line

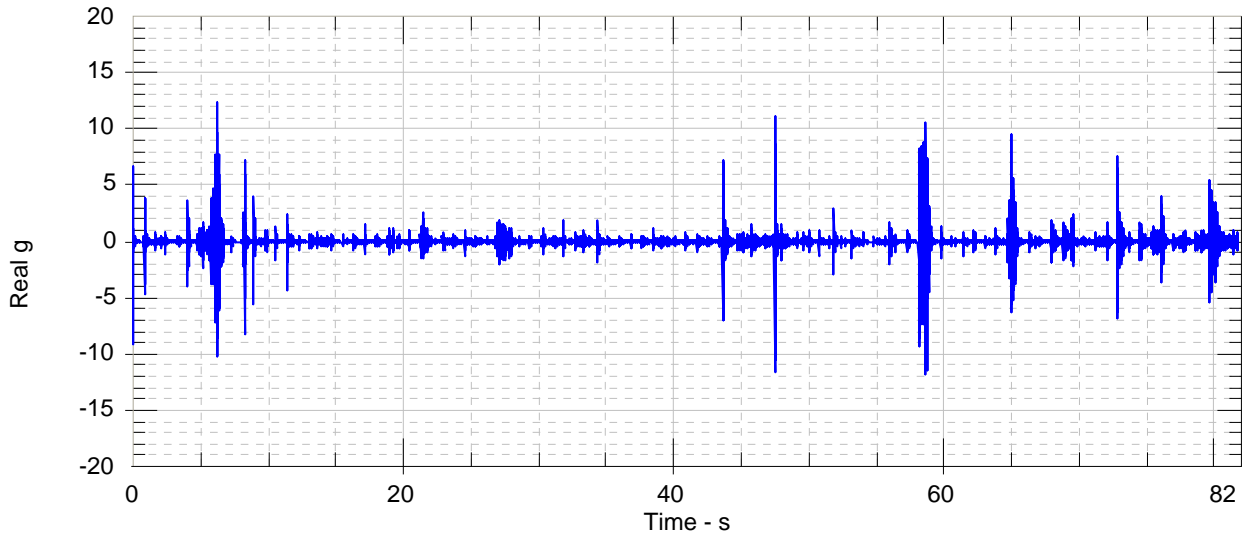


Figure A.3 : Typical data measured at Site 1 in vicinity of Cattle Line

This represents a concatenation of 100 triggered events each of 0.819s captured over a period of approximately 15 minutes. It is typical of the measurements made in this location where the environment was noisier and the hydraulics of the cattle crush caused peaks of shock at intervals during the passage of stock into the crush and its consequent motion during the stun process.

Analysis of this data in the frequency domain using a peak hold averaging method gives the following ASD plot which gives an overall RMS value of 3.7g. This is of course largely driven by a few dominant high amplitude events. A linear average of the same data results in a similar shape plot but with the RMS reduced to 0.4g

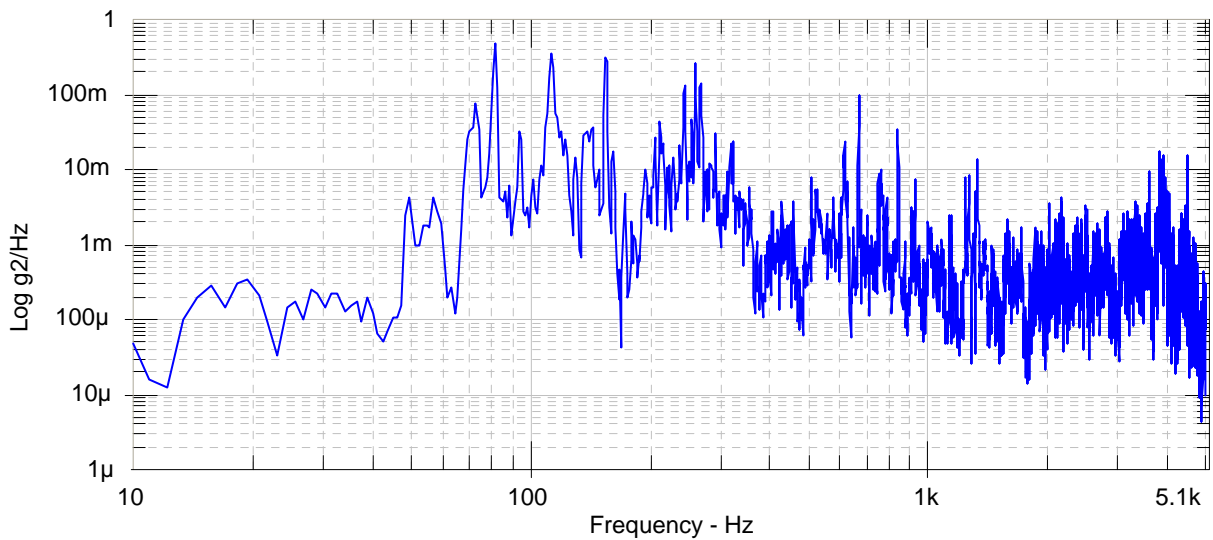


Figure A.4 : ASD of data measured at Site 1 in vicinity of Cattle Line

Site 2 – Stirling Auction Mart

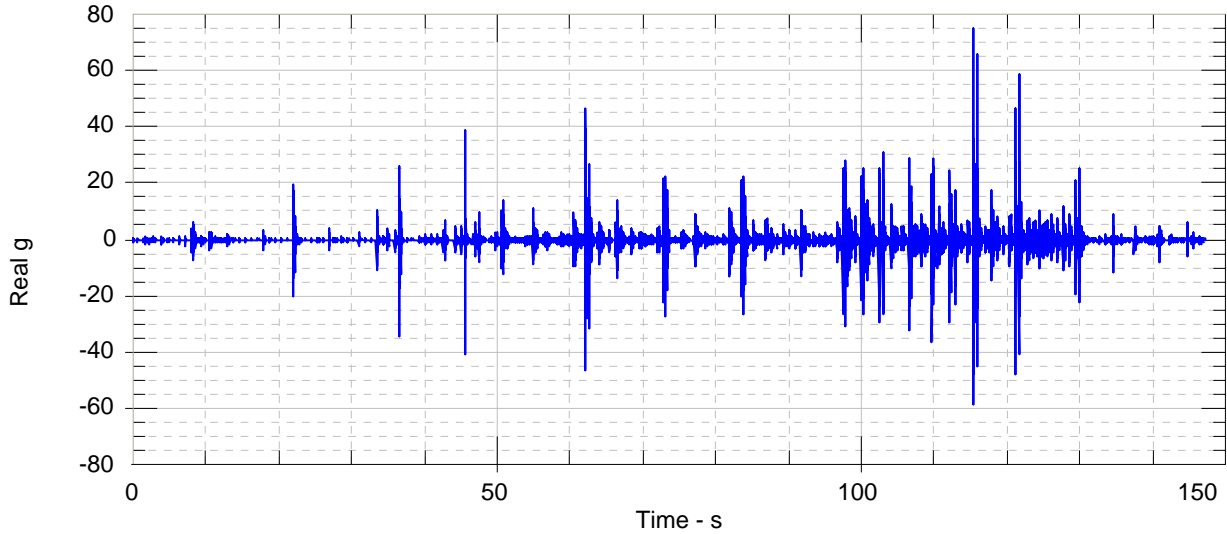


Figure A.5 : Typical data measured at Site 2 in vicinity of Sales Ring

This represents a concatenation of 180 triggered events each of 0.819s. It is typical of the measures made in this location where the area consisted largely of steel fences and supporting structure. The levels measured are dominated by the effects of such activities as slamming of gates and metal to metal contact. This causes high levels short duration transients which can clearly be seen in the preceding plot.

Analysis of this data in the frequency domain using a peak hold averaging method gives the following ASD plot which gives an overall RMS value of 12.4g. This represents the levels seen mainly during the high level transients. A linear average of the same data results in a similar shape plot but with the RMS reduced to 1.7g. This is more representative of the general level present. In general the frequency content is largely in the 100 to 1kHz region.

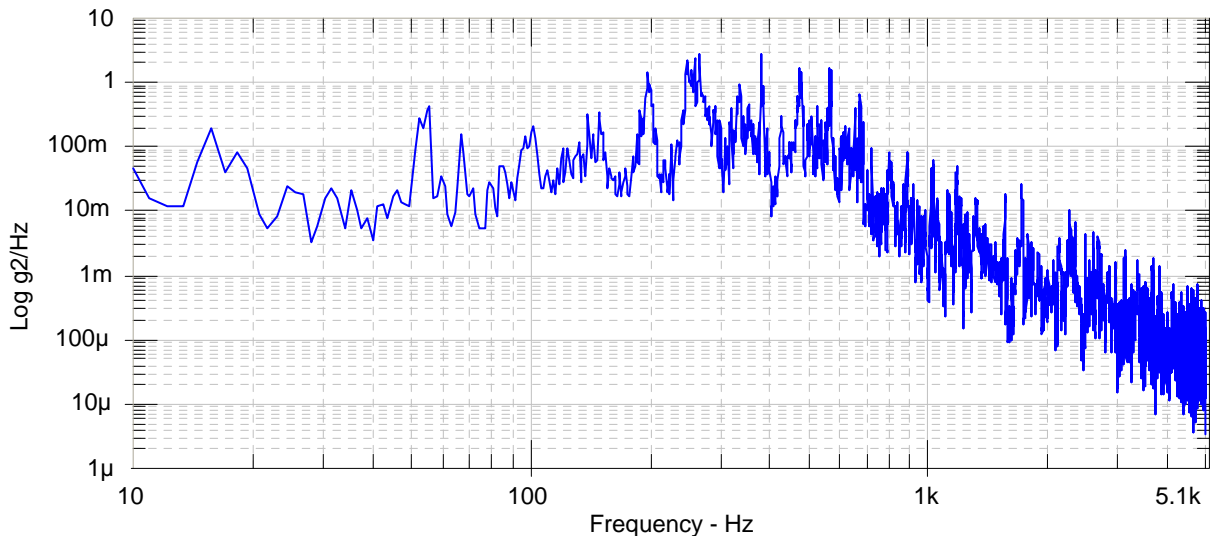


Figure A.6 : ASD of data measured at Site 2 in vicinity of Sales Ring

Site 3 – Portlethen Abattoir

At this site measurements were taken in the area where reading of tags is currently undertaken. This is at a point in the race leading to the stun station where a head clamp is fitted to hold the cattle whilst the tag is read. This clamp was not functional during the early part of the visit but was repaired during the visit. Measurements were therefore taken both whilst the clamp was not being used and later whilst it was in use.

Morning Measurements (Head Clamp Non-Operational)

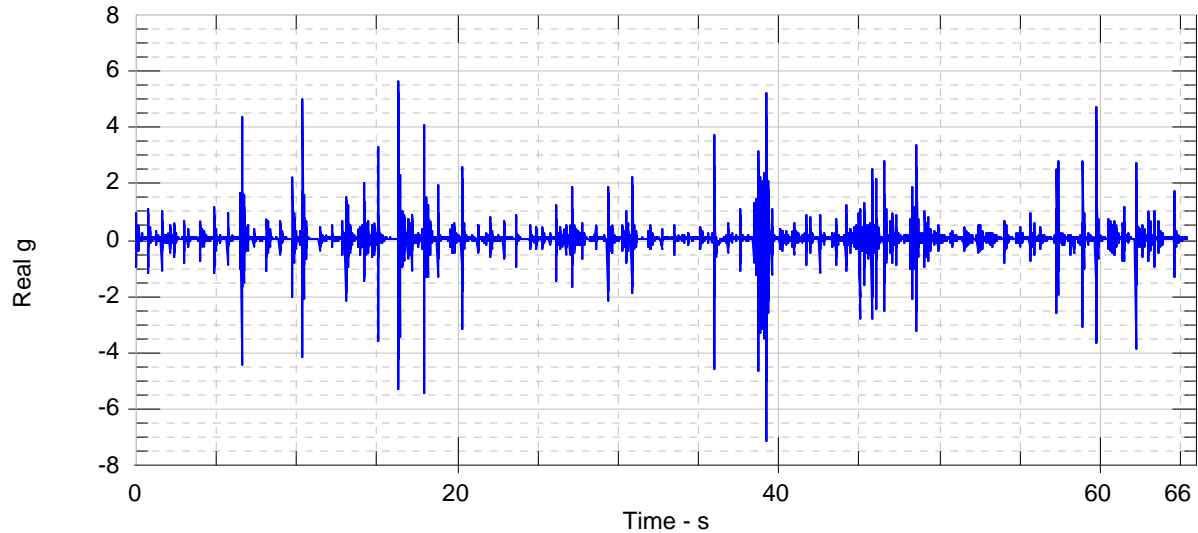


Figure A.7 : Typical data at Site 3 in vicinity of Cattle Line Head Clamp

This represents a concatenation of 80 triggered events each of 0.819s. It is typical of the measures made in locations where the area consists largely of steel fences and supporting structure but the amplitudes are relatively small since there was little slamming of gates or similar in close proximity.

Analysis of this data in the frequency domain using a peak hold averaging method gives the following ASD plot which gives an overall RMS value of 0.6g.

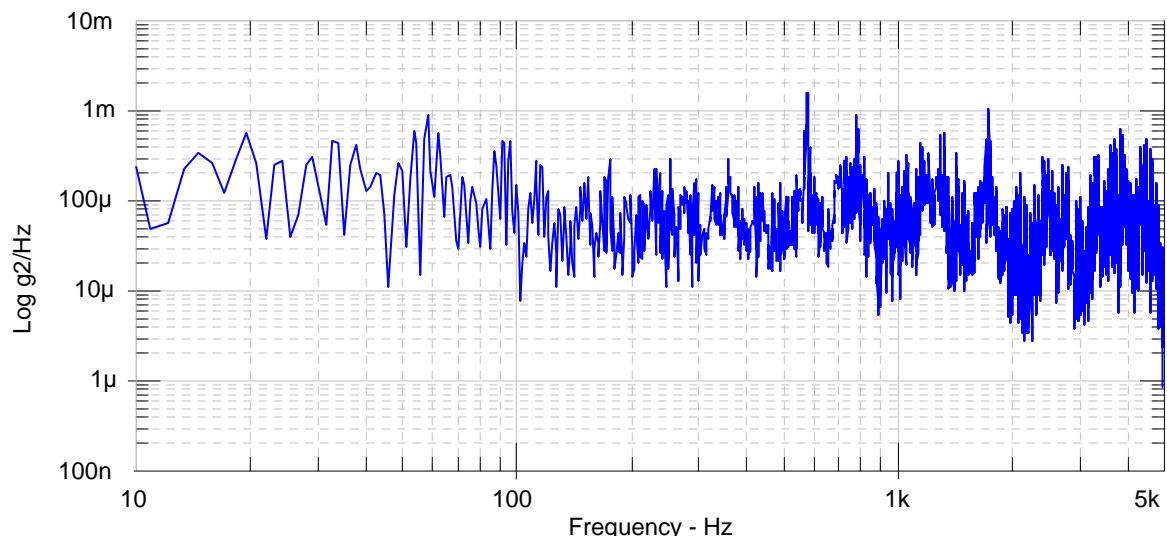


Figure A.8 : ASD of data measured at Site 3 in vicinity of Cattle Line

Afternoon Measurements (Head Clamp Operational)

This represents a concatenation of 40 triggered events each of 0.17s. The reinstatement of the head clamp led to an increase in the incidence of high amplitude short duration transients resulting from metal to metal contact which occurred during operation of the head clamp gate and ratchet mechanism.

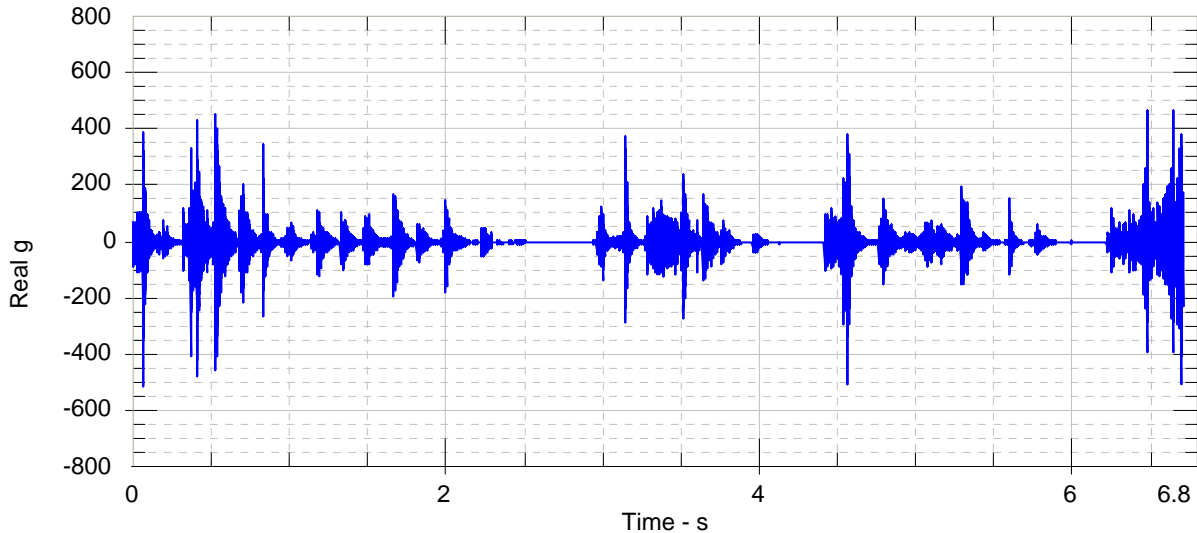


Figure A.9 : Typical data measured at Site 3 in vicinity of Cattle Line Head Clamp (Ratchet Mechanism Operational)

Analysis of this data in the frequency domain using a peak hold averaging method gives the following ASD plot which gives an overall RMS value of 91.5g and shows a large peak around 1291 Hz which is caused by the resonant behaviour of the metal structure. This results not only in a high amplitude peak at the resonant frequency of the structure but also a general increase in stimulus at frequencies above this. The linear average results in a RMS value of 23.9g.

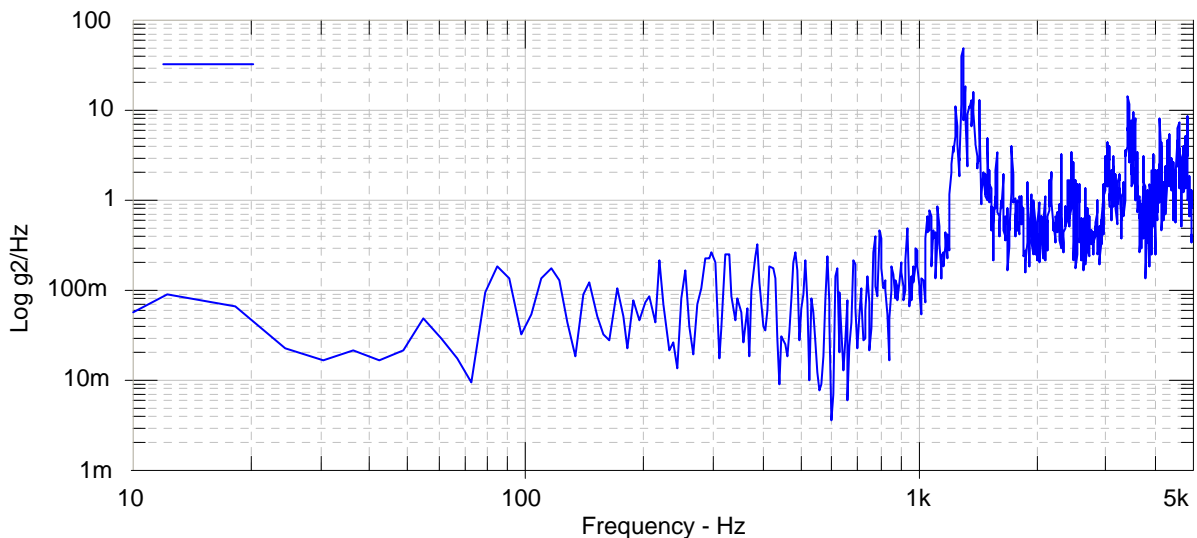


Figure A.10 : ASD of data measured at Site 3 in vicinity of Cattle Line Head Clamp (Ratchet Mechanism Operational)

Site 4 – Inverurie Auction Mart

At this site measurements were taken in the area of the weighbridge leading to the auction ring adjacent to the area where tags are currently read. A slightly different approach was taken since a number of longer continuous measurements were taken, typically of 60 seconds in duration. A typical plot follows.

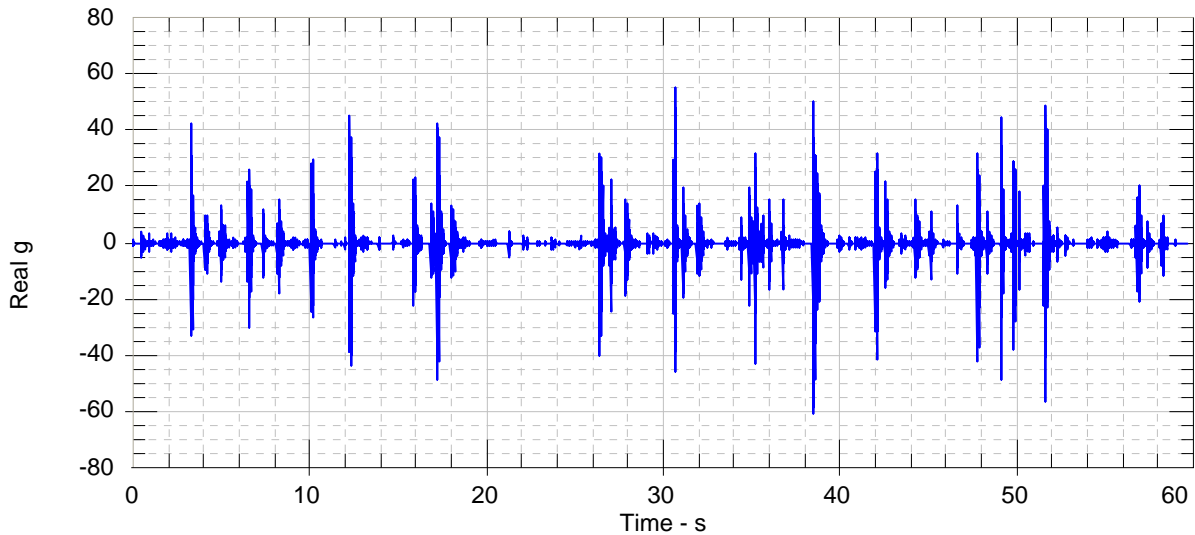


Figure A.11 : Typical data measured at Site 4 in vicinity of Sales Ring

The plot once more shows the short term high amplitude transient shocks resulting from metal to metal contact which occurs during shutting of gates and similar operations.

Analysis of a number of sets of data of this type in the frequency domain using a k hold averaging method gives the following ASD plot which gives an overall RMS value of 21.9g and shows peaks in the 1 to 2 kHz region which are probably caused by the resonant behaviour of the metal structure. This results not only in a high amplitude peak at these resonant frequencies of the structure but also a general increase in stimulus at frequencies above this. The linear average results in a RMS value of 1.6g.

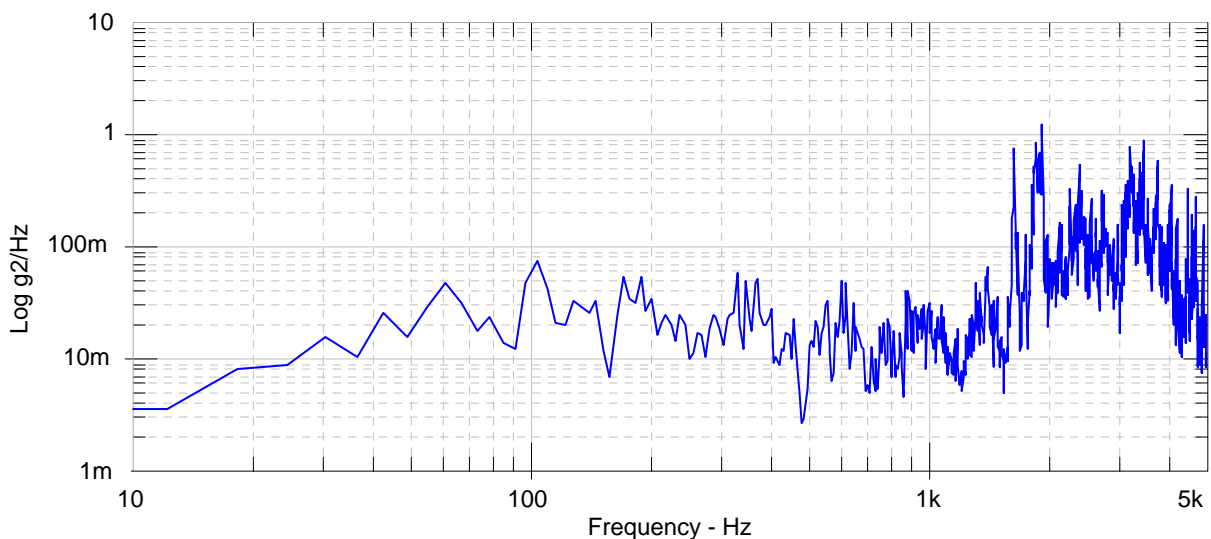



Figure A.12 : ASD of data measured at Site 4 in vicinity of Sales Ring

Annex B Test Equipment

Equipment Description	Maker	Type Number	Identification Number	Calibration Period	Uncertainty	Remarks
Accelerometer	Endevco	7252A-10	ANE36	1/08-1/09	 7% Sine 14% Random Overall Uncertainty	
Accelerometer	PCB	352A21	80307	5/07-5/08		
Accelerometer	PCB	352A21	80324	11/07-11/08		
Accelerometer	PCB	352A21	48954	1/08-1/09		
Accelerometer	PCB	352A21	84389	11/07-11/08		
Accelerometer	PCB	352A21	84391	11/07-11/08		
Vibration Controller	M+P		EEDC07	8/07-8/08		
Vibration Generator	LDS	V890- HBT900	EEDV05	N/A		
Accelerometer	PCB	356A11	10151	3/07-3/08	3%	
Signal Analyser	M+P	USB4	12443A9			Calibrated before use using Fluke calibration source
Calibrator	Fluke	743	6790812	3/07-3/08	2%	

Appendix 4 Study of Modulation/Metallic Interference – Report 2527CR1

**Investigation into the Effect of
Acoustic/Mechanical Interference
on Radio Frequency Identity (RFID)
Systems used to Identify Animals
Electronically**

**Characterisation of Magnetic Field
and Tag Readability With and
Without the Presence of Metallic
Structures**

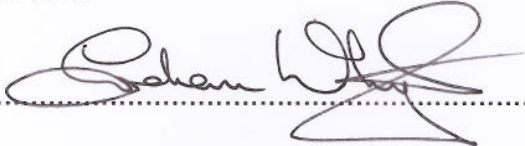
(copy 1 of 2)


for


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List of terms and abbreviations

AC	Alternating Current
CENELEC	Comité Européen de Normalisation Electrotechnique
CISPR	Comité International Spécial des Perturbations Radioélectriques
COTS	Commercial Off The Shelf
DC	Direct Current
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test
FAR	Full Anechoic Room
FFT	Fast Fourier Transform
OATS	Open Area Test Site
PC	Personal Computer
RF	Radio Frequency
RFID	Radio Frequency Identification
RMS	Root mean square
SG	Scottish Government
UKAS	United Kingdom Accreditation Service
YES	York EMC Services (2007) Ltd

Executive summary

The Scottish Government have commissioned York EMC Services (2007) Ltd to investigate certain aspects of the functional reliability of RFID Tags and their readers when used for identification of farm animals and includes immunity of the whole system to certain external disturbances.

Four samples of RFID tag reader were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. The study was conducted on an anonymous basis such that equipment identity is protected.

This report is concerned with the study of the modulation and characterisation of the magnetic field produced by the tag reader panel antenna when subject to external influences, which may reduce the effectiveness of a tag read.

The environment in which the readers may be used will contain metal fencing or enclosures, concrete walls with steel reinforcing, etc. In a typical installation, the tag reader would necessarily be mounted on either the fencing or the wall in order to read the animal tag as it passed.

From a physical concept viewpoint, the presence of metallic structure is likely to impact on the tag readability. Furthermore, it is presumed that metal structures present within the magnetic field may detune the system, again leading to a reduction in read efficiency.

The high volume throughput of animals and abattoirs requires RFID to distinguish individual tags data when there are multiple tags within the reading field.

The findings of this study can be summarised as follows;

1. The presence of metal within a fencing structure seriously affects magnetic field distribution through distortion and reduction of its overall field amplitude.
2. The reduction and distortion the magnetic field within the presence of metallic structure reduced the reading range to well below 0.5 m limit in all four samples tested, thus seriously affecting the RFID reading ability.
3. The presence of metal structure within the magnetic field does not significantly alter the Q-factor of the antenna system as demonstrated both experimentally and theoretically.
4. As the tag loading in the magnetic field at any one time increases, the ability of the system to distinguish individual tags decreases. Experimental results demonstrate that there appears to be a maximum of 6 tags distinguishable in the field simultaneously.
5. The performance of the RFID systems tested varied substantially throughout the various tests performed.

1 Introduction

1.1 Background

The Scottish Government have commissioned York EMC Services (2007) Ltd to investigate certain aspects of the functional reliability in service of RFID system when used for identification of farm animals.

As detailed in the Tender Document 2333CR1 (York EMC Services (2007) Ltd) [1], there are various physical sources of interference that may cause a reduction in tag reading efficiency, which this study intends to investigate. These are as follows:

- a) Acoustic High levels of acoustic noise in the environment, for example, due to slamming of steel gates which form the animal pens in markets.
- b) Vibration Vibration of the structure (often metallic) to which panel antennas are fixed, for example, shock and vibration transferred via steel fencing.
- c) Modulation Modulation/modification of the magnetic field produced by the tag reader antenna or detuning of the system due to the presence of ferromagnetic material (typically fencing) or multiple tags in the field.

This report describes the investigation into the modulation/modification of the magnetic field of the RFID system, measurements of the key physical parameters of RFID systems and research as whether RFID systems function satisfactorily within the presence of metallic structure.

1.2 Test Samples

Four samples of RFID tag reader, designed and built in accordance to the technical requirements of ISO11784 [2] and code structure ISO11785 [3], were provided for this study, along with a number of tags to a universal specification that could be read by any of the readers provided. In this study, only full duplex (FDX) tags were used. As this study is not intended to identify specific products or manufacturers, the samples are referred to only as Sample 1, Sample 2, Sample 3 and Sample 4 throughout this report.

Some photographs of the test setup include views of one or more parts of the tag readers. Care has been taken to blank out any identifiable parts from photographs.

For the purpose of this study, the metallic structure consisted of a tubular steel frame, the 'kiosk', intended for use in cattle farming to which the panel reader could be mounted as shown in Figure 1.2-1. This tubular fencing is readily available on the market and is used to represent a typical installation within an environment such as an auction mart or abattoir.



Figure 1.2-1 Tubular fencing kiosk used for the purpose of this study

1.3 Scope of this study

The modulation/modification of the magnetic field study concentrated at the following specific measurements and characterisation:

1.3.1 Panel reader without the presence of metallic structure (kiosk, race type structure)

- Magnetic field distribution in X, Y and Z-axes (magnetic field axes)
- The maximum distance for tag readability
- The bandwidth at the magnetic field frequency (134.2kHz) and the calculation of its Q-factor
- The effect of the number of tags within the field at any one time

1.3.2 Panel reader mounted on the metallic structure (kiosk, race type structure)

- a) Magnetic field distribution in X, Y and Z-axes (magnetic field axes)
- b) The maximum distance for tag readability
- c) The bandwidth at the magnetic field frequency (134.2kHz) and the calculation of its Q-factor
- d) The effect of the number of tags within the field at any one time

Results of the measurements are presented in Section 3 of this report.

2 Preliminary Investigation and Test Setup

2.1 Magnetic Field Distribution

Magnetic field distribution measurements were performed to characterise the magnetic field within a specific area in front of the antenna coil. Such measurements enable to understand the homogeneity and strength of the RF field. The measurements were performed with the antenna coil with and without the presence of metallic fencing in order to assess and quantify the potential effect of metallic structure in the case of the magnetic field distribution.

2.1.1 Test Method

To ensure that the measurements were performed in a repetitive manner, a wooden sheet was marked out with a grid with a spacing of 10cm between each of the points as shown in Figure 2.1.1-1. The wooden sheet was 1.05m length by 1.05m wide, enabling a total of 100 measurements to be performed each time (10 by 10 grid points). This number of readings was considered sufficient to plot an accurate representation of the field within the area of interest.

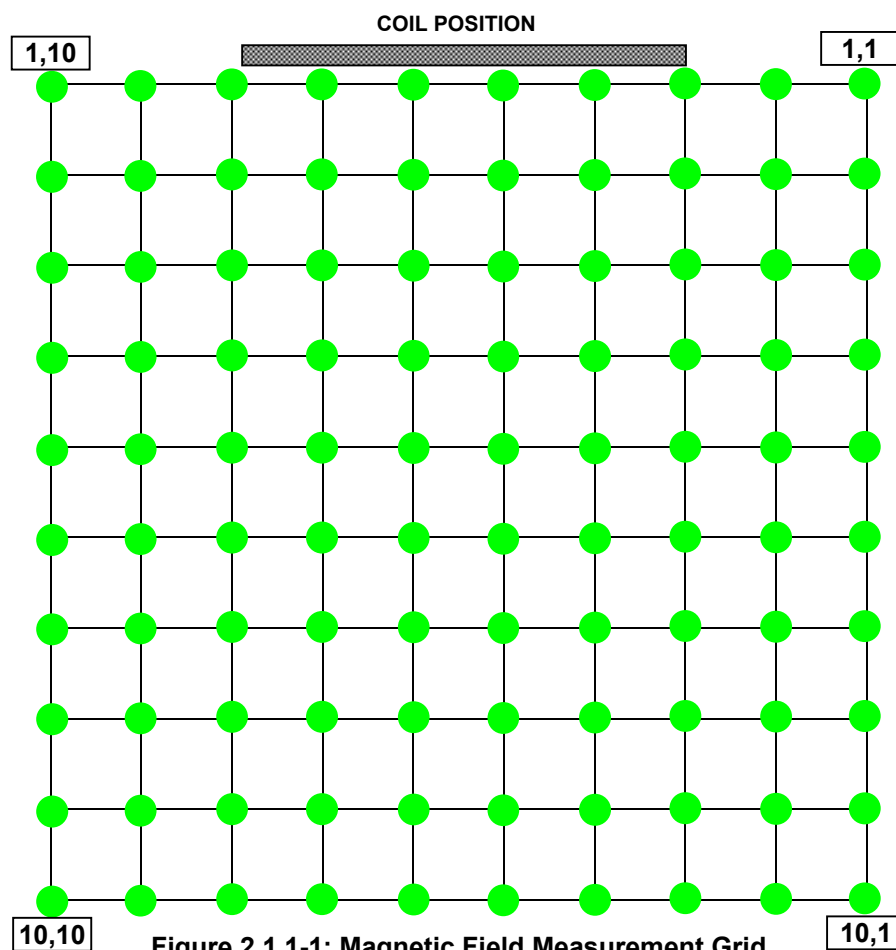


Figure 2.1.1-1: Magnetic Field Measurement Grid

Measurements were performed with the grid plane placed at the centre level of the RFID reader coil and in 3 axes:

- X-axis antenna vertical and perpendicular to coil
- Y-axis antenna vertical and parallel to coil
- Z-axis antenna horizontal to coil

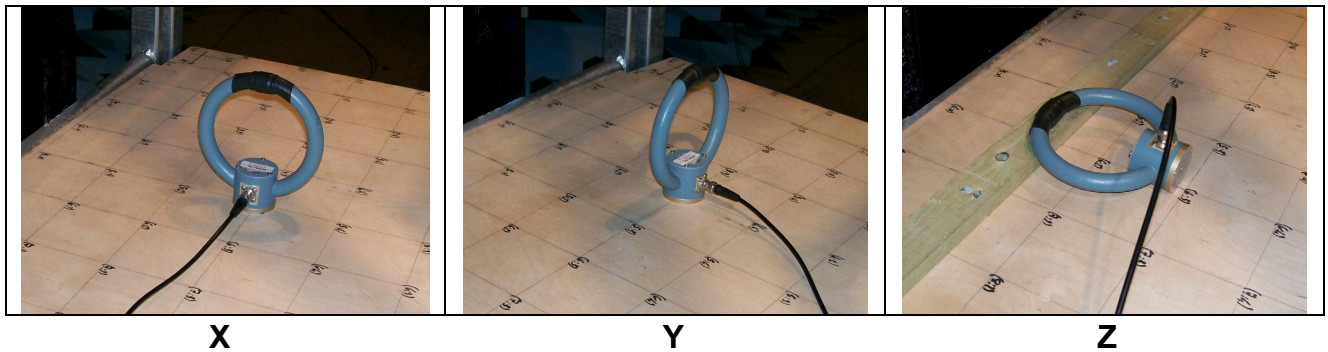


Figure 2.1.1-2: Antenna orientation for the three axis measurements, X, Y and Z

The results were used to produce a field distribution plot over the measurement area, specific to each axis.

2.1.2 Test Equipment

The relative magnetic field strength at the centre frequency of 134.2kHz was measured using:

- i) Eaton 94605-1, 5.25” magnetic field loop antenna
- ii) HP 8594E spectrum analyser
- iii) RF cables

All the measurements were performed in a semi anechoic chamber in order to minimise the effect of any ambient (or interfering) surrounding magnetic fields. The measurements were quantified based on the maximum field strength value at the operating centre frequency.

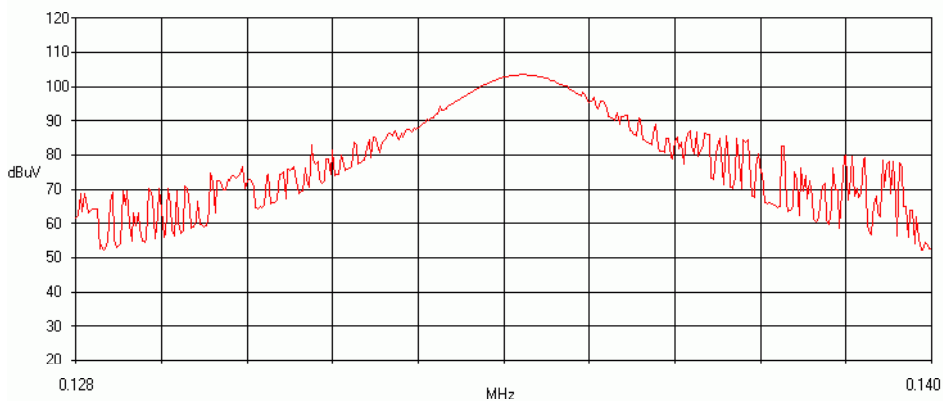


Figure 2.1.2-1: Typical Analyser display of the RFID magnetic field (1kHz RBW)

All the reported measurements are quantified in dB μ V (and not dB μ A/m) as only relative measurements are considered in this study and not absolute value.

2.2 Antenna Reading Distance

Antenna reading distance capability measurements were performed in order to quantify the reading range of each of the RFID system.

2.2.1 Test Method

The previously described measurement grid was used to assess the maximum tag read distance from the antenna coil. A tag was moved along each perpendicular grid line until the maximum read point was determined. This distance was recorded and plotted on a plan view of the magnetic field distribution for the RFID antenna coil. This was repeated for each of the 3 axes (the tag aligned according to each magnetic field direction – Figure 2.1.1-2).

The read distances noted are measured from the zero line of the grid.

For an absolute distance from the antenna coil, the following values shall be added:

- i) 1cm for measurements with no metal structure
- ii) 5cm for measurements with metal structure (diameter of steel tubing)

A 50cm limit line (from the zero line of the grid) has been added to the plots to compare read distances to the requirements defined by JRC [4].

2.3 Effect of moving metal fencing on tag readability

The effect of moving metal object (in this case a steel gate section of the kiosk typical of those used in the farming industry) on RFID tag readability was investigated as detailed below.

2.3.1 Test method

A tag was placed in the magnetic field at a distance of 25cm from the centre of the antenna coil. The 25 cm was chosen as being the middle of the read range as specified by the JRC technical requirements [4]. A consistent read signal was obtained and monitored for the correct tag data on a PC.

The field at this point was also monitored on the spectrum analyser using the 5.25” measurement antenna to assess any potential alteration of the RF signal.

On the opposite side of the antenna coil a tubular steel gate was swung repeatedly through the magnetic field as shown in Figure 2.3.1-1.

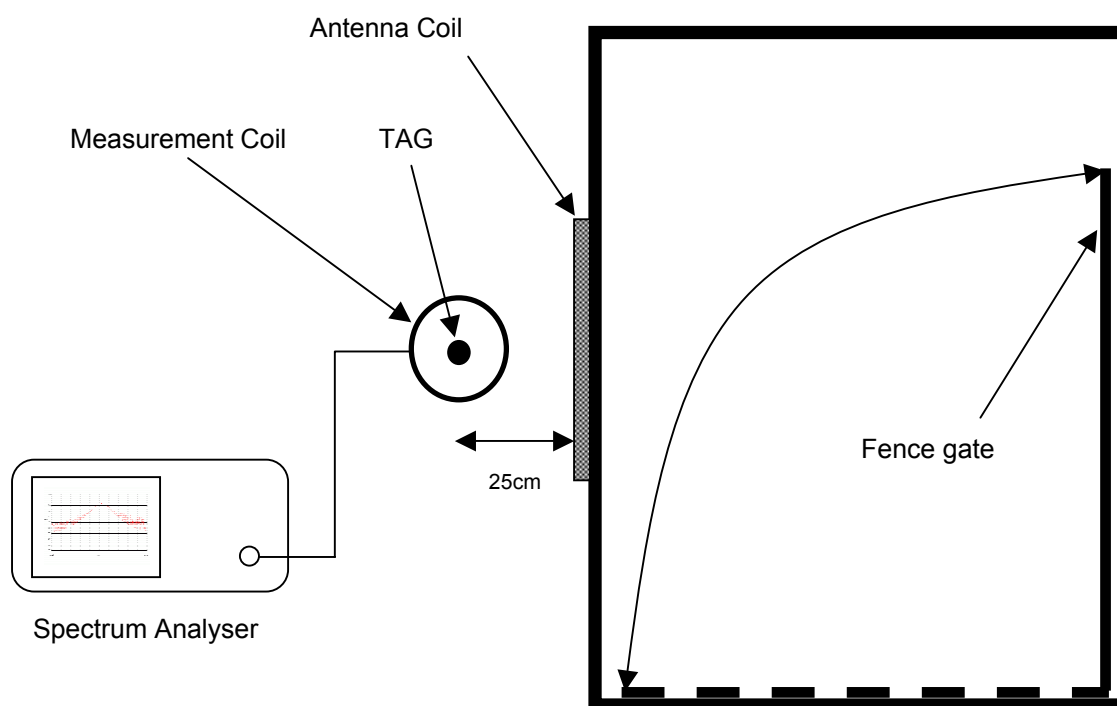


Figure 2.3.1-1 Plan View of steel gate moving in the magnetic field

2.4 Bandwidth and Q-factor Measurement

For each of the tag reader system, the effect on the bandwidth of the magnetic field (and hence the Q-factor) by the presence of metallic structures was investigated.

2.4.1 Test Method

Measurements were performed at parallel line 2 of the grid, 10cm from antenna coil.

At each point along parallel grid line 2, the peak level and the bandwidth at the -6dB points was recorded. The measurement units were dB μ V, therefore the bandwidth at the -6dB points equates to the half power level. An average of ten bandwidth readings was calculated.

The readings were repeated for spectrum analyser resolution bandwidths of;

- i) 30Hz (resolution BW low enough to show details of the transmitted frequency)
- ii) 200Hz (CISPR bandwidth used in measurements within the frequency range 9kHz to 150kHz)
- iii) 1kHz (bandwidth suggested by manufacturer)

The Q-factor was calculated from the average bandwidth measured with a nominal centre frequency for all devices of 134.2kHz as;

$$Q = F_0/BW - \text{Equation 1}$$

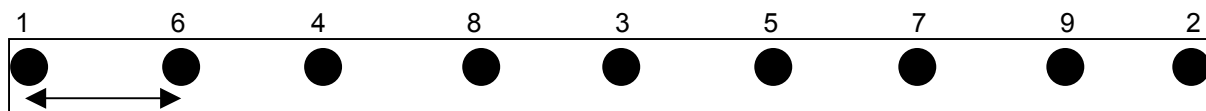
2.5 Tag Loading

The effect of tag loading was investigated for all four samples in order to assess the effect of multiple tags present in the field on individual tag readability.

2.5.1 Test Method

Tags were fixed to a wooden bar, separated by a spacing of 15 cm and the number of tags was increased in the order shown in Figure 2.5.1-1. The wooden bar was displayed in front of the antenna coil at an approximate speed of 0.75 meter per second in order to simulate a typical livestock walking speed. The tags were passed through the antenna coil field at grid line #3 (20cm plus adjustment) and the tag information was displayed on the PC via customer software or HyperTerminal. The number of individual tags read by the system could thus be checked.

The number of tags used below.



Tag spacing 15cm

Figure 2.5.1-1 Tag spacing and order added

The test was repeated for the tags oriented in 3 different axes and with the antenna on the bench and mounted to the steel kiosk.

3 Results

3.1 Magnetic Field Distribution

The magnetic field distribution for each of the samples was measured as detailed in Section 2.1. The results for each of the samples are presented below.

3.1.1 Sample 1

Sample 1 Magnetic Field, X-polarity
Sample on bench

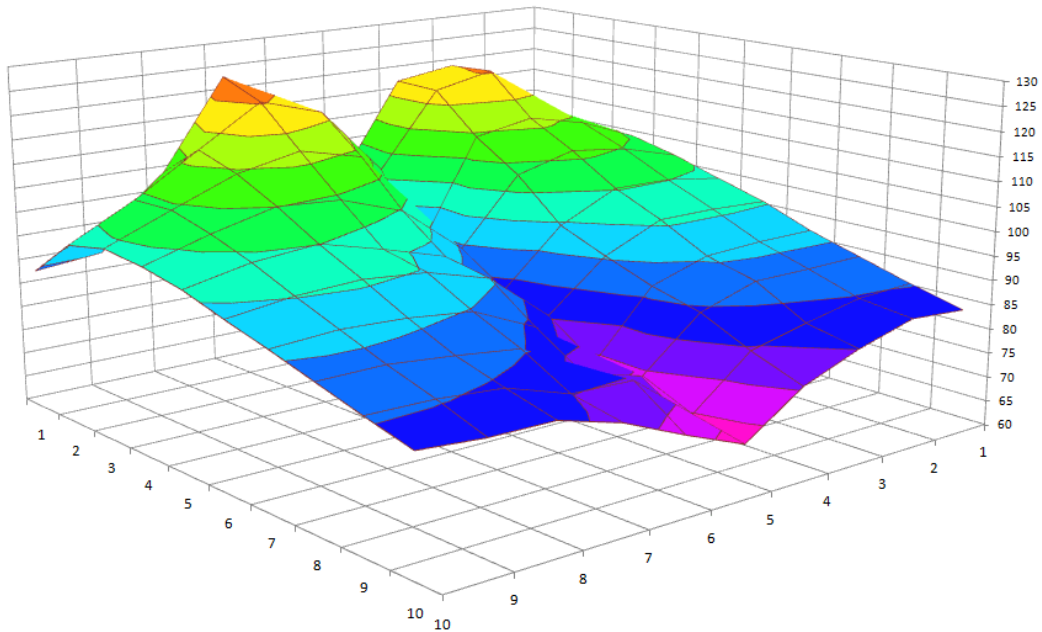


Figure 3.1.1-1: Sample 1 - Hx plot, sample on bench

Sample 1 Magnetic Field, X-polarity
Sample attached to tubular steel kiosk

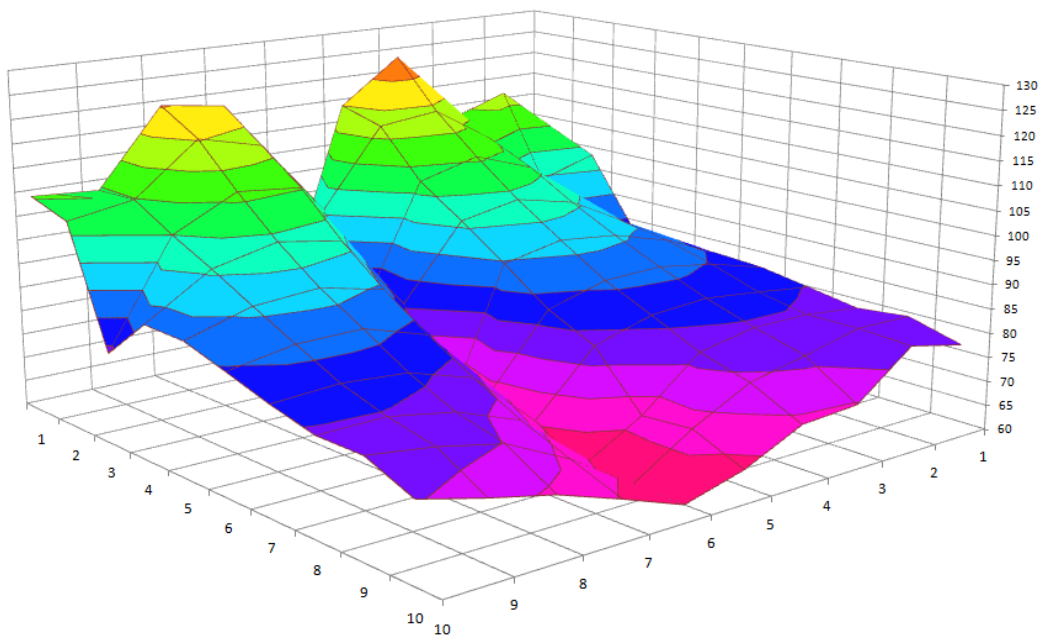


Figure 3.1.1-2: Sample 1 - Hx plot, sample attached to kiosk

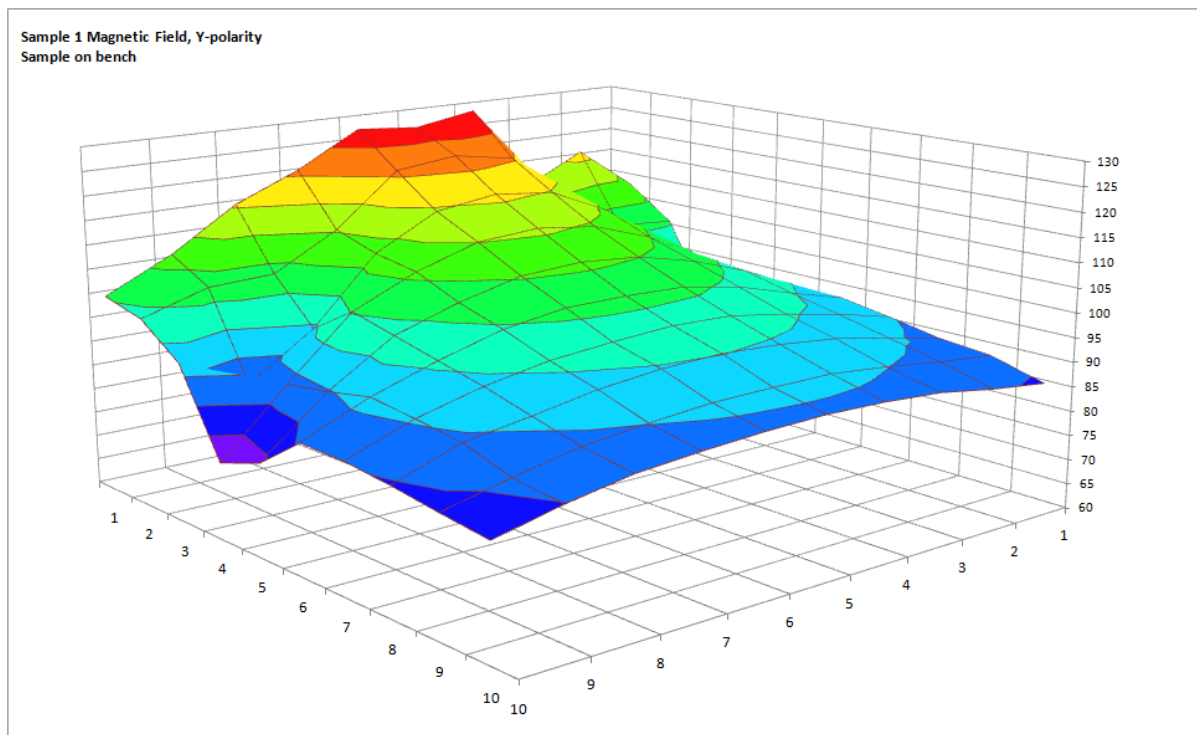


Figure 3.1.1-3: Sample 1 - Hy plot, sample on bench

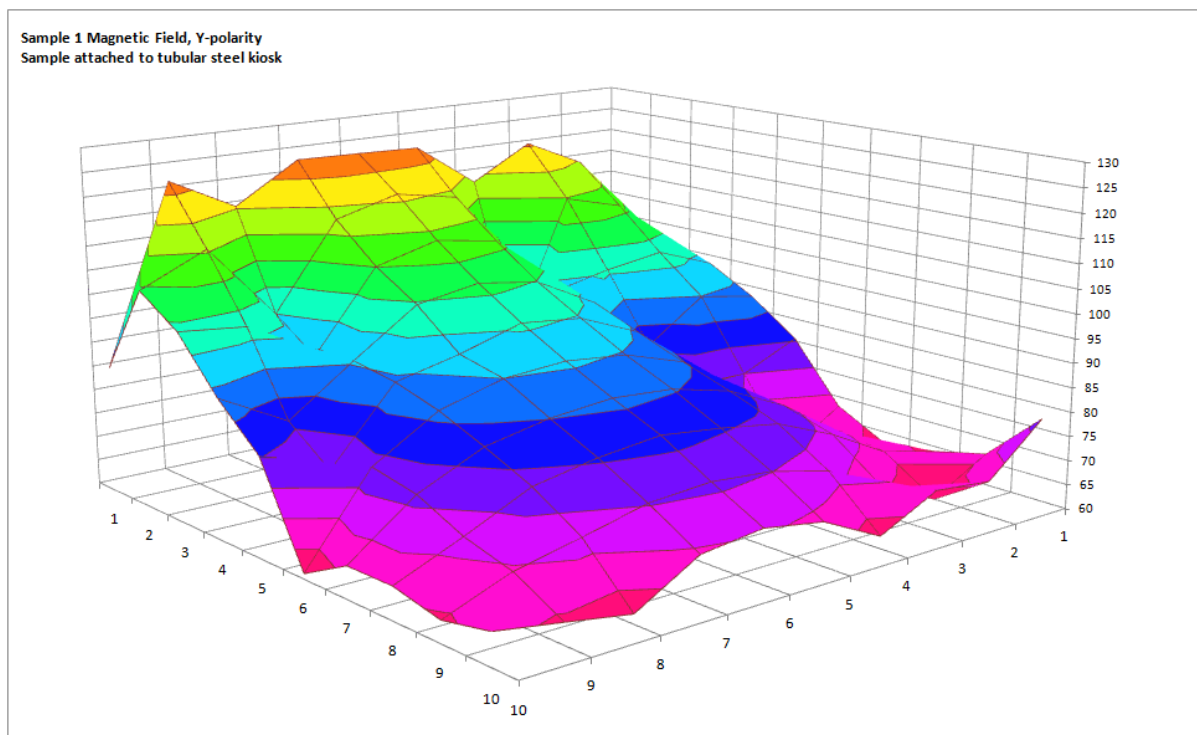


Figure 3.1.1-4: Sample 1 - Hy plot, sample attached to kiosk

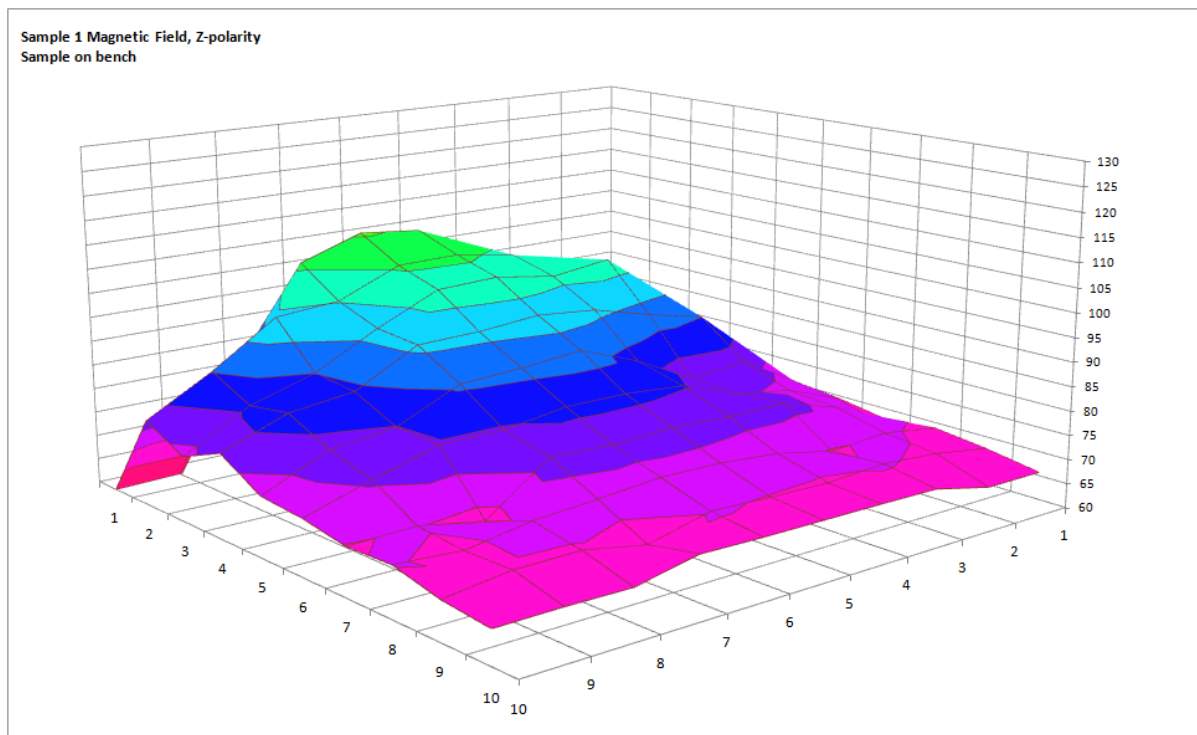


Figure 3.1.1-5: Sample 1 - Hz plot, sample on bench

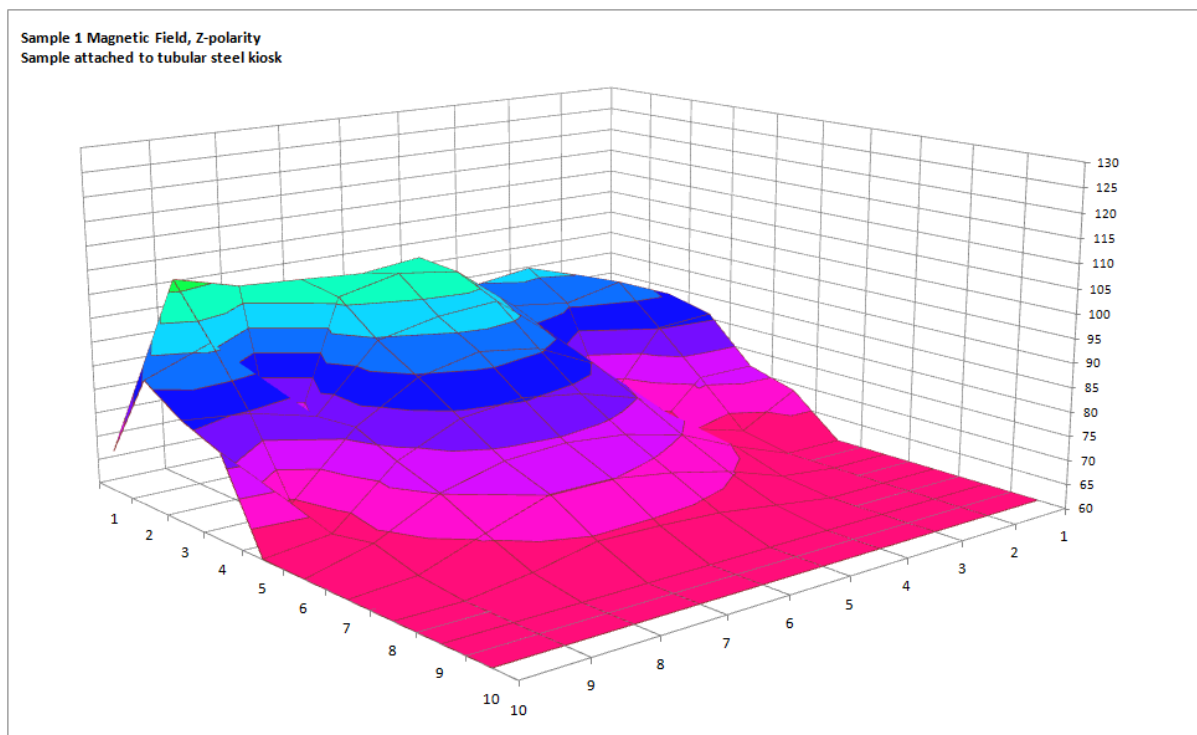


Figure 3.1.1-6: Sample 1 - Hz plot, sample attached to kiosk

3.1.2 Sample 2

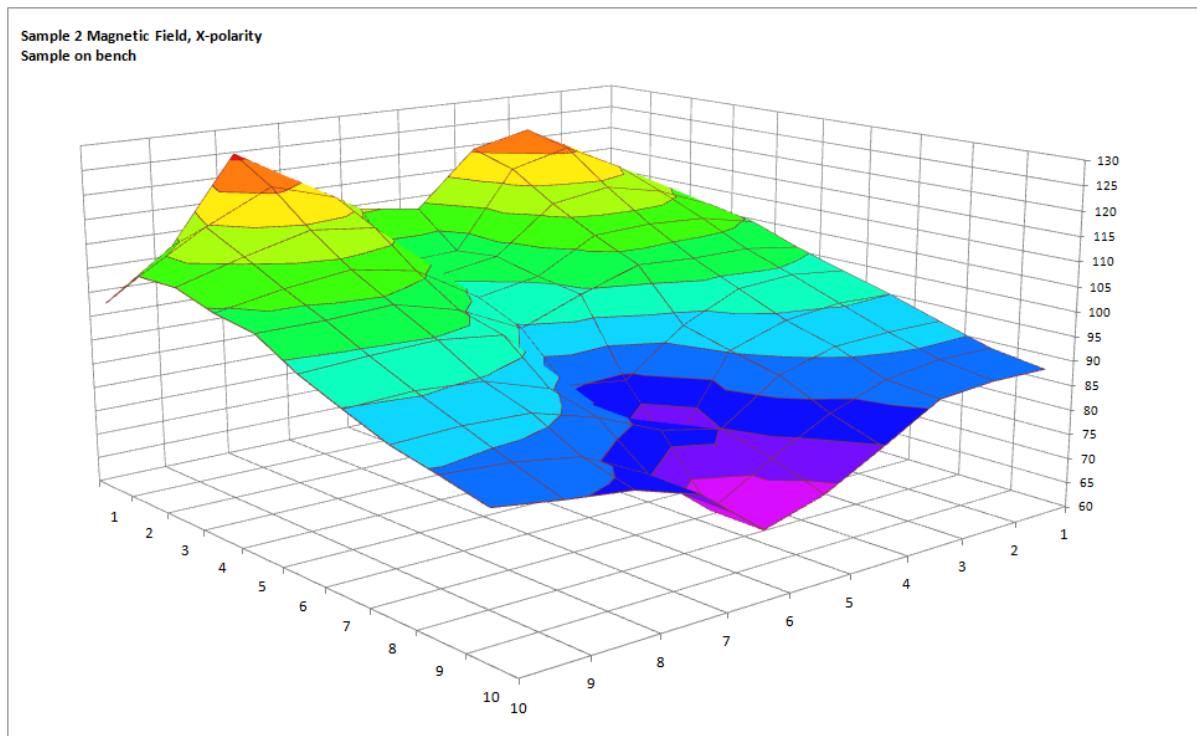


Figure 3.1.2-1: Sample 2 - Hx plot, sample on bench

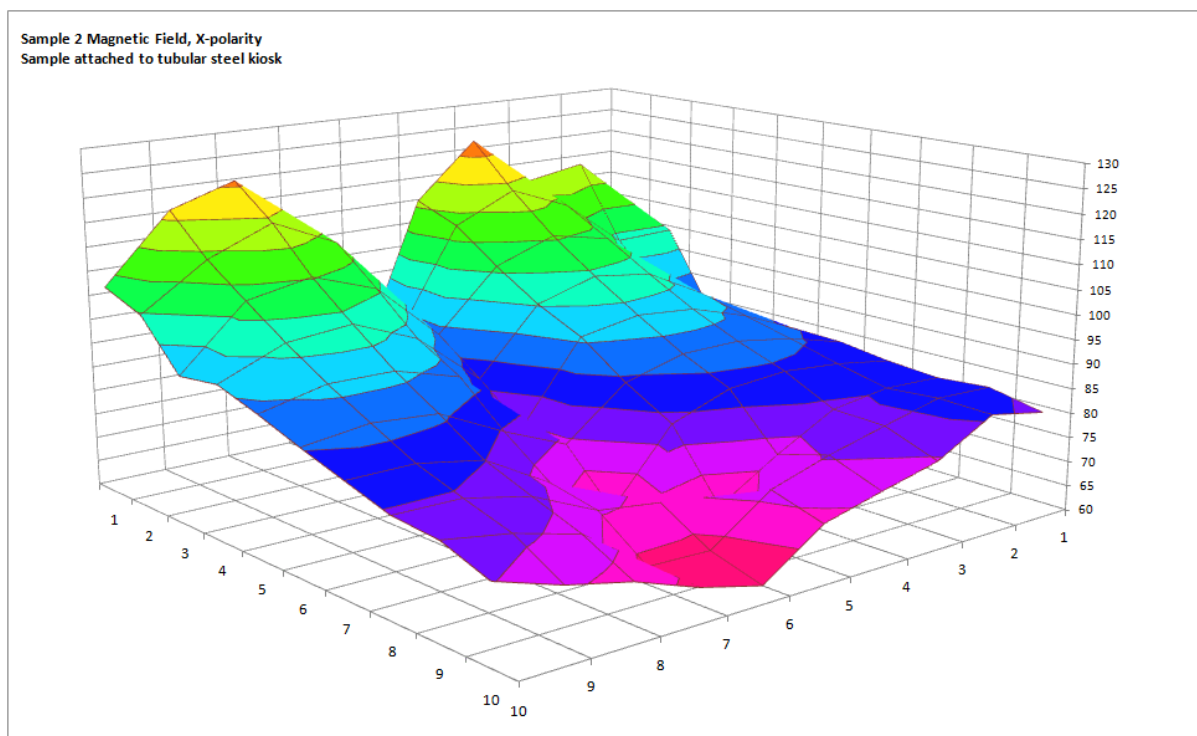


Figure 3.1.2-2: Sample 2 - Hx plot, sample attached to kiosk

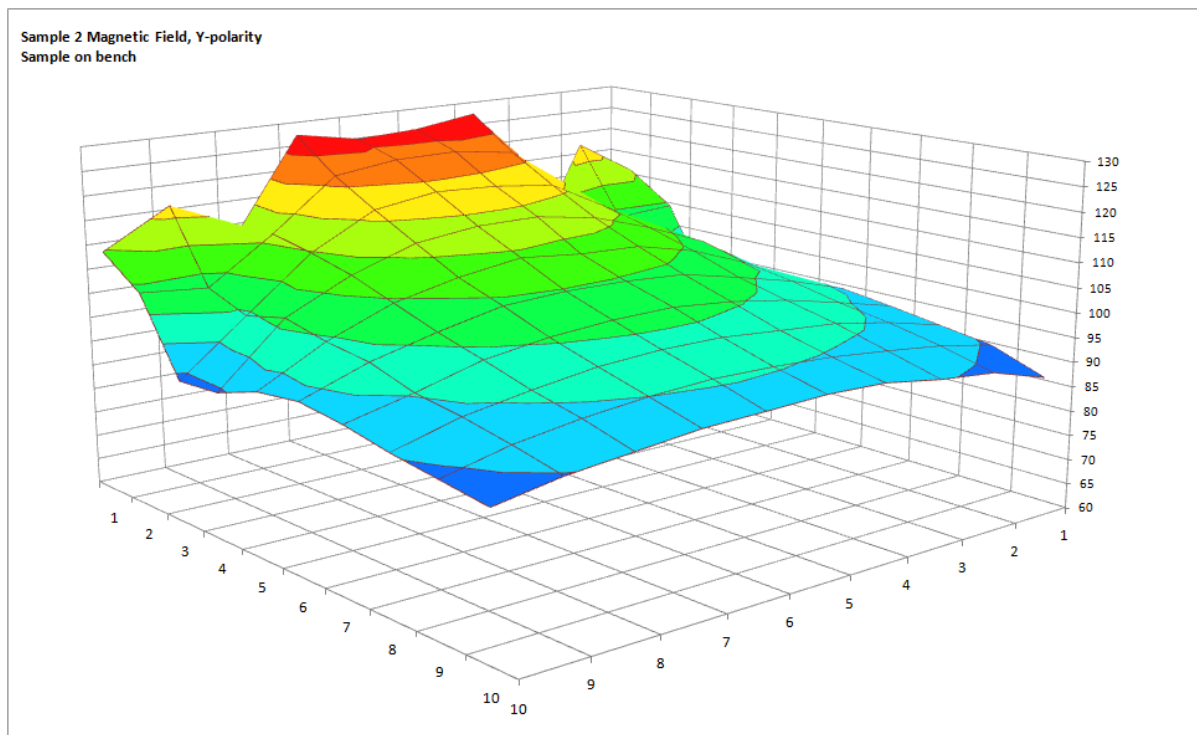


Figure 3.1.2-3: Sample 2 - Hy plot, sample on bench

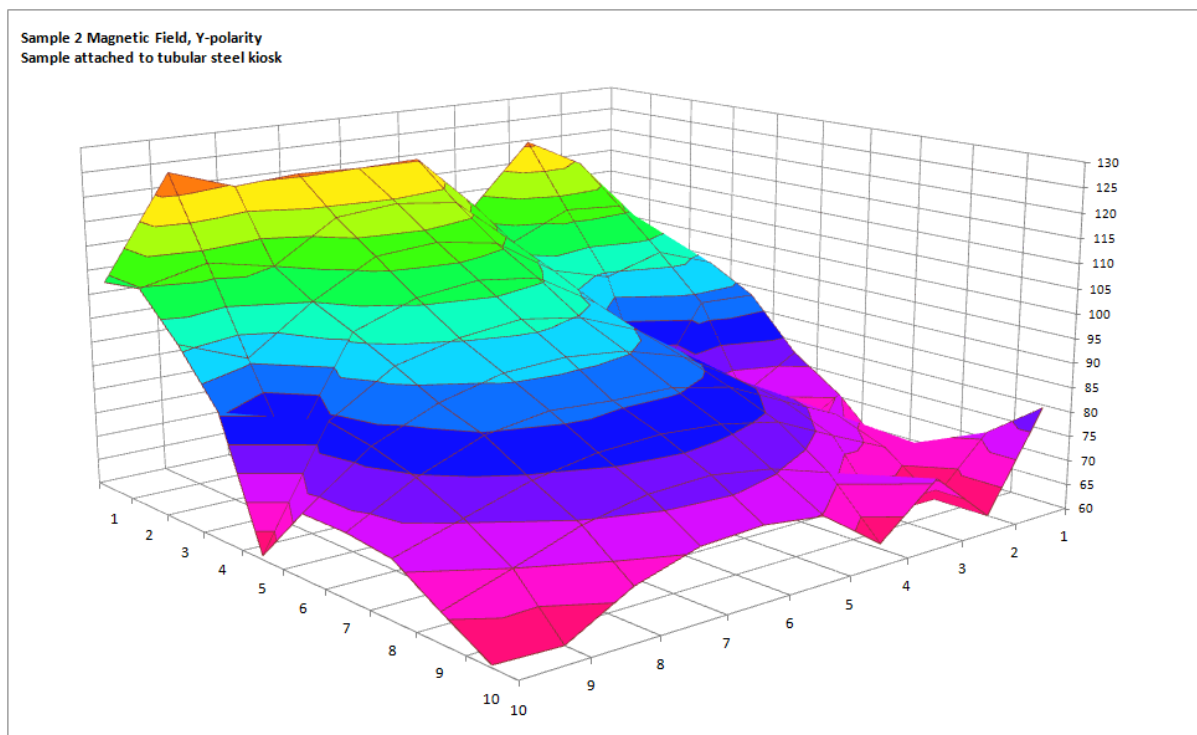


Figure 3.1.2-4: Sample 2 - Hy plot, sample attached to kiosk

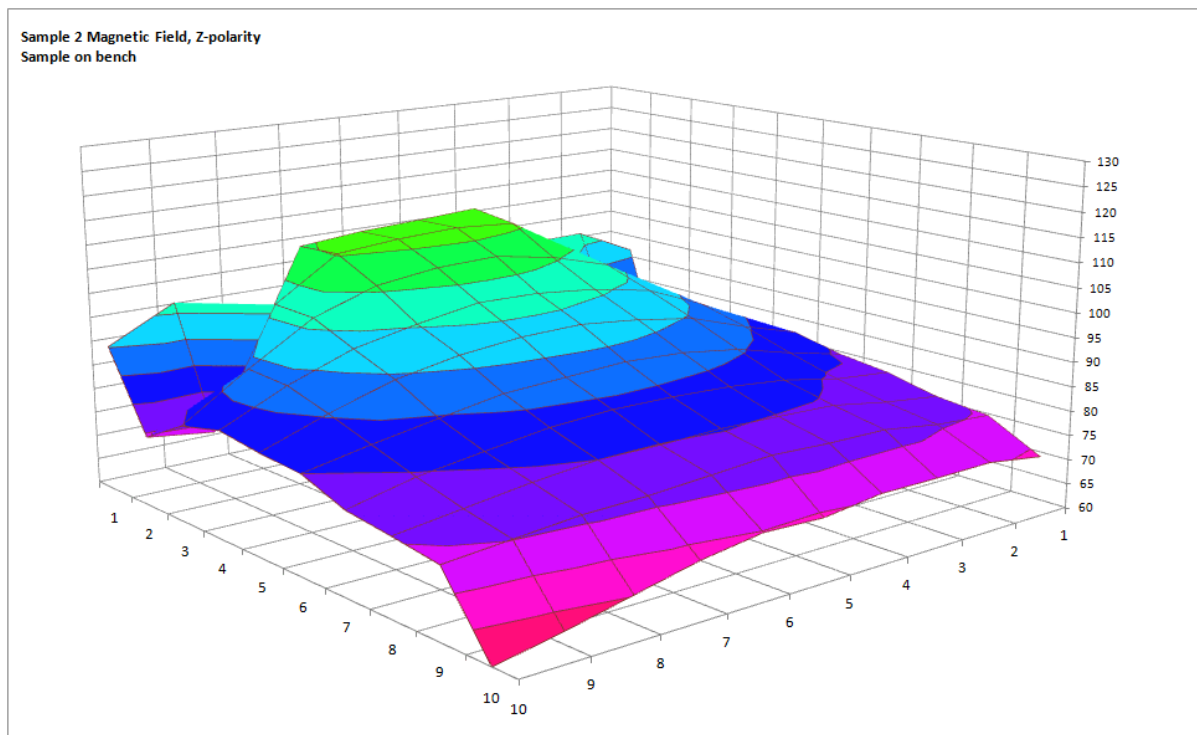


Figure 3.1.2-5: Sample 2 - Hz plot, sample on bench

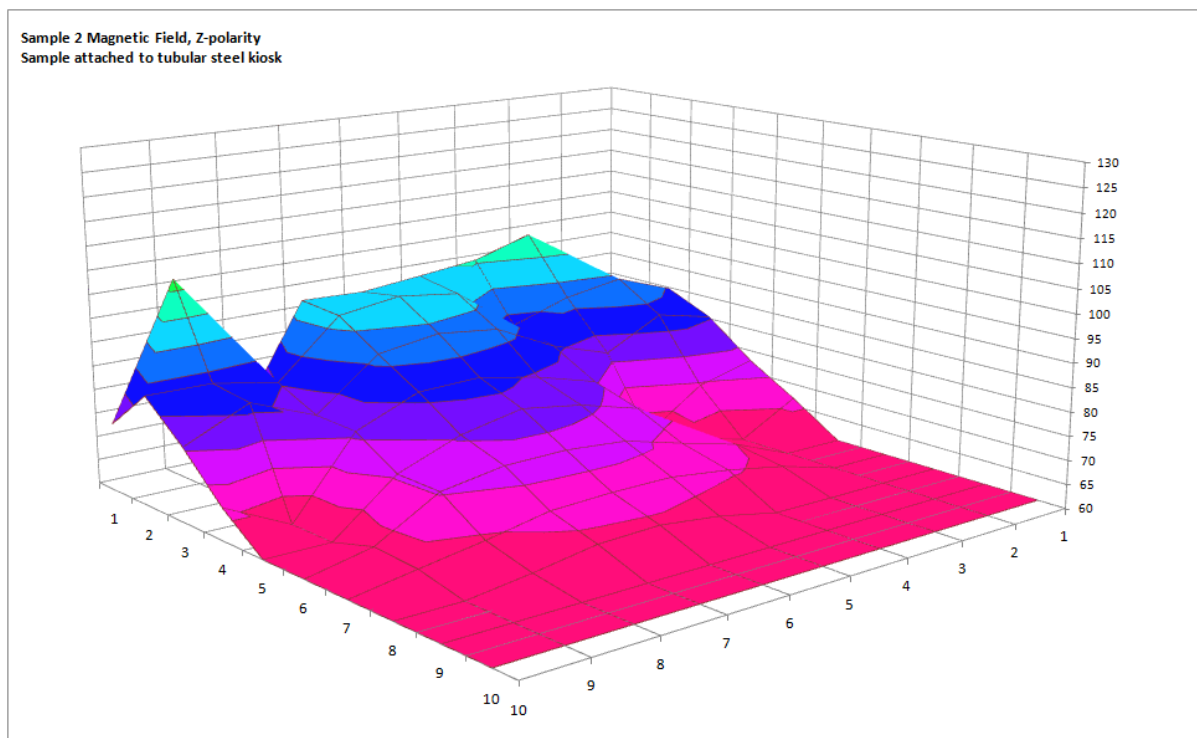


Figure 3.1.2-6: Sample 2 - Hz plot, sample attached to kiosk

3.1.3 Sample 3

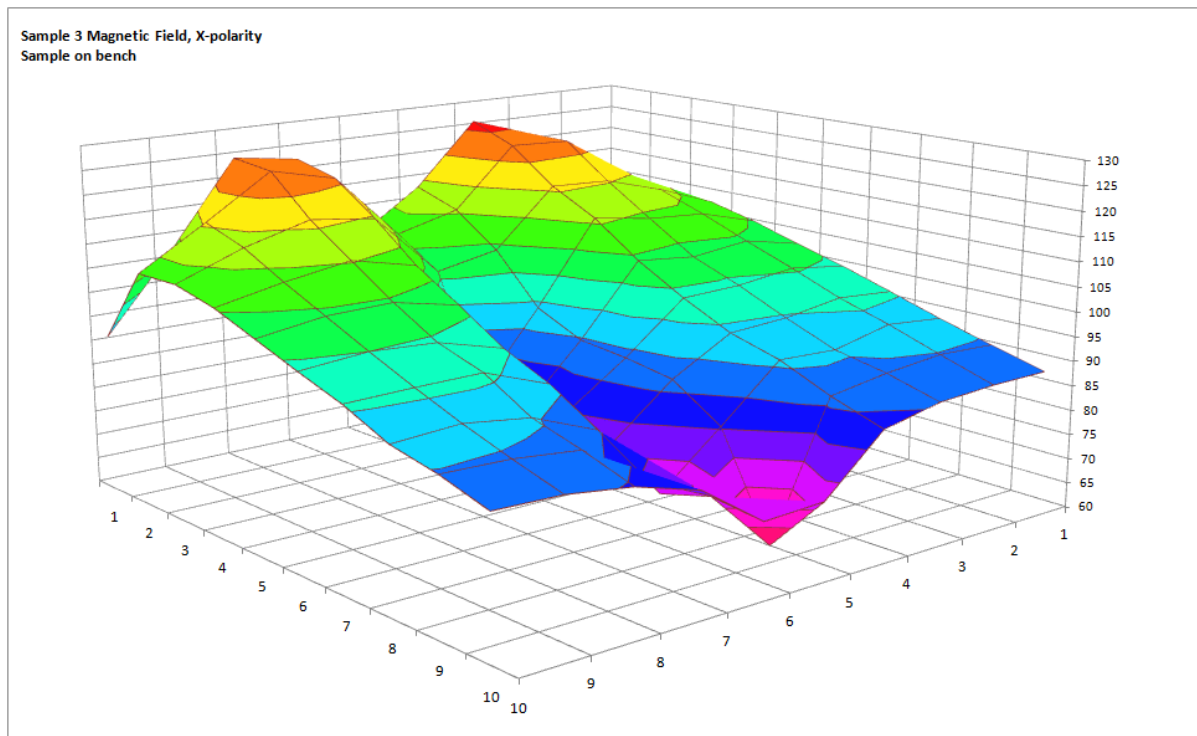


Figure 3.1.3-1: Sample 3 - Hx plot, sample on bench

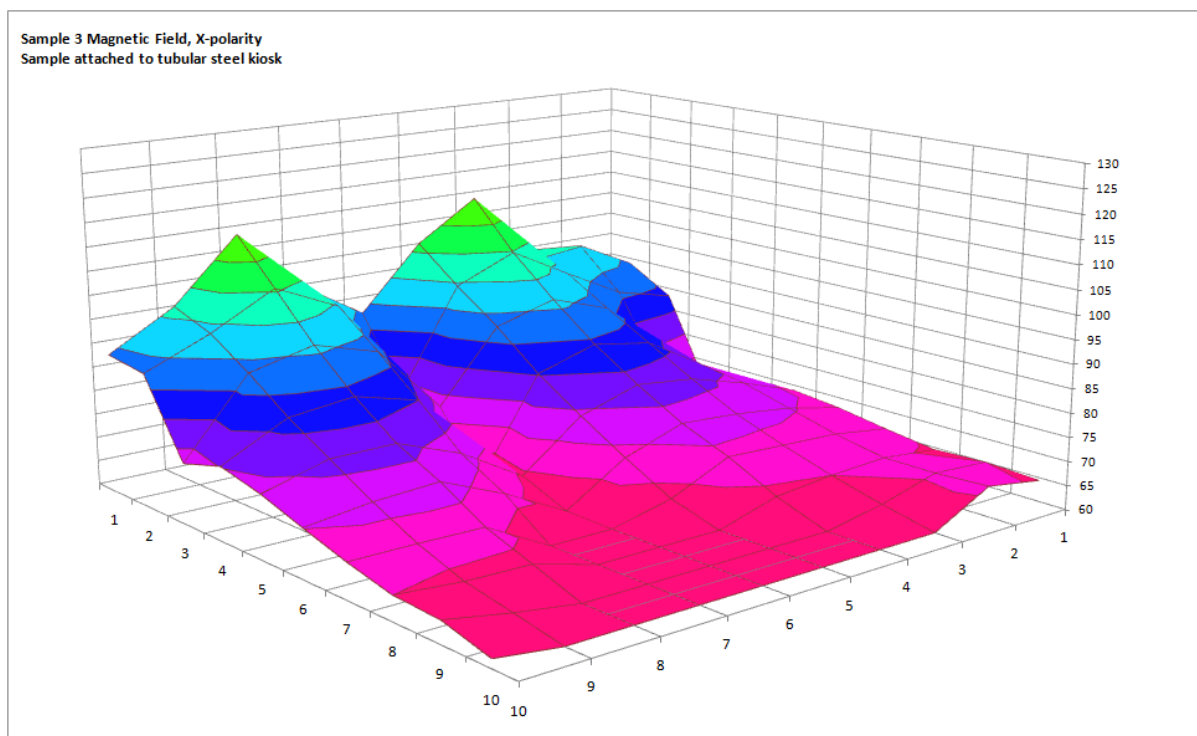


Figure 3.1.3-2: Sample 3 - Hx plot, sample attached to kiosk

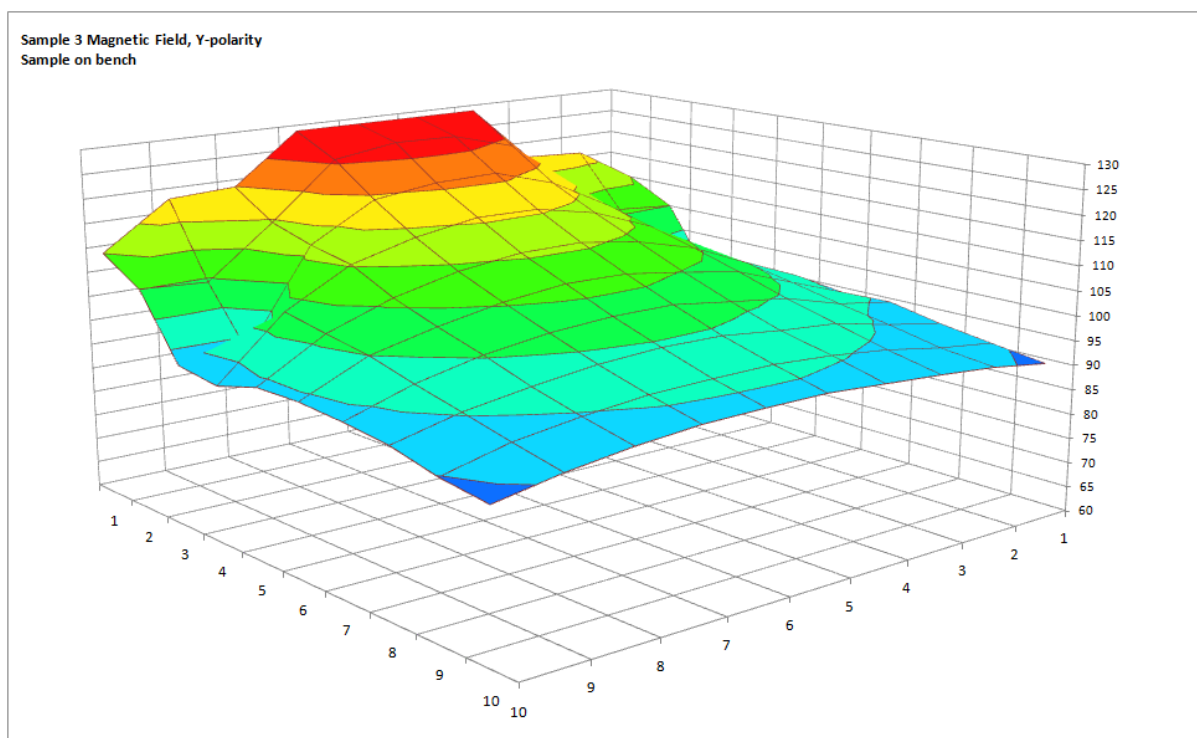


Figure 3.1.3-3: Sample 3 - Hy plot, sample on bench

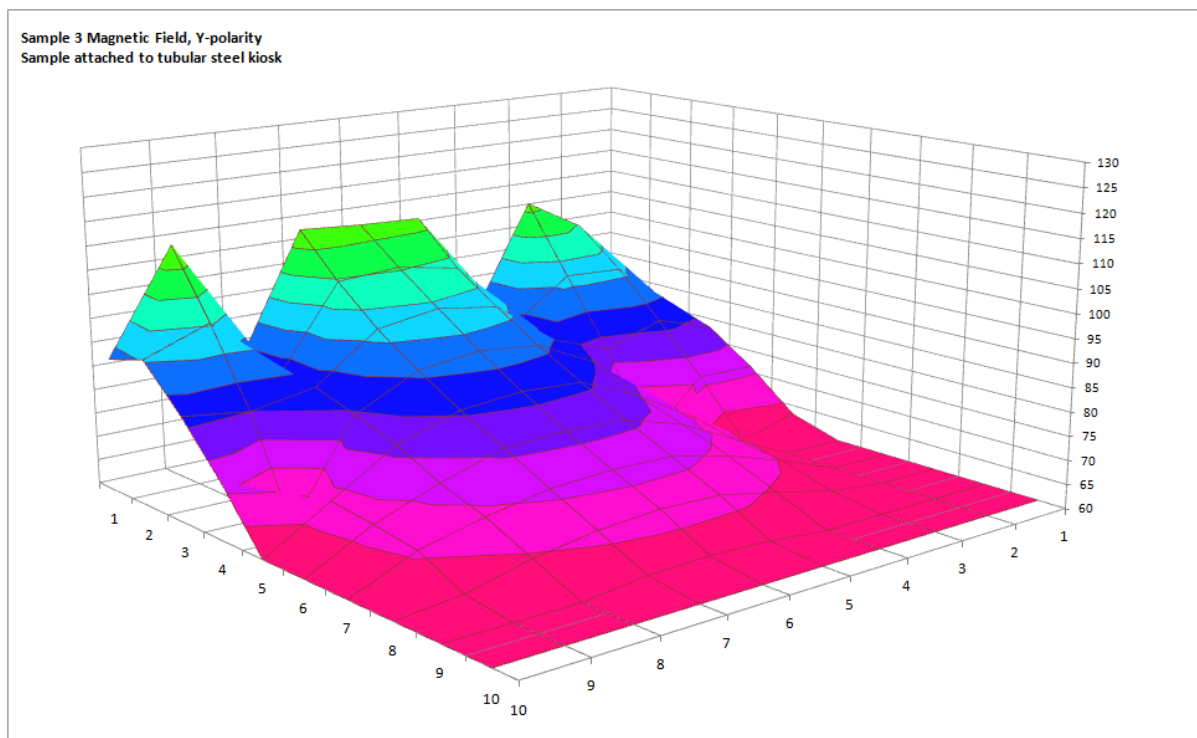


Figure 3.1.3-4: Sample 3 - Hy plot, sample attached to kiosk

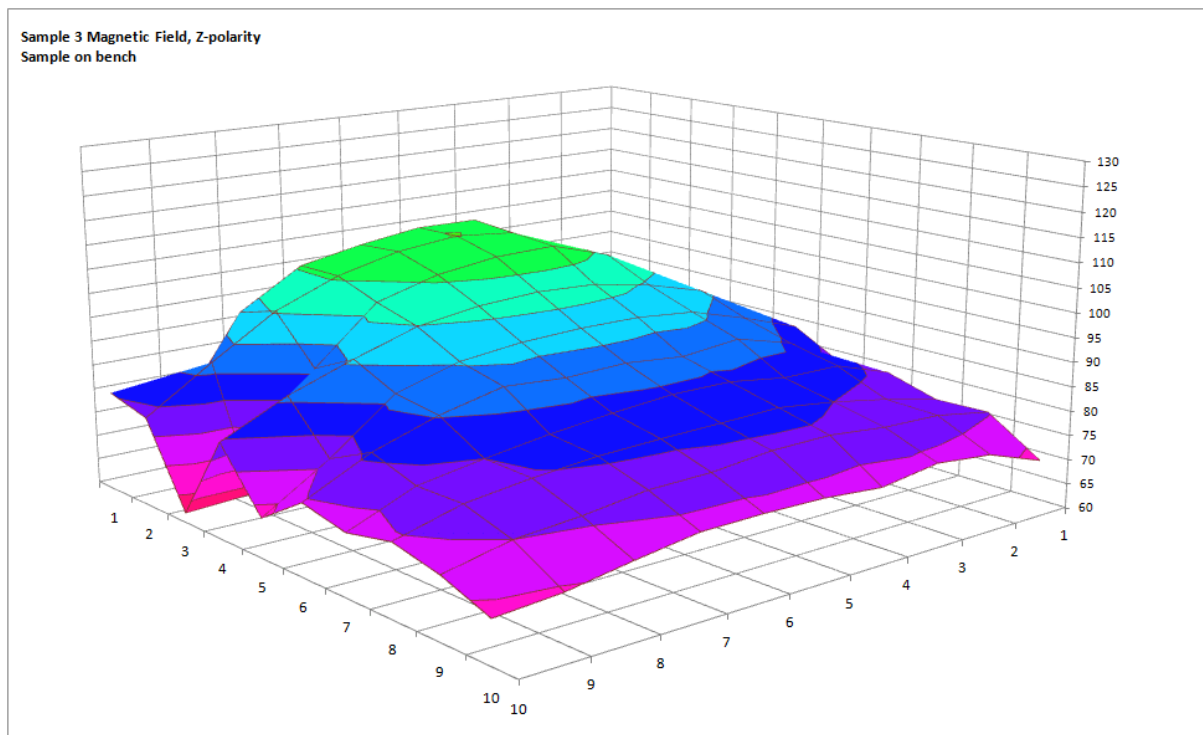


Figure 3.1.3-5: Sample 3 - Hz plot, sample on bench

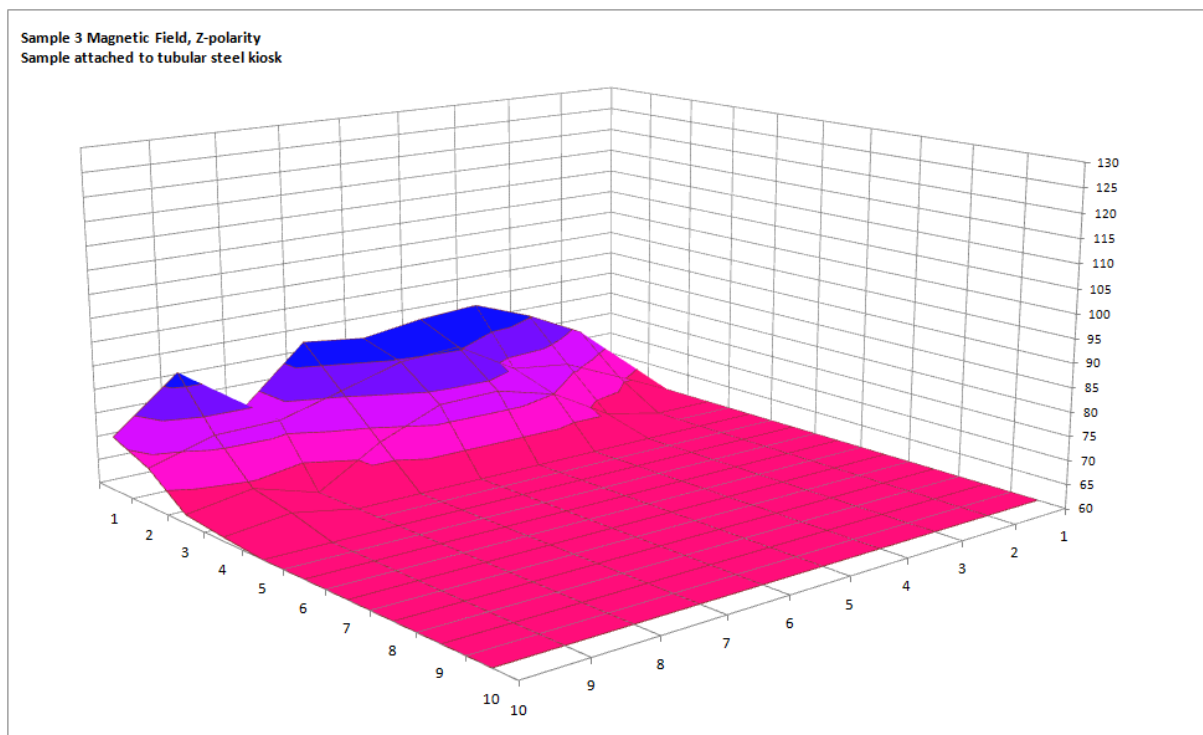


Figure 3.1.3-6: Sample 3 - Hz plot, sample attached to kiosk

3.1.4 Sample 4

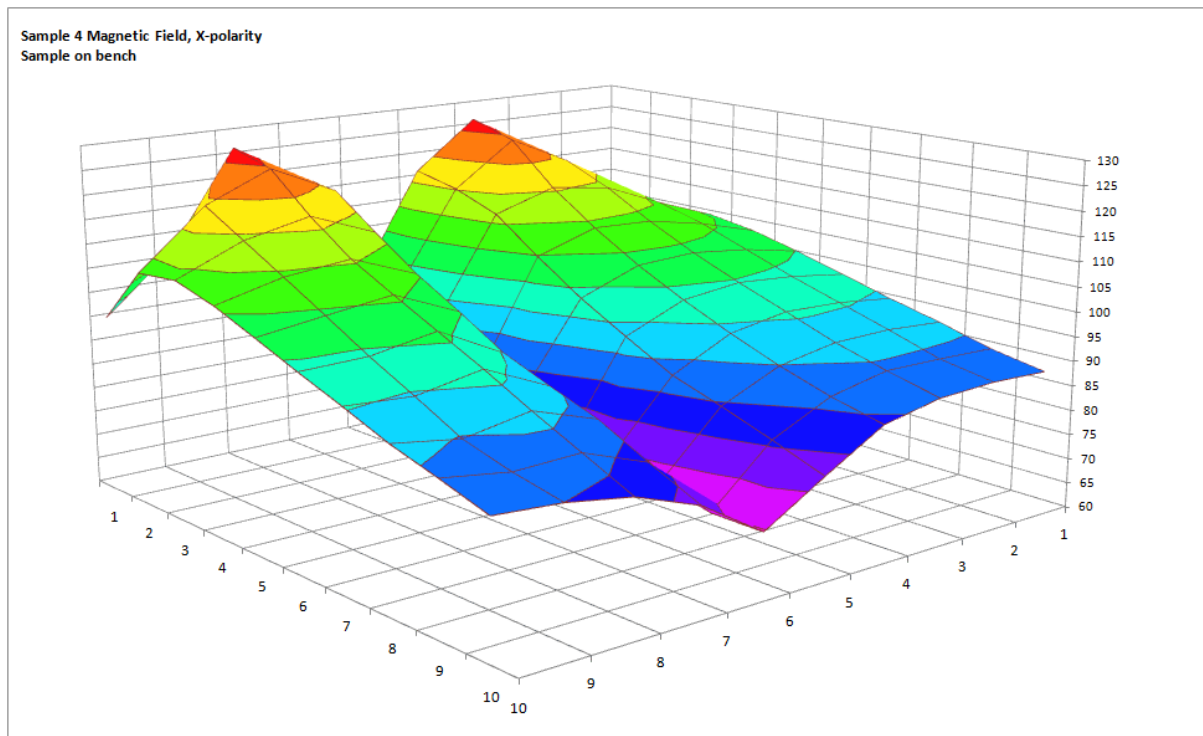


Figure 3.1.4-1: Sample 4 - Hx plot, sample on bench

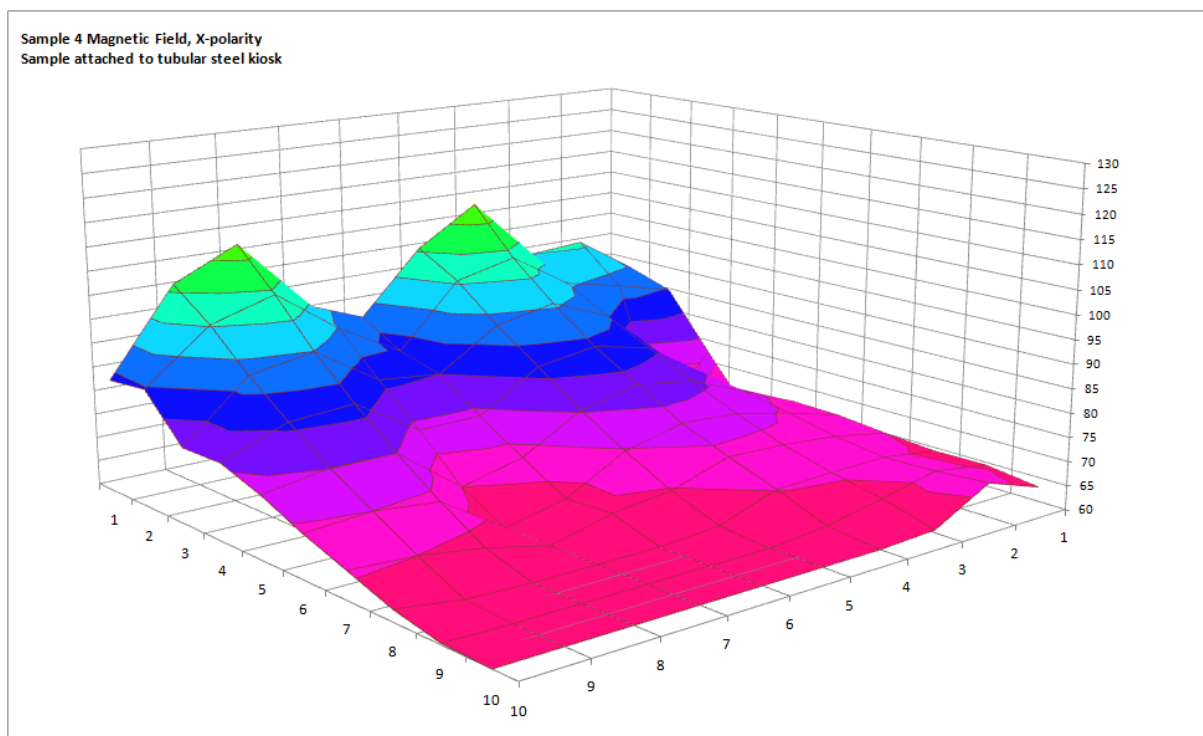


Figure 3.1.4-2: Sample 4 - Hx plot, sample attached to kiosk

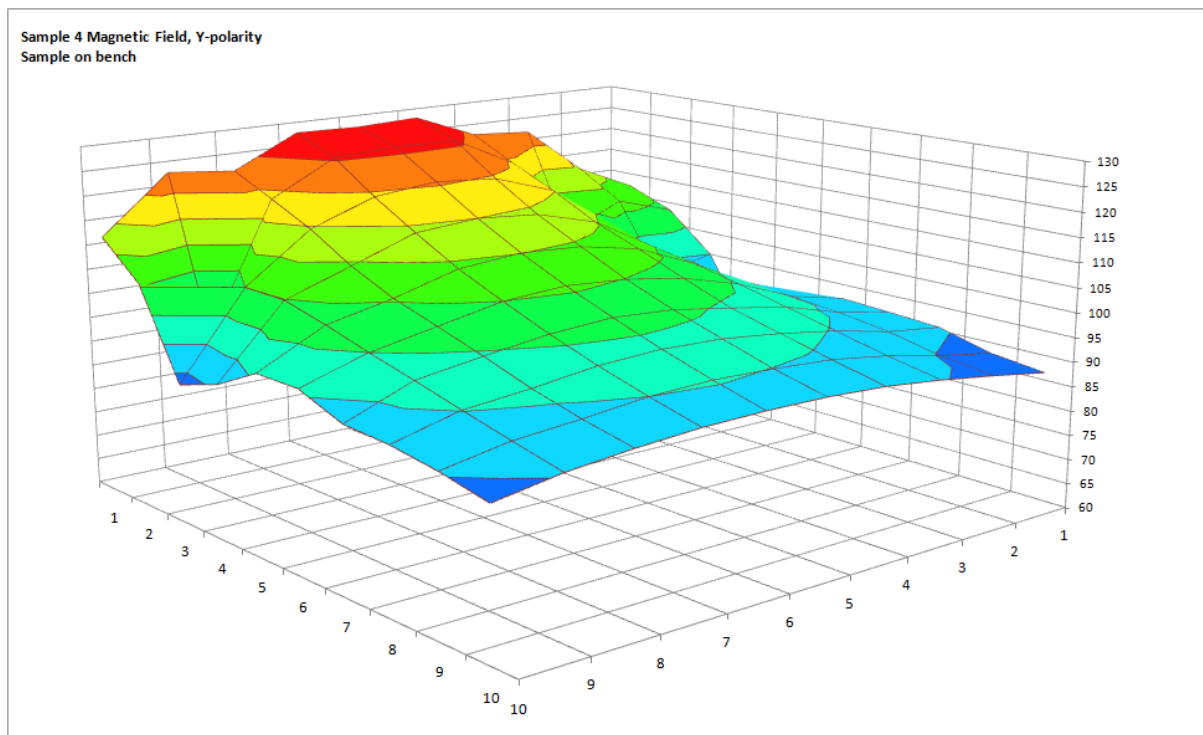


Figure 3.1.4-3: Sample 4 - Hy plot, sample on bench

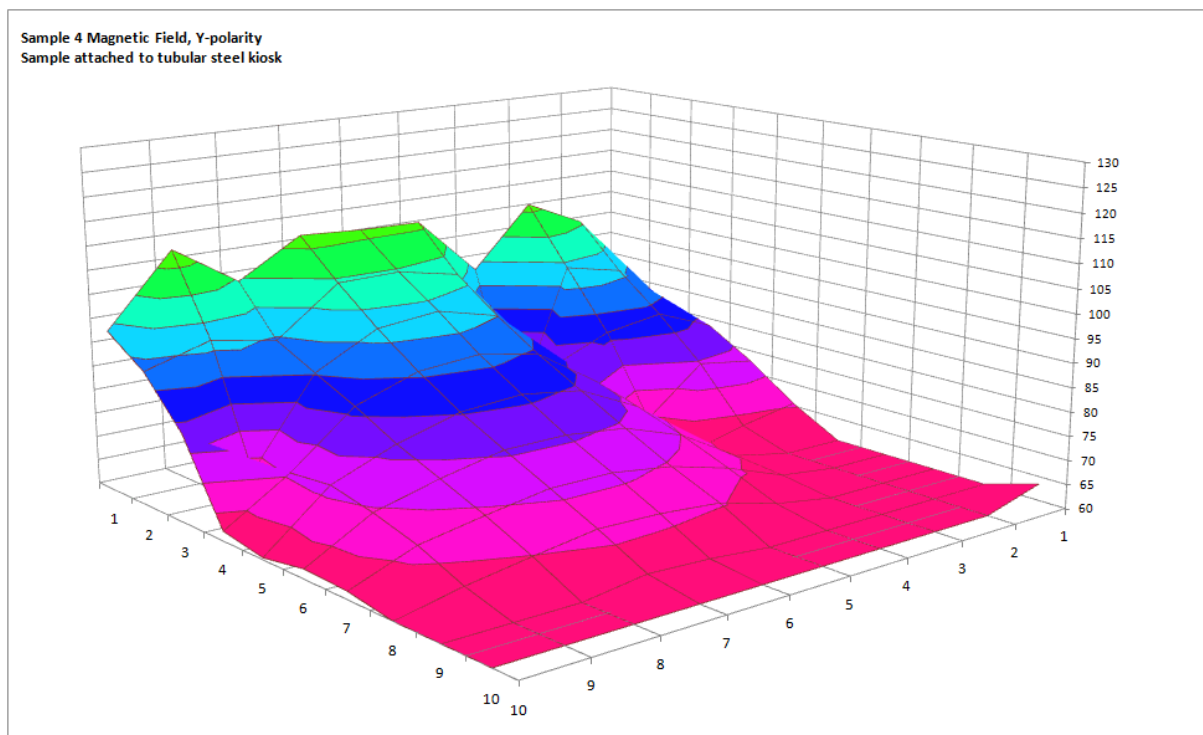


Figure 3.1.4-4: Sample 4 - Hy plot, sample attached to kiosk

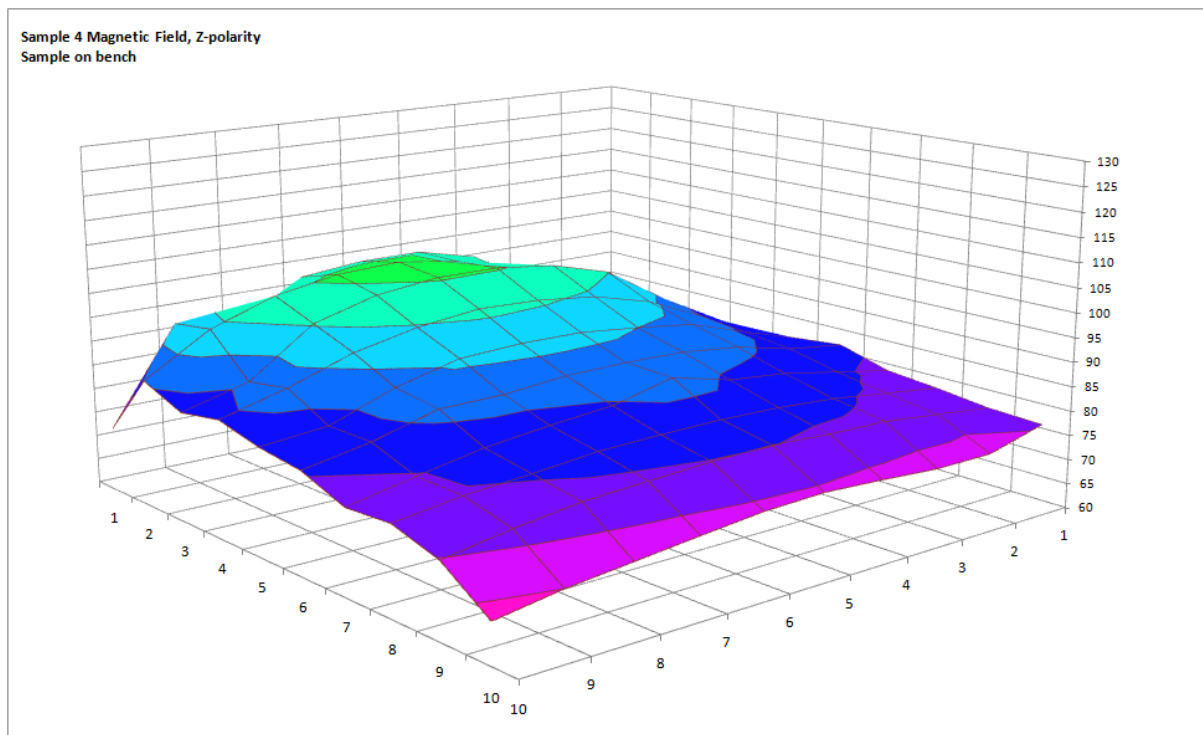


Figure 3.1.4-5: Sample 4 - Hz plot, sample on bench

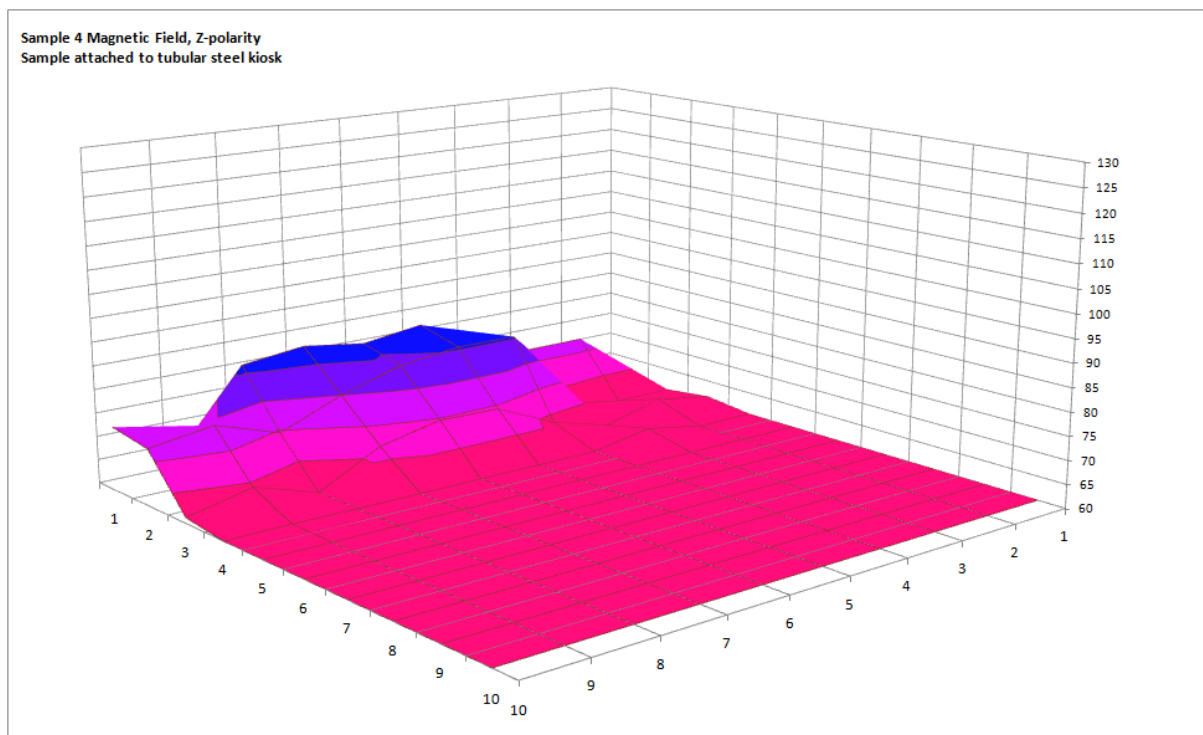


Figure 3.1.4-6: Sample 4 - Hz plot, sample attached to kiosk

3.1.5 Conclusion

The simulated 3-D plots provide a good indication of the distribution and levels of the magnetic field in free space. By directly comparing each of the plot (bench measurement and kiosk measurement), it is clear that the presence of the metal fencing structure affects both the magnitude and distribution of the field.

Looking specifically in each of the sample, the following observations and conclusions can be made:

3.1.5.1 Sample 1

a) In the X-axis

The peak values of the field on the bench and in the kiosk are similar at around 120-125dB μ V (relative).

However, the plot for the kiosk measurements shows that the 'valley' between the peaks deepens and the rate at which the field reduces with distance increases.

Bench measurement: 80-85dB μ V at 1m from antenna

Kiosk measurement: 80-85dB μ V at 0.7m from antenna

b) In the Y-axis

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 120-125dB μ V (relative).

In the plot for the kiosk measurements the rate at which the field reduces with distance increases.

Bench measurement: 85-90dB μ V at 1m from antenna

Kiosk measurement: 85-90dB μ V at 0.7m from antenna

c) In the Z-axis

The peak values of the field on the bench and in the kiosk are similar at around 95-100dB μ V (relative).

In the plot for the kiosk measurements the rate at which the field reduces with distance increases.

Bench measurement: 65-70dB μ V at 1m from antenna

Kiosk measurement: 65-70dB μ V at 0.7m from antenna

d) Conclusion of Sample 1

The magnetic field amplitude is reduced by approximately 30% when the antenna is mounted in the kiosk. Furthermore, the kiosk also introduces distortion of the magnetic field.

3.1.5.2 Sample 2

a) In the X-axis

The peak values of the field on the bench and in the kiosk are similar at around 120-125dB μ V (relative).

However, the plot for the kiosk measurements shows that the 'valley' between the peaks deepens and the rate at which the field reduces with distance is further increased.

Bench measurement: 85-90dB μ V at 1m from antenna

Kiosk measurement: 85-90dB μ V at 0.6m from antenna

b) In the Y-axis

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 120-125dB μ V (relative).

In the plot for the kiosk measurements the rate at which the field reduces with distance is further increased.

Bench measurement: 90-95dB μ V at 1m from antenna

Kiosk measurement: 90-95dB μ V at 0.6m from antenna

c) In the Z-axis

The peak values of the field on the bench are reduced in the kiosk from 100-105dB μ V (relative) to 95-100dB μ V (relative). Distortion of the field is also evident.

In the plot for the kiosk measurements the rate at which the field reduces with distance is further increased.

Bench measurement: 70-75dB μ V at 1m from antenna

Kiosk measurement: 65-70dB μ V at 0.6m from antenna

d) Conclusion of Sample 2

The field is reduced by 40% when the antenna is mounted in the kiosk. Furthermore, the kiosk also introduces distortion of the magnetic field.

3.1.5.3 Sample 3

a) In the X-axis

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 105-110dB μ V (relative).

The plot for the kiosk measurements also shows that the 'valley' between the peaks deepens and the rate at which the field reduces with distance is further increased.

Bench measurement: 85-90dB μ V at 1m from antenna

Kiosk measurement: 85-90dB μ V at 0.3m from antenna

b) In the Y-axis

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 105-110dB μ V (relative).

In the plot for the kiosk measurements the rate at which the field reduces with distance is further increased.

Bench measurement: 90-95dB μ V at 1m from antenna

Kiosk measurement: 90-95dB μ V at 0.3m from antenna

c) In the Z-axis

The peak values of the field on the bench are reduced in the kiosk from 100-105dB μ V (relative) to 80-85dB μ V (relative). Distortion of the field is also evident.

In the plot for the kiosk measurements the rate at which the field reduces with distance increases.

Bench measurement: 70-75dB μ V at 1m from antenna

Kiosk measurement: 65-70dB μ V at 0.2 to 0.3m from antenna

d) Conclusion of Sample 3

The field is reduced by 70-80% when the antenna is mounted in the kiosk. Furthermore, the kiosk also introduces distortion of the magnetic field.

3.1.5.4 Sample 4**a) In the X-axis**

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 105-110dB μ V (relative).

The plot for the kiosk measurements also shows that the 'valley' between the peaks deepens and the rate at which the field reduces with distance increases.

Bench measurement: 85-90dB μ V at 1m from antenna

Kiosk measurement: 85-90dB μ V at 0.3m from antenna

b) In the Y-axis

The peak values of the field on the bench are reduced in the kiosk from 125-130dB μ V (relative) to 105-110dB μ V (relative).

In the plot for the kiosk measurements the rate at which the field reduces with distance increases.

Bench measurement: 90-95dB μ V at 1m from antenna

Kiosk measurement: 90-95dB μ V at 0.3m from antenna

c) In the Z-axis

The peak values of the field on the bench are reduced in the kiosk from 100-105dB μ V (relative) to 80-85dB μ V (relative). Distortion of the field is also evident.

In the plot for the kiosk measurements the rate at which the field reduces with distance increases.

Bench measurement: 70-75dB μ V at 1m from antenna

Kiosk measurement: 65-70dB μ V at 0.2 to 0.3m from antenna

d) Conclusion of Sample 4

The field is reduced by 70 to 80% when the antenna is mounted in the kiosk. The kiosk also introduces distortion of the field.

3.2 Magnetic Field Distribution Around Centre Section

The magnetic field distribution was investigated at a distance of 15cm above and below the centre cross section to check for planarity of the field. This was performed in the Y magnetic field orientation only (Figure 2.1.1-2).

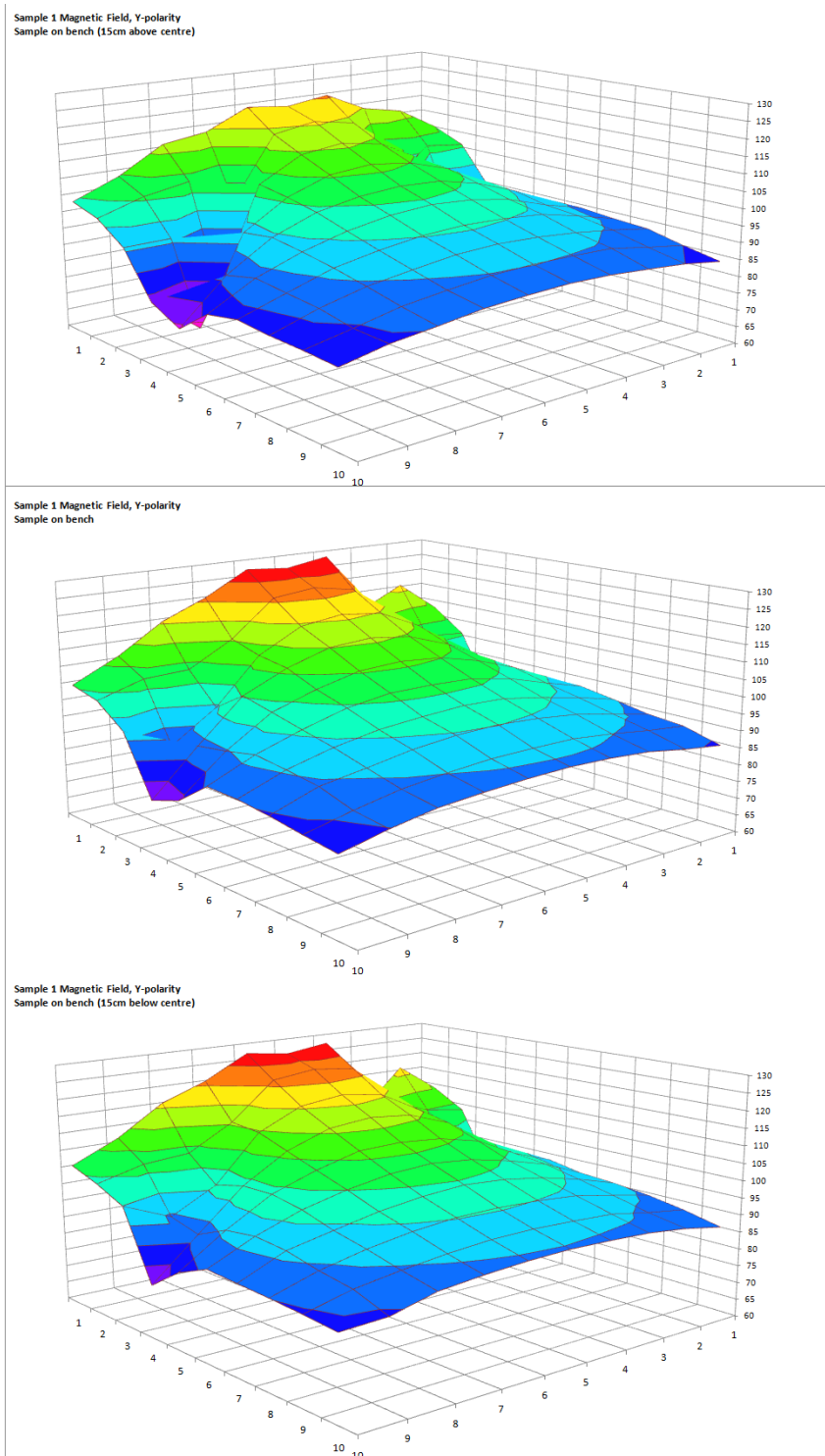


Figure 3.1.5-1: Sample 1 - Hy plot, sample on bench +15cm, Centre, -15cm

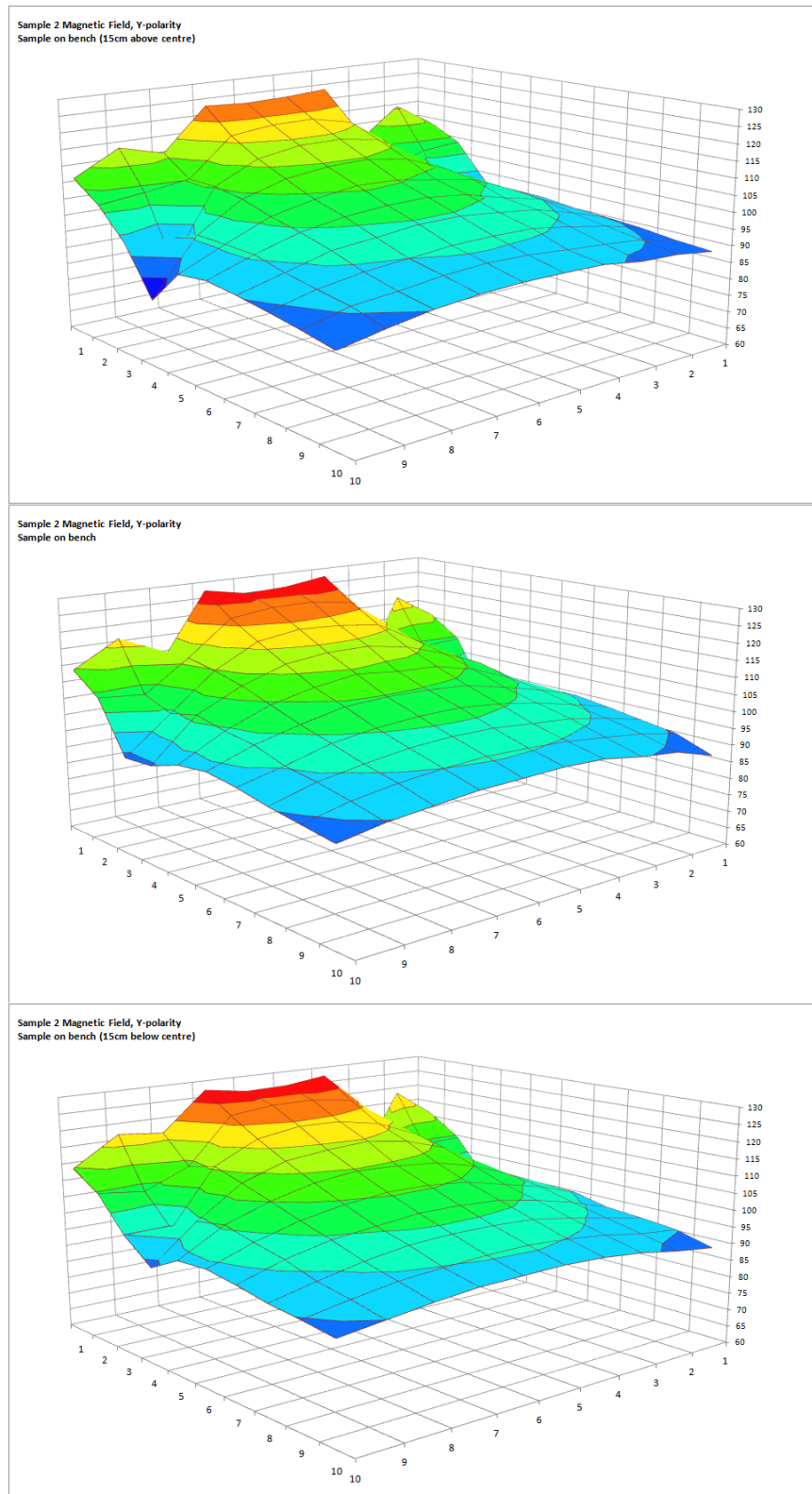


Figure 3.1.5-2: Sample 2 - Hy plot, sample on bench +15cm, Centre, -15cm

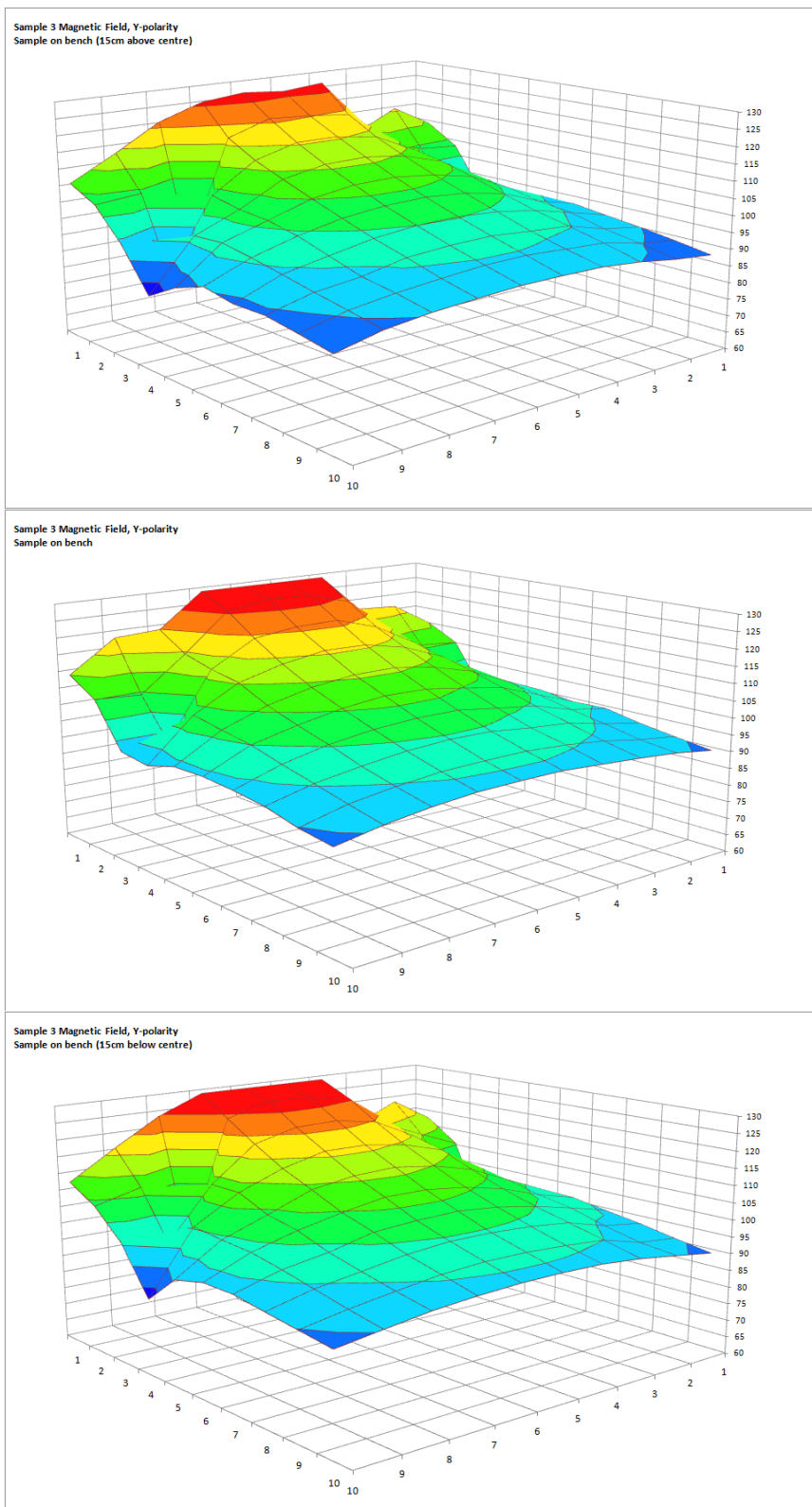


Figure 3.1.5-3: Sample 3 - Hy plot, sample on bench +15cm, Centre, -15cm

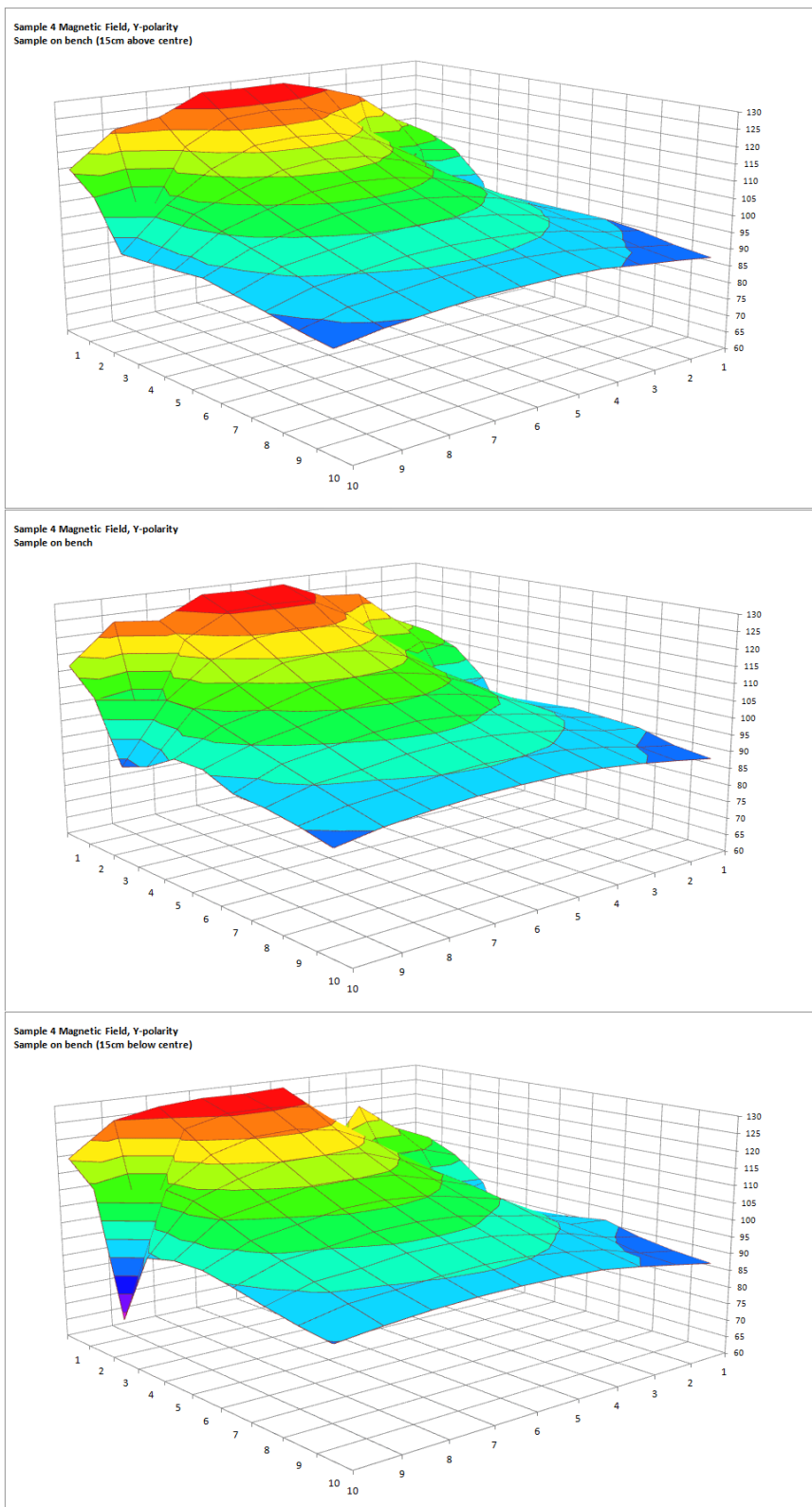


Figure 3.1.5-4: Sample 4 - Hy plot, sample on bench +15cm, Centre, -15cm

3.2.1 Conclusion

The measurements performed on all four samples show that there are slight variations in the magnetic field around the centre lines but generally the field produced by each of the sample appears quite planar within the measured areas, thus contributing to consistent tag reading in those regions.

3.3 Antenna Reading Distance

The antenna reading distance for each of the samples was measured as detailed in Section 2.2. The results for each of the samples are presented below.

3.3.1 Sample 1

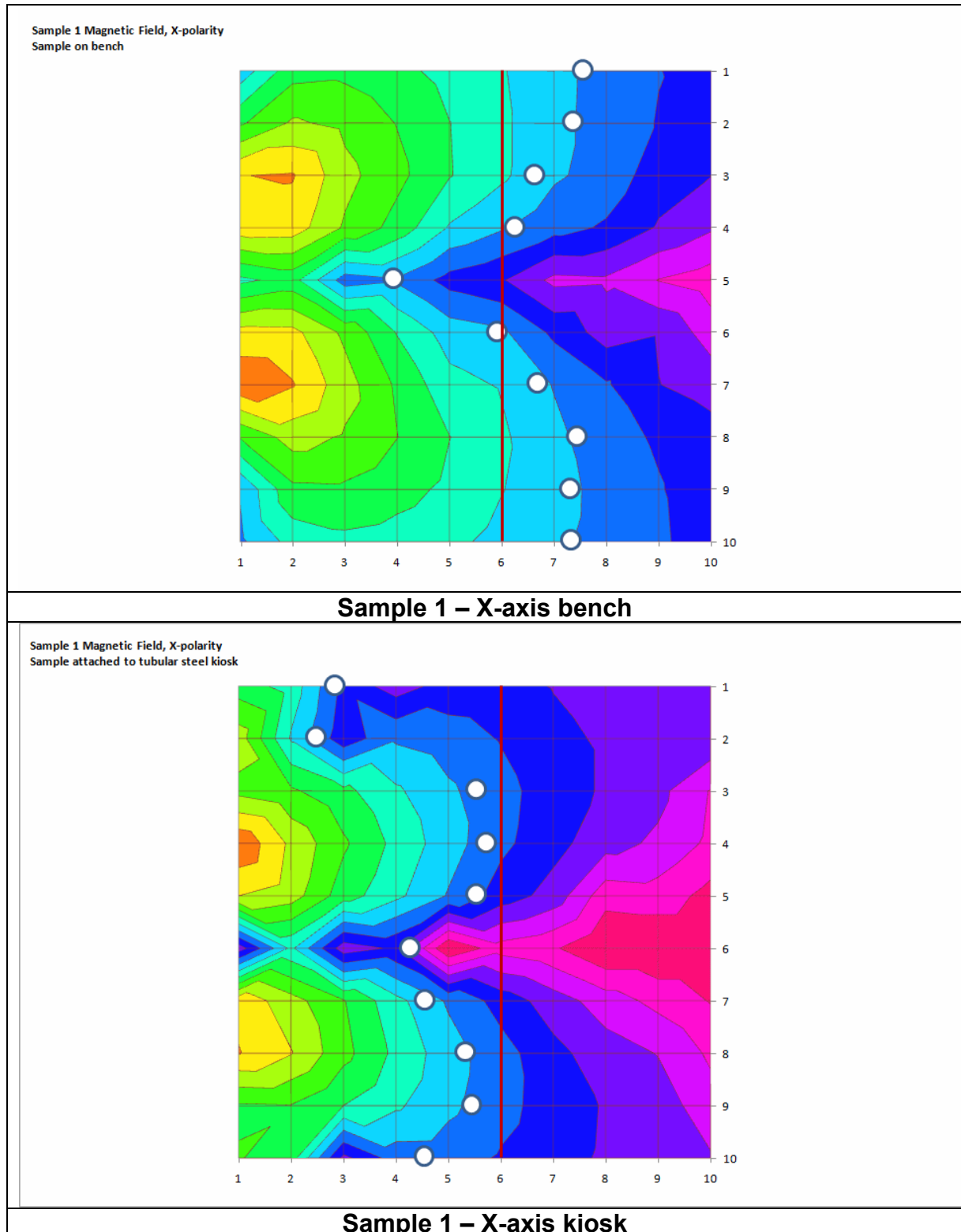
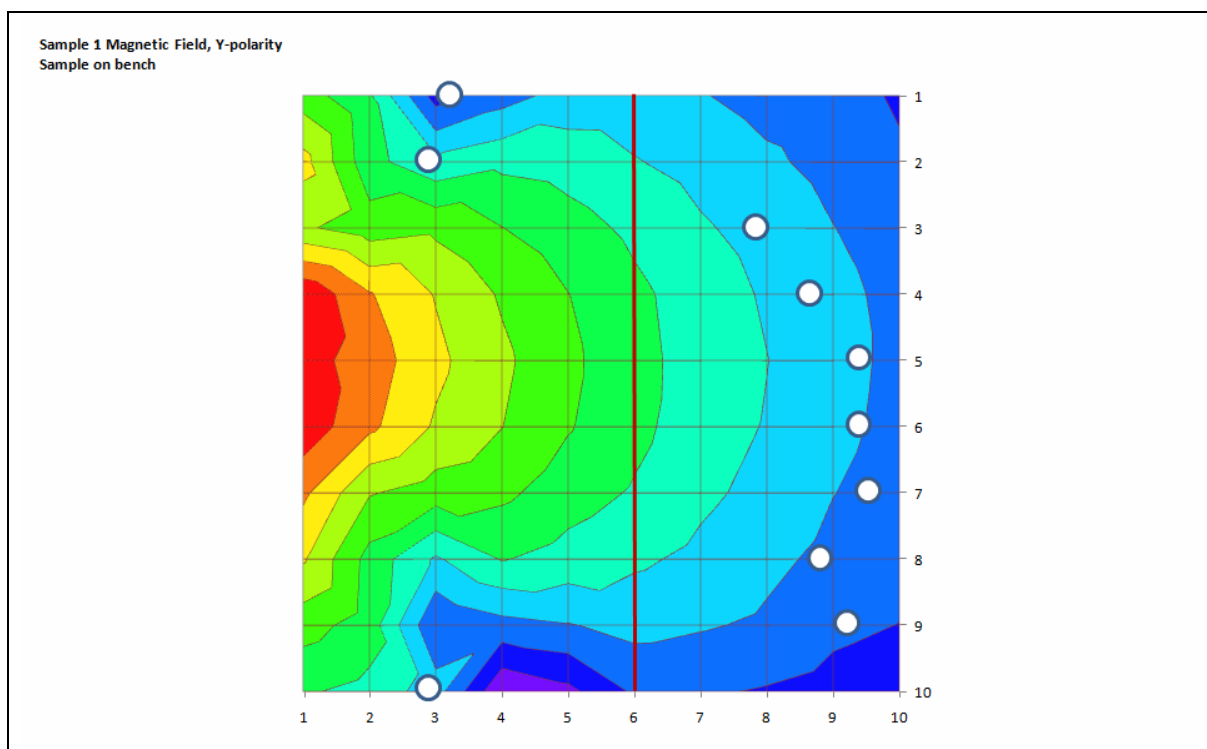
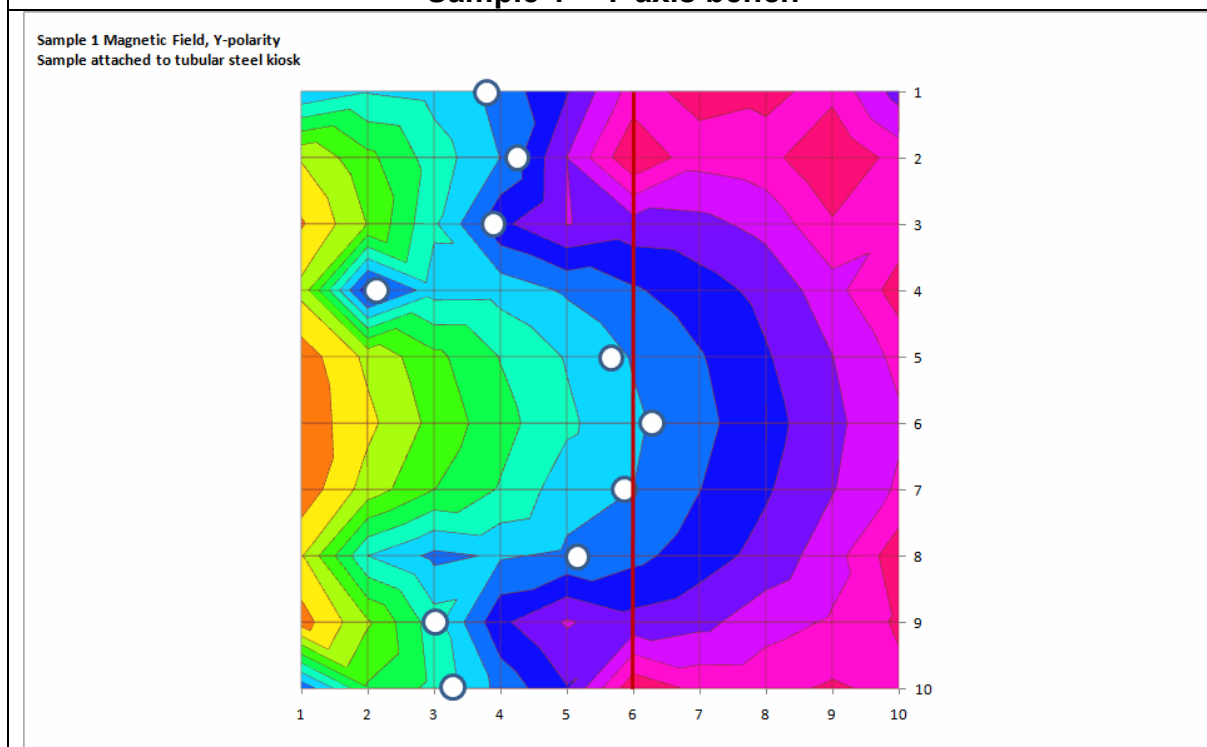


Figure 3.3.1-1: Sample 1 – X-axis – Antenna reading distance (bench/kiosk)

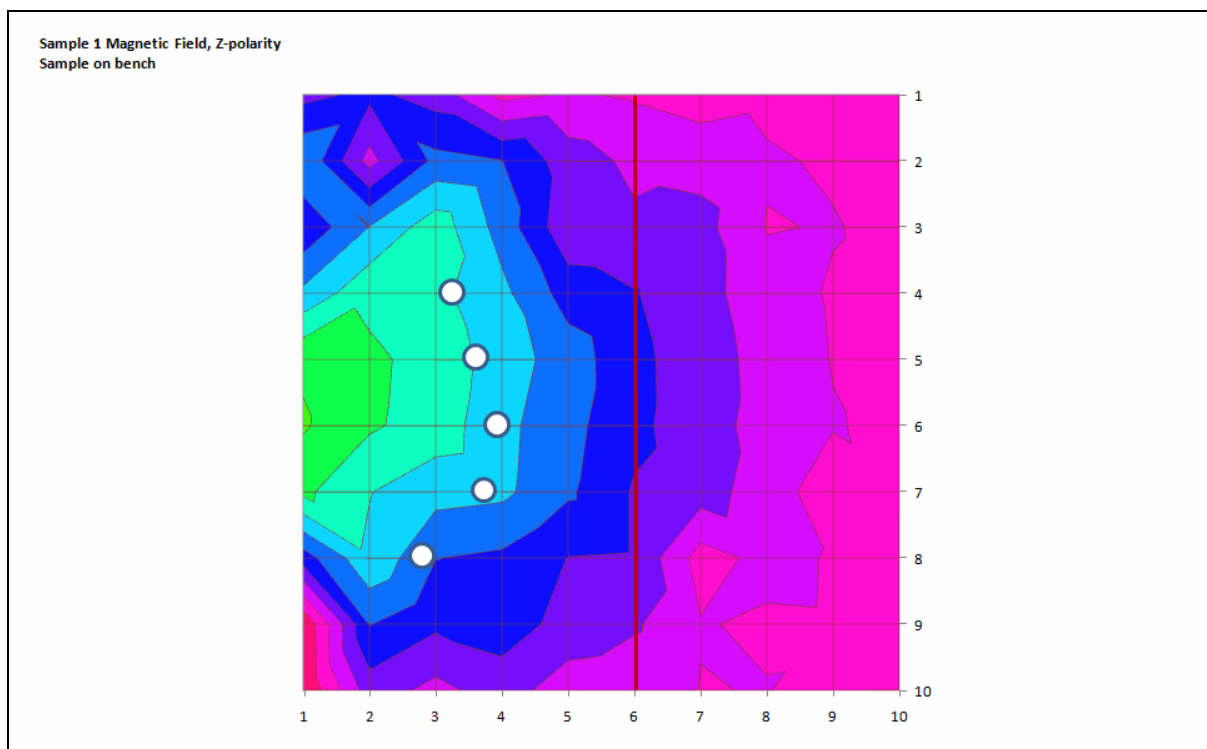


Sample 1 – Y-axis bench

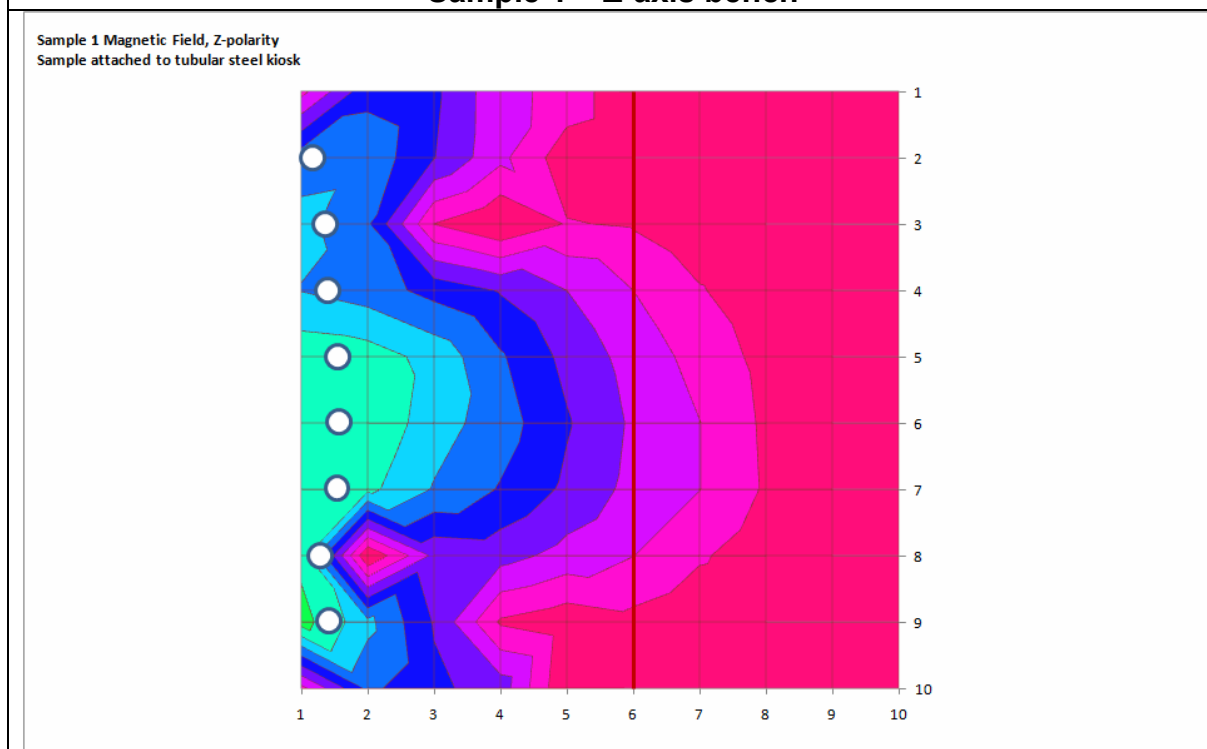


Sample 1 – Y-axis kiosk

Figure 3.3.1-2: Sample 1 – Y-axis – Antenna reading distance (bench/kiosk)



Sample 1 – Z-axis bench



Sample 1 – Z-axis kiosk

Figure 3.3.1-3: Sample 1 – Z-axis – Antenna reading distance (bench/kiosk)

3.3.2 Sample 2

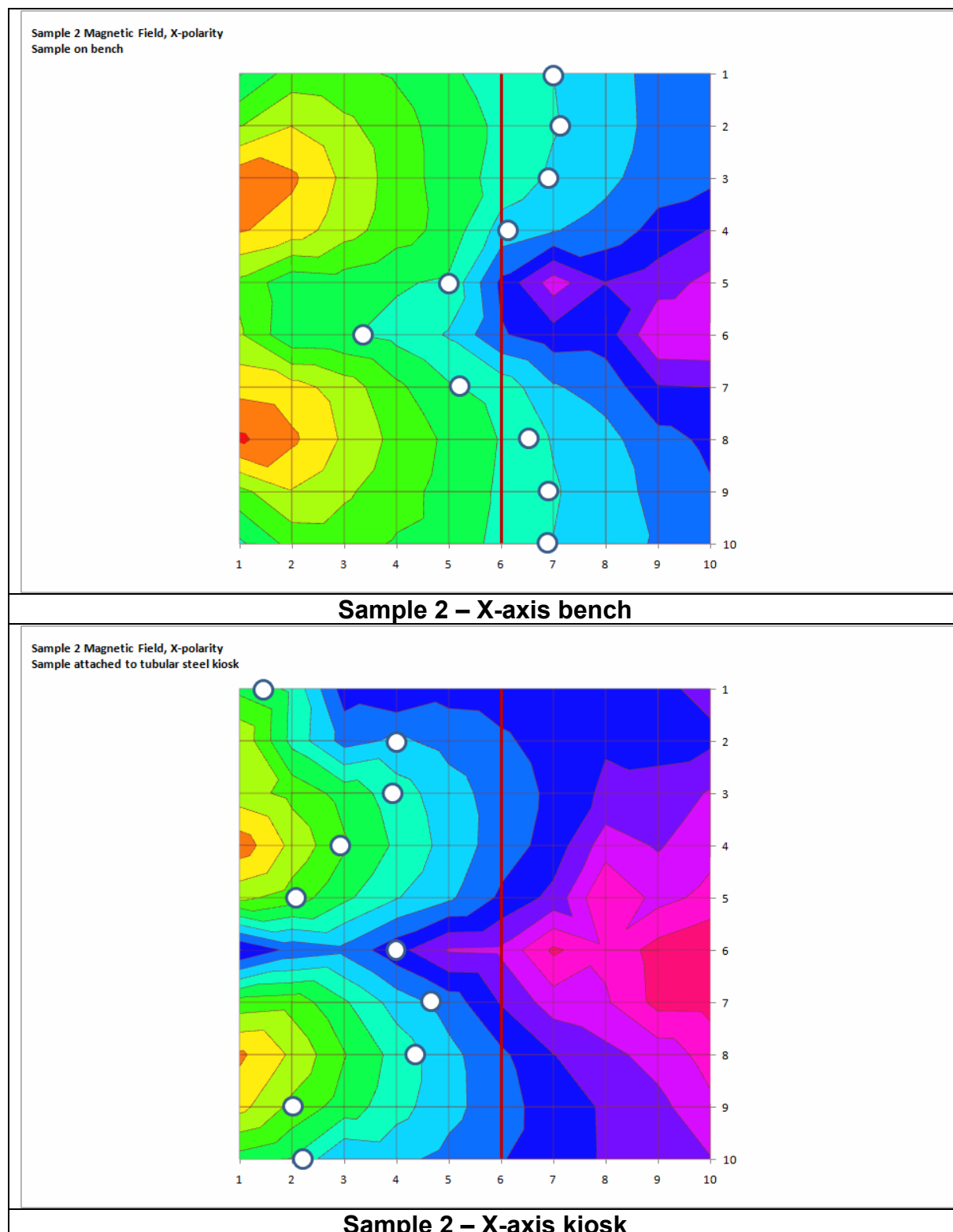
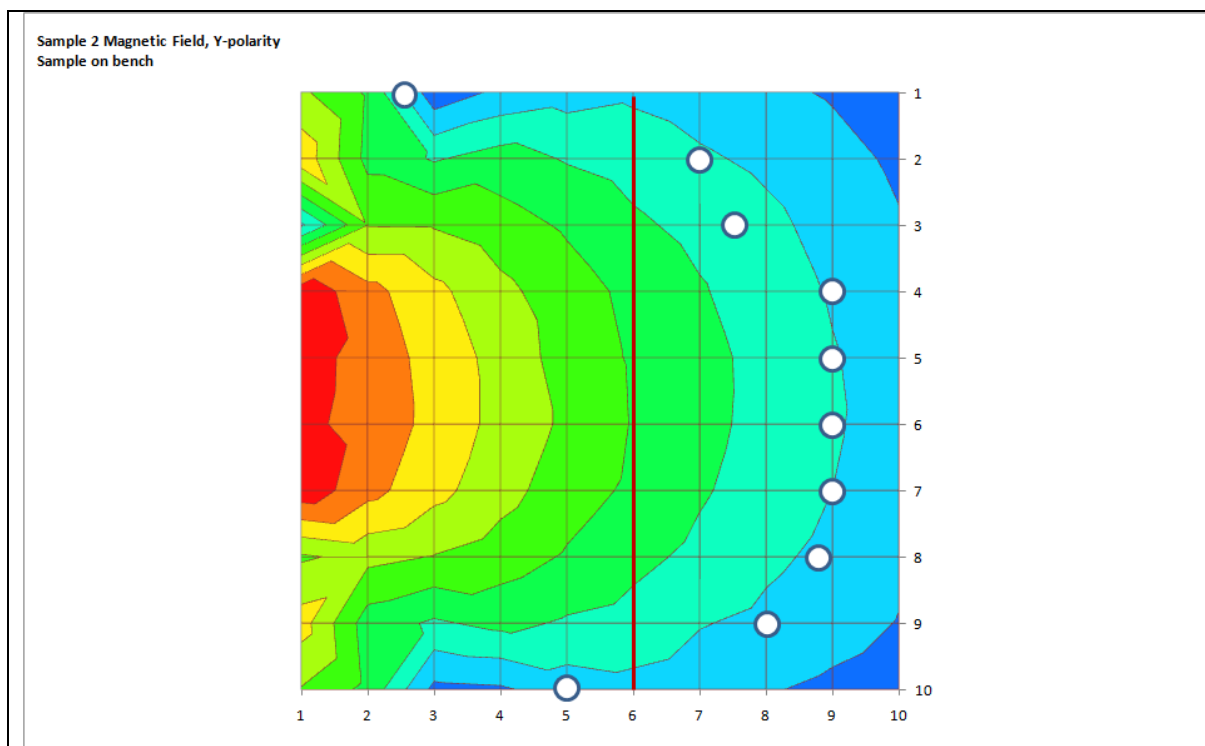
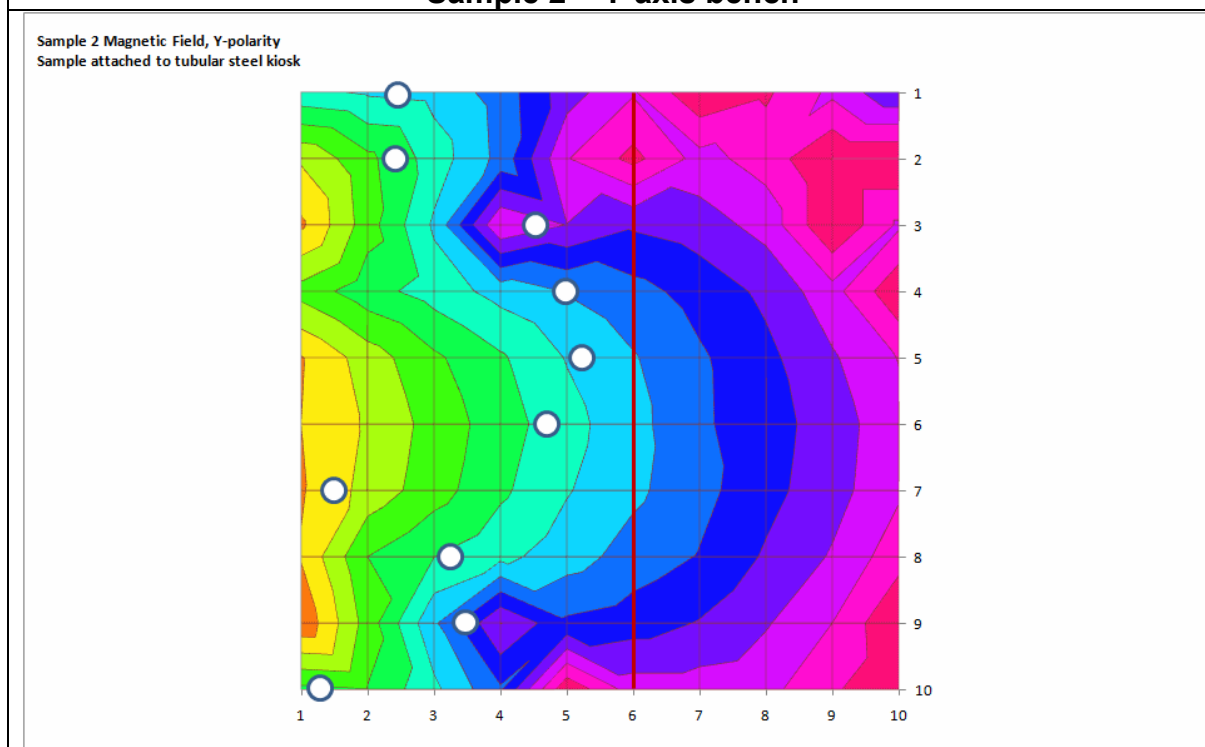


Figure 3.3.2-1: Sample 2 – X-axis – Antenna reading distance (bench/kiosk)

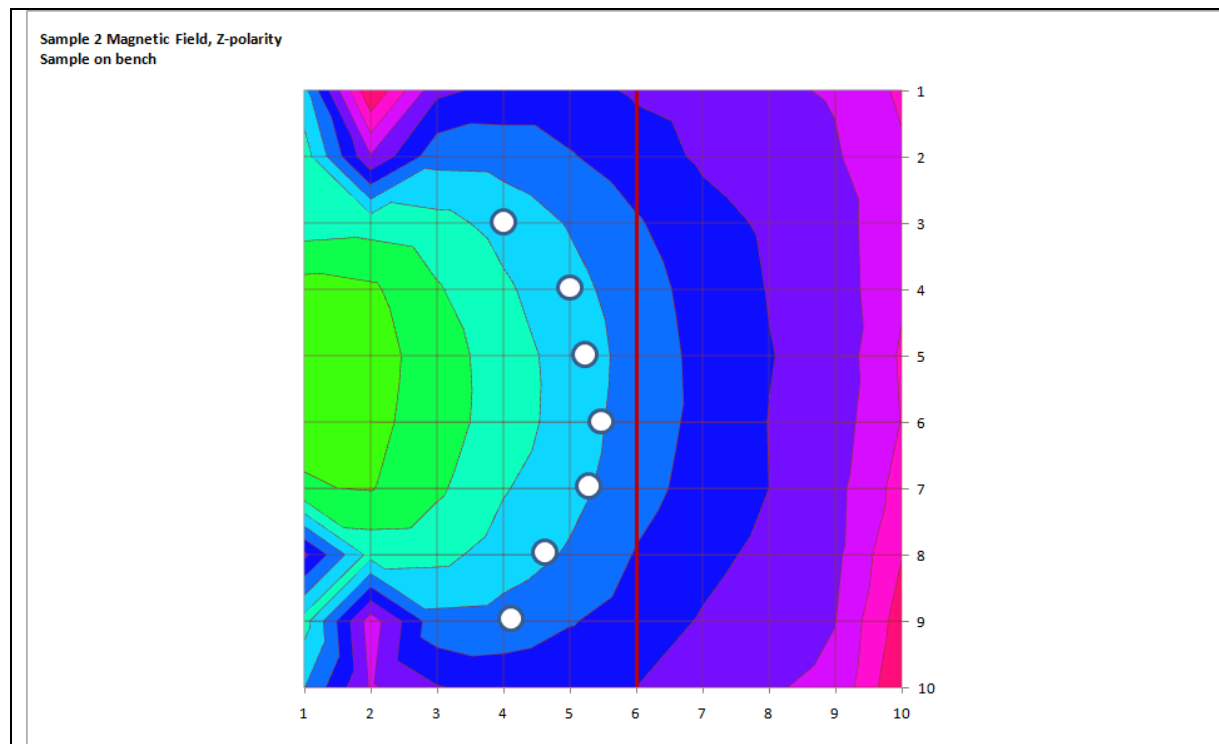


Sample 2 – Y-axis bench

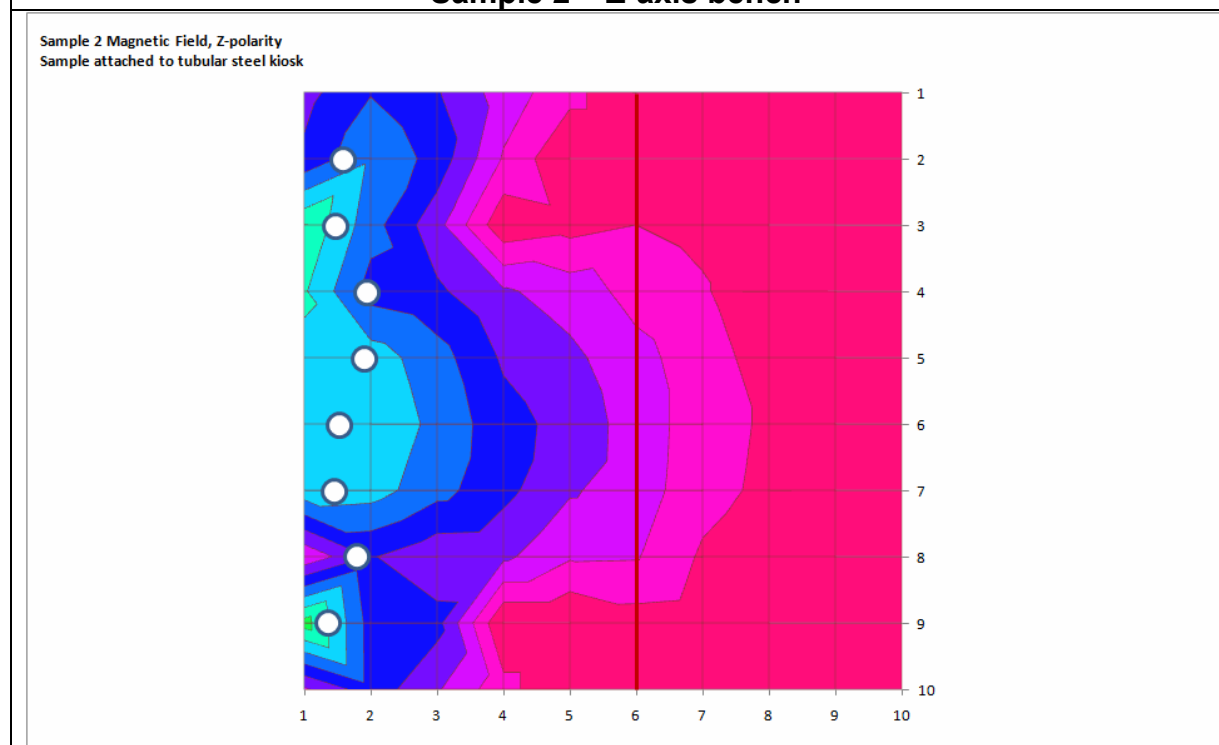


Sample 2 – Y-axis kiosk

Figure 3.3.2-2: Sample 2 – Y-axis – Antenna reading distance (bench/kiosk)



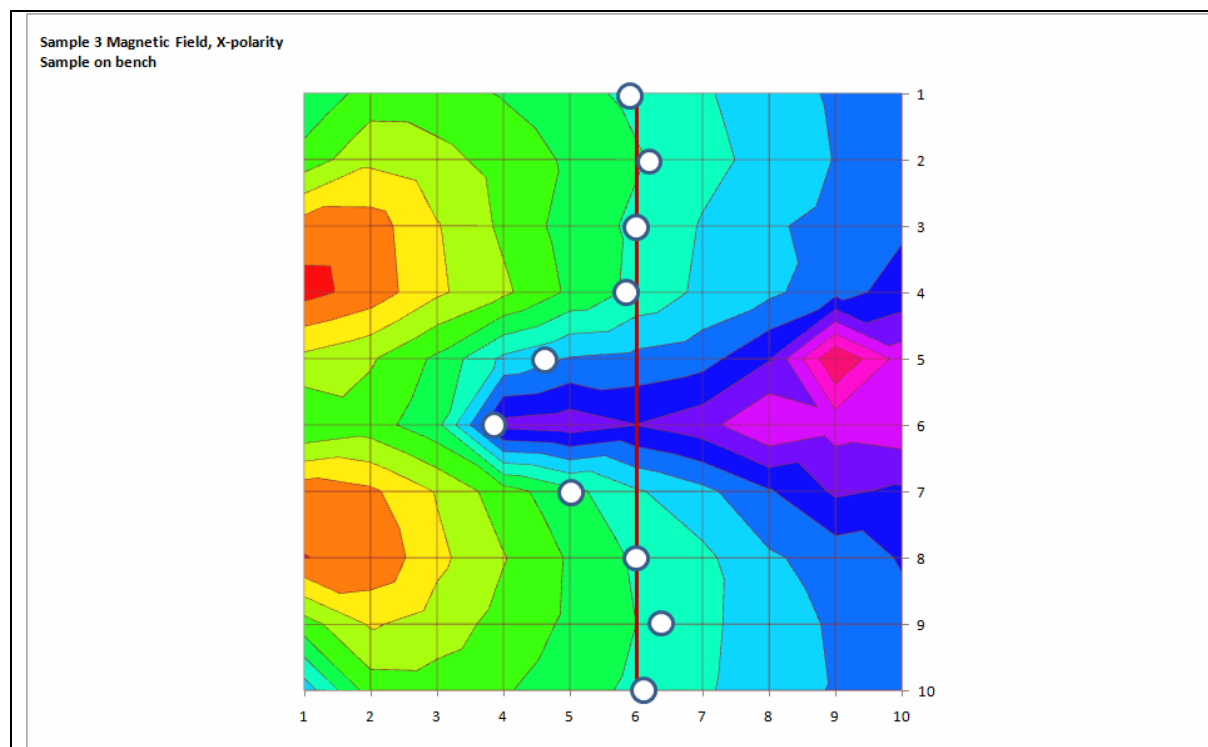
Sample 2 – Z-axis bench



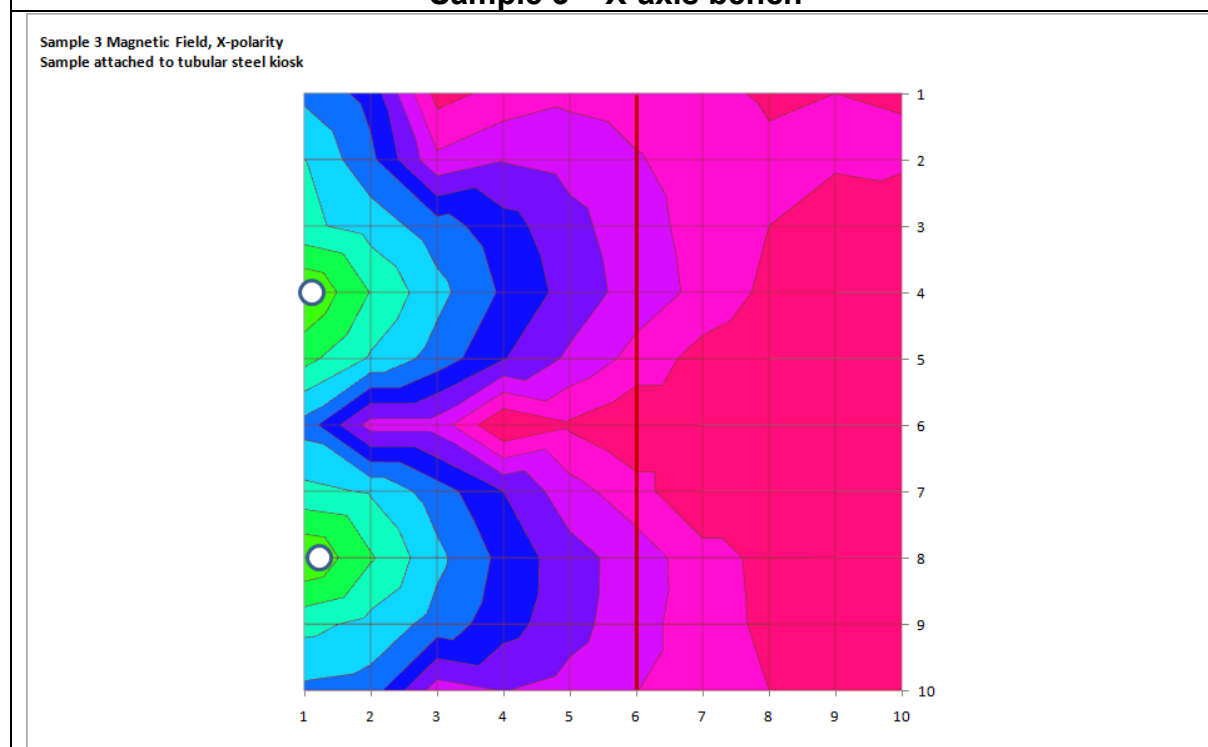
Sample 2 – Z-axis kiosk

Figure 3.3.2-3: Sample 2 – Z-axis – Antenna reading distance (bench/kiosk)

3.3.3 Sample 3

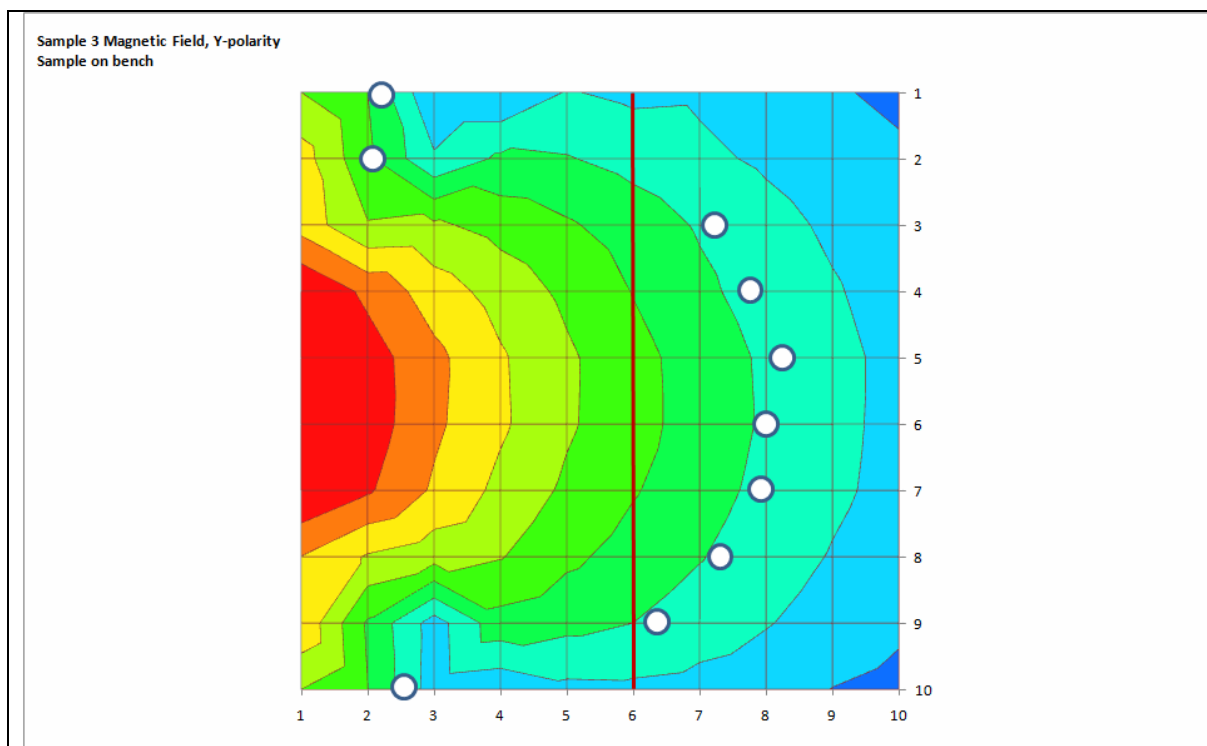


Sample 3 – X-axis bench

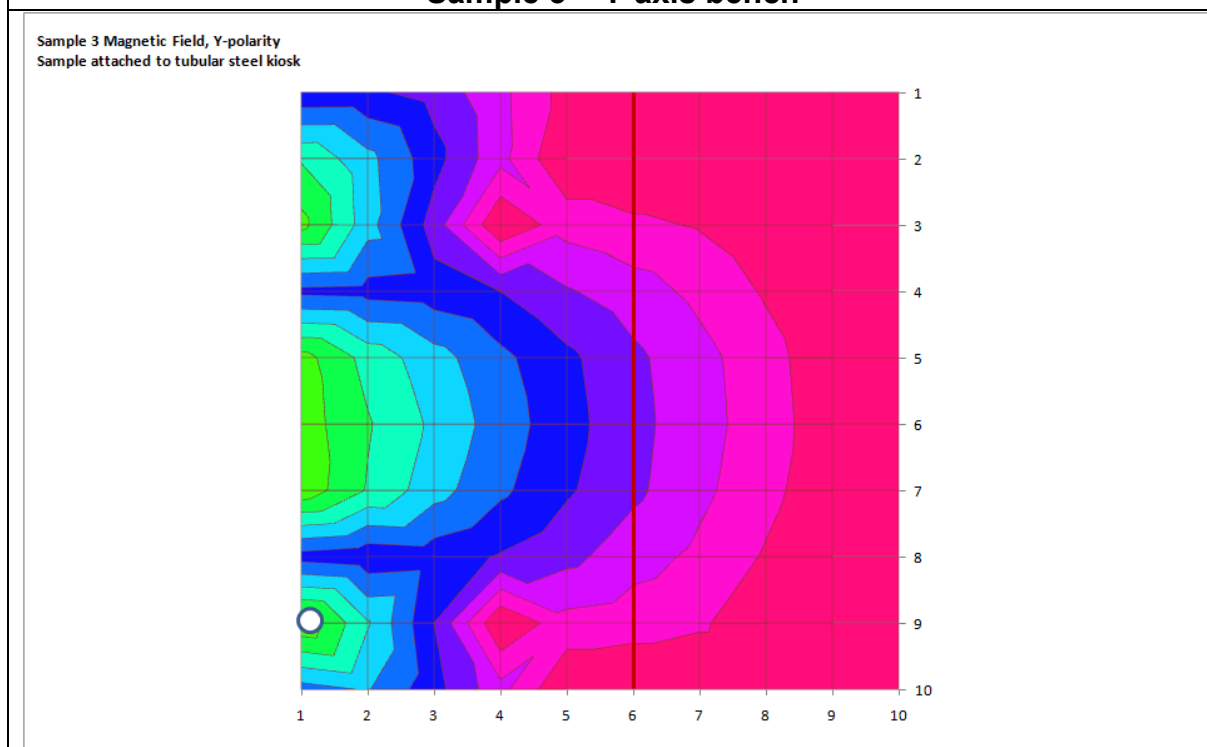


Sample 3 – X-axis kiosk

Figure 3.3.3-1: Sample 3 – X-axis – Antenna reading distance (bench/kiosk)

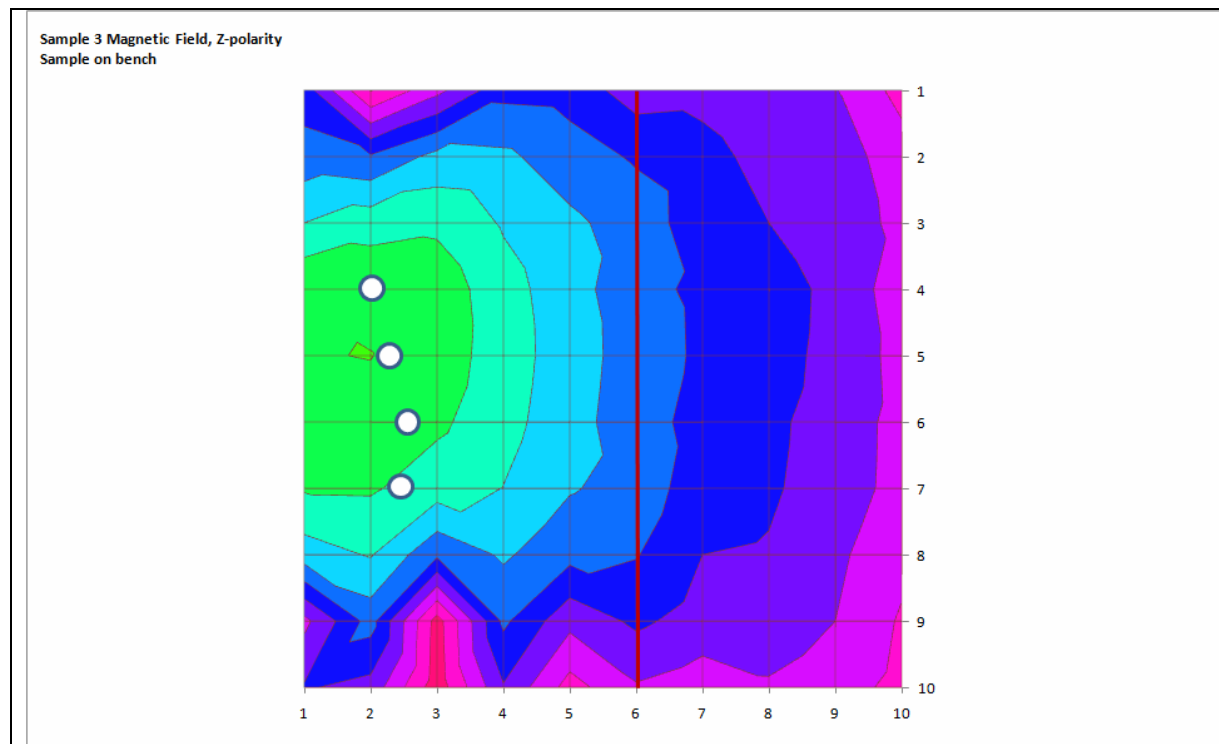


Sample 3 – Y-axis bench

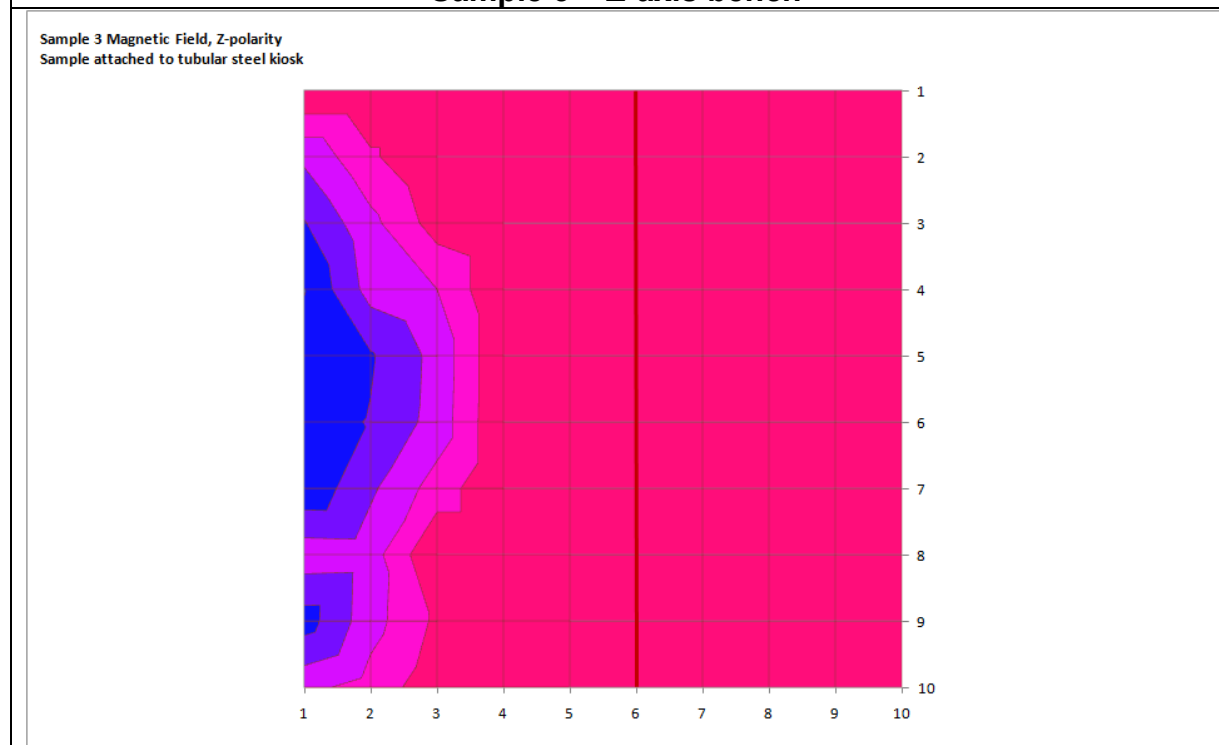


Sample 3 – Y-axis kiosk

Figure 3.3.3-2: Sample 3 – Y-axis – Antenna reading distance (bench/kiosk)



Sample 3 – Z-axis bench



Sample 3 – Z-axis kiosk

Figure 3.3.3-3: Sample 3 – Z-axis – Antenna reading distance (bench/kiosk)

3.3.4 Sample 4

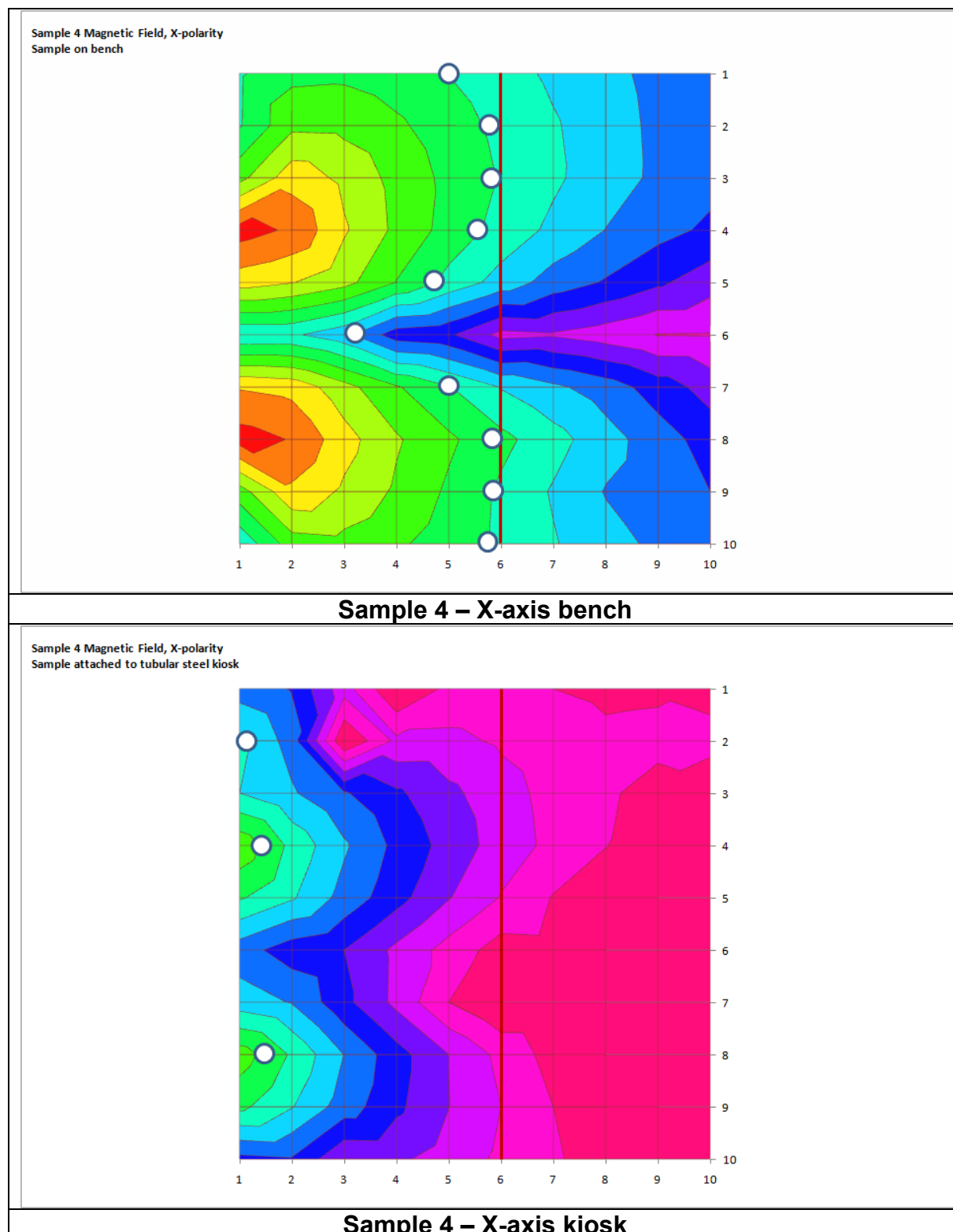
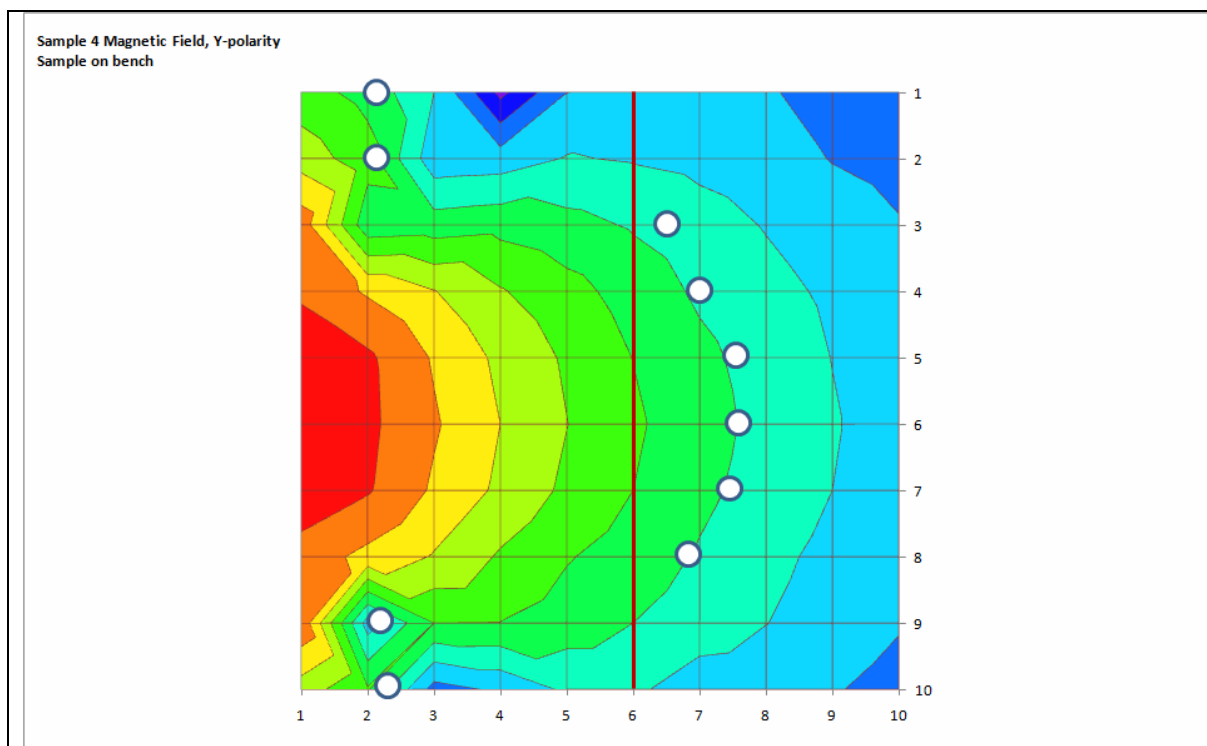
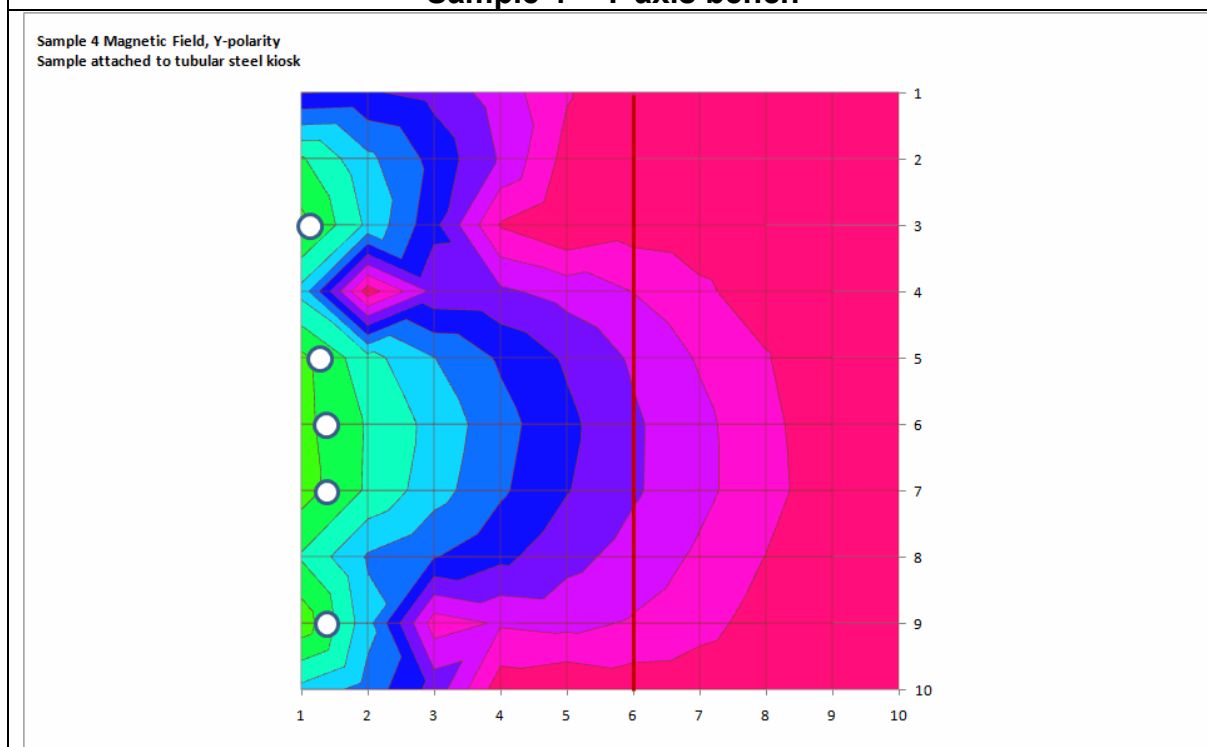


Figure 3.3.4-1: Sample 4 – X-axis – Antenna reading distance (bench/kiosk)

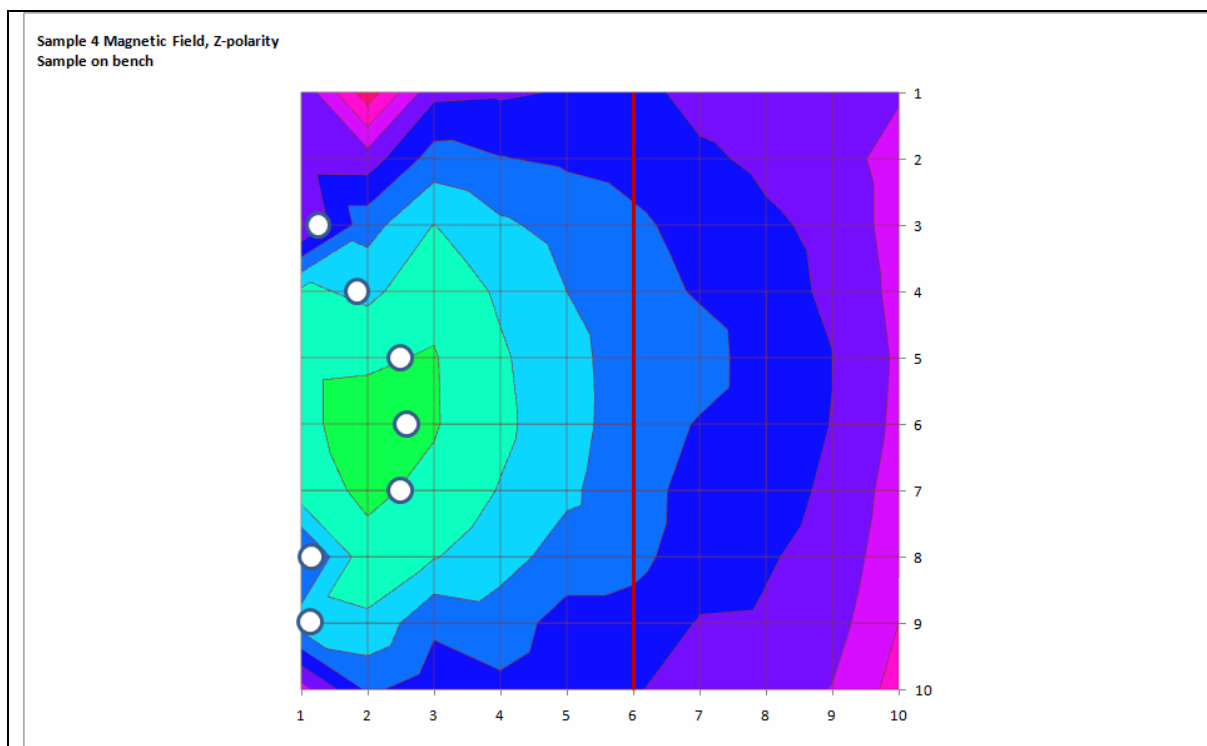


Sample 4 – Y-axis bench

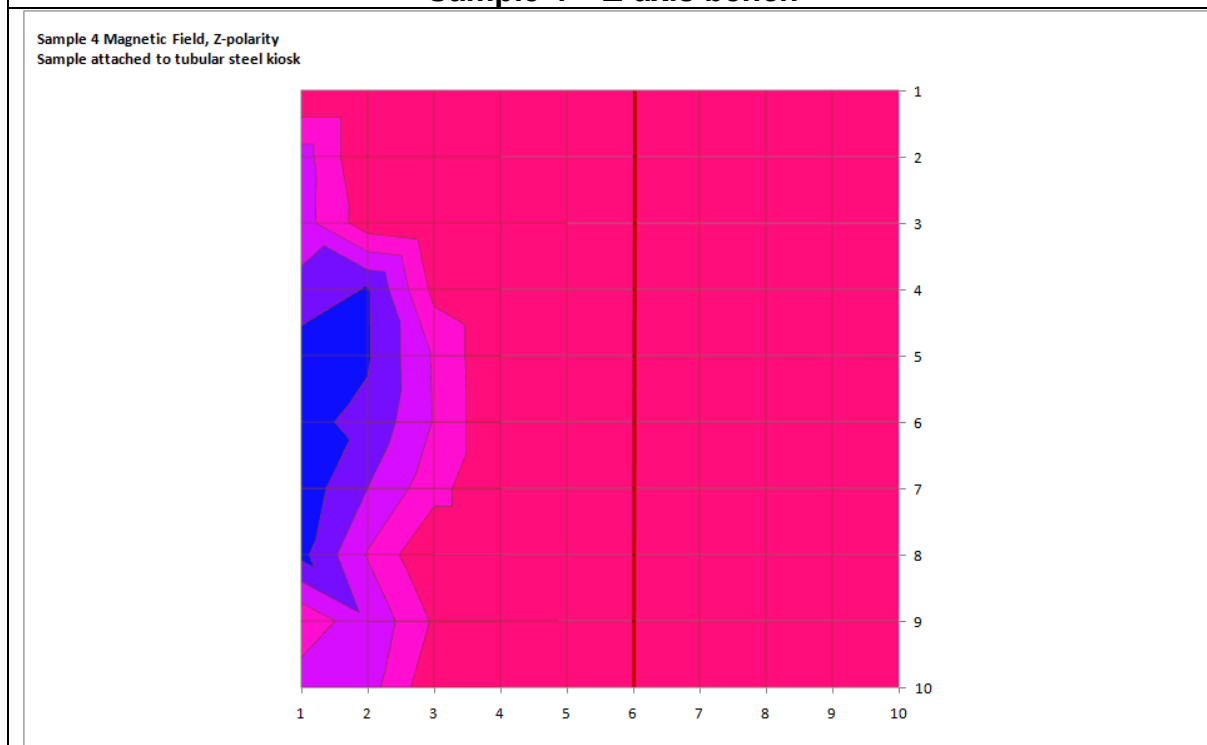


Sample 4 – Y-axis kiosk

Figure 3.3.4-2: Sample 4 – Y-axis – Antenna reading distance (bench/kiosk)



Sample 4 – Z-axis bench



Sample 4 – Z-axis kiosk

Figure 3.3.4-3: Sample 4 – Z-axis – Antenna reading distance (bench/kiosk)

3.3.5 Conclusion

By directly comparing each of the plots (bench measurement and kiosk measurement), the results show that the presence of the metal fencing kiosk affects the reading distance of the RFID system.

The minimum required read distance is specified as 0.5m in the Joint Research Centre document [4]. Looking specifically in each of the sample, the following observations and conclusions can be drawn (please note the percentages relate to the original reading performed with no metal structure present):

3.3.5.1 Sample 1

a) X-axis

The results obtained correlate well with the field contour indicated by colour.

The average reading distance was reduced to 69.9% when the antenna system was affixed to the kiosk.

b) Y-axis

The results obtained correlate well with the field contour indicated by colour.

The average reading distance was reduced to 72.1% when the antenna system was affixed to the kiosk.

c) Z-axis

The results obtained correlate well with the field contour indicated by colour.

The average reading distance was reduced to 8.0% when the antenna system was affixed to the kiosk.

d) Conclusion

The reduction of reading distance for the X and Y-axes follows quite closely the reduction in field strength to around 70% measured in the field distribution investigation as demonstrated by the various figures. The reading distance was reduced to less than 0.5m from the antenna coil due to the presence of metal from the kiosk.

3.3.5.2 Sample 2

a) X-axis

The results obtained mostly correlate well with the field contour indicated by colour.

The average read distance was reduced to 48.7% when the antenna system was affixed to the kiosk.

b) Y-axis

The results obtained mostly correlate well with the field contour indicated by colour. The read ranges measured in the metal kiosk correlate less well with the field contours.

The average read distance was reduced to 39.1% when the antenna system was affixed to the kiosk.

c) Z-axis

The results obtained correlate well with the field contour indicated by colour.

The average read distance was reduced to 11.0% when the antenna system was affixed to the kiosk.

d) Conclusion

The reduction of read distance for the X and Y-axes is greater than the reduction in field strength to around 60% measured in the field distribution investigation. The reading distance was reduced to less than 0.5m from the antenna coil due to the presence of metal from the kiosk.

3.3.5.3 Sample 3**a) X-axis**

The results obtained correlate well with the field contour indicated by colour.

The average read distance was reduced to less than 1% when the antenna system was affixed to the kiosk.

b) Y-axis

The results obtained correlate well with the field contour indicated by colour.

The average read distance was reduced to less than 1% when the antenna system was affixed to the kiosk.

c) Z-axis

The results obtained correlate well with the field contour indicated by colour.

No tag read was obtained when the antenna system was affixed to the kiosk.

d) Conclusion

Sample 3 was severely affected by the presence of metal from the kiosk. The results show that sample 3 could not operate satisfactorily when affixed to metal structures.

3.3.5.4 Sample 4

a) X-axis

The results obtained correlate well with the field contour indicated by colour.

The average read distance was reduced to less than 2% when the antenna system was affixed to the kiosk.

b) Y-axis

The results obtained correlate well with the field contour indicated by colour.

The average read distance was reduced to less than 5% when the antenna system was affixed to the kiosk.

c) Z-axis

The results obtained correlate well with the field contour indicated by colour.

No tag read was obtained when the antenna system was affixed to the kiosk.

d) Conclusion

Sample 4 was severely affected by the presence of metal from the kiosk. The results show that sample 4 could not operate satisfactorily when affixed to metal structures.

3.4 Effect of moving metal fencing on tag readability

The effect of moving metal fencing on tag readability was assessed as detailed in Section 2.3. The results for each of the samples are presented below.

3.4.1 Results

The effect of moving metal fencing did not show any measurable difference on tag readability for all four samples.

There was no visibly discernable variation of the RFID field as displayed on the spectrum analyser as the gate was swung through the magnetic field.

3.4.2 Conclusion

For all four samples, the movement of metallic structure in close proximity to the reader loop antenna does not seem to significantly affect the performance of the RFID system.

3.5 Bandwidth and Q-factor Measurement

The bandwidth and Q-factor were measured for all four samples as detailed in section 2.4. The results for each of the samples are presented below.

The value of Q is calculated as: $Q = F_0/BW$ with $F_0 = 134.2\text{kHz}$

3.5.1 Results

3.5.1.1 Sample 1

Resolution BW	6dB BW _{no metal}	Q _{no metal}	6dB BW _{metal}	Q _{metal}	%age Difference
30Hz	43.4Hz	3094.8	51.3Hz	2616.0	-15.5
200Hz	164.4Hz	816.5	191.2Hz	701.9	-14.0
1kHz	1.56kHz	86.1	1.53kHz	87.7	1.9

3.5.1.2 Sample 2

Resolution BW	6dB BW _{no metal}	Q _{no metal}	6dB BW _{metal}	Q _{metal}	%age Difference
30Hz	51.1Hz	2626.1	50.35Hz	2657.4	1.2
200Hz	193.6Hz	693.2	198.0Hz	677.8	-2.2
1kHz	1.55kHz	86.7	1.54kHz	87.1	0.5

3.5.1.3 Sample 3

Resolution BW	6dB BW _{no metal}	Q _{no metal}	6dB BW _{metal}	Q _{metal}	%age Difference
30Hz	50.9Hz	2636.5	52.4Hz	2561.1	-2.9
200Hz	184.1Hz	729.0	197.2Hz	680.5	-6.7
1kHz	1.56kHz	85.9	1.57kHz	85.4	-0.6

3.5.1.4 Sample 4

Resolution BW	6dB BW _{no metal}	Q _{no metal}	6dB BW _{metal}	Q _{metal}	%age Difference
30Hz	53.7Hz	2499.1	54.0Hz	2485.2	-0.6
200Hz	204.6Hz	655.9	198.0Hz	677.8	3.3
1kHz	1.57kHz	85.6	1.56kHz	86.1	0.6

3.5.2 Conclusion

Reducing the spectrum analyser resolution bandwidth (RBW) allows more detail to be seen in the frequency characteristics of the magnetic field. The effects of modulation of the frequency can therefore be seen, with the centre fundamental frequency displaying a correspondingly narrow bandwidth.

The Q-factor calculation performed has been based on the 6dB bandwidth measured at the centre frequency hence at lower RBW the value of Q appears high.

An alternative definition of the antenna Q-factor is the ratio of the energy stored (E_{stored}) in the system divided by the energy dissipated (E_{diss}) in the system per cycle. The RBW of the spectrum analyser should be made wide enough to include the modulation frequencies either side of the fundamental, i.e. to include all the frequencies which contribute to the energy in the magnetic field. Note that the peak level remains essentially unchanged.

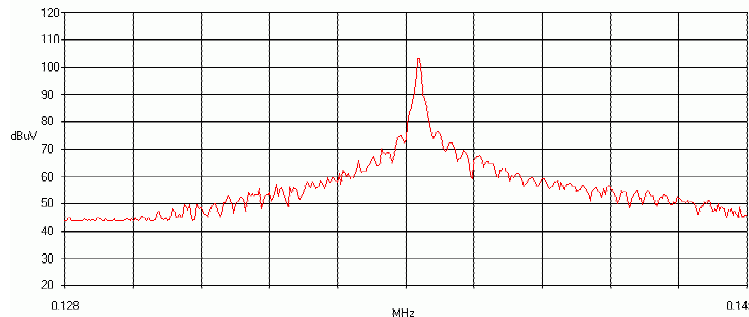


Figure 3.5.2-1 Analyser Display at 30Hz RBW

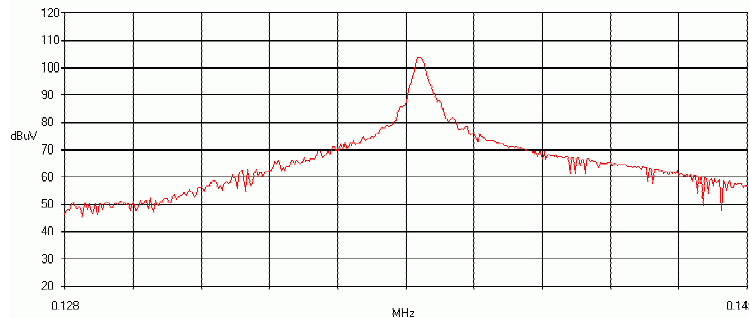


Figure 3.5.2-2 Analyser Display at 200Hz RBW

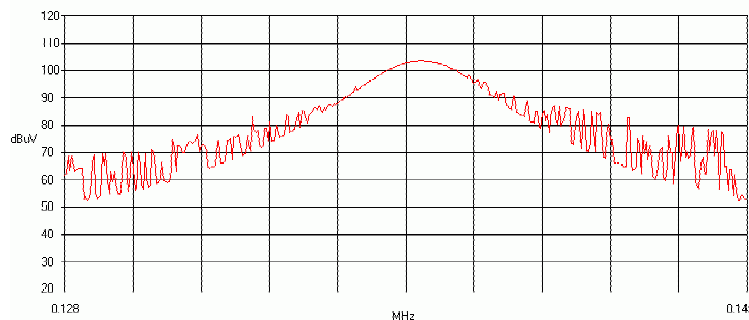


Figure 3.5.2-3 Analyser Display at 1kHz RBW

For all four samples, the measurements performed (with all three bandwidths) show that the presence of metal has a small effect (<2%) on the Q factor of the RFID system at 1kHz RBW.

The Q-factor deviations on Samples 2-4 at 30Hz and 200Hz RBW are slightly greater but <7%

Unexpectedly, the sample showing the greatest variation in Q-factor of up to 15.5%, Sample 1, was the sample which performed best.

The calculation of Q however will be a determination of the “quality” of the resonance of the antenna circuit. Since this value is a ratio (either F_o/BW or $E_{\text{stored}}/E_{\text{diss}}$) it does not take into account the absolute value of the magnetic field, therefore it can be expected that the value of Q will remain relative constant. This will be the case even if the level of the magnetic field is reduced significantly.

Regarding the Q factor, it is of interest to determine whether or not this should change significantly in the presence of the metal gate. For a source loop in the RFID system that is driven by a current source (which could be determined by examining the circuit diagram of the RFID system), no change in Q factor should be expected in the received magnetic signal on the far side of the gate, at the location of the tag. All that will be seen is a reduced amplitude magnetic field, with the same resonant shape. The gate and loop are both electrically small, and the gate is likely simply to attenuate the received signal whilst introducing no significant frequency variation in the attenuation.

For a source loop that is driven by a voltage source V with series capacitance to introduce a resonance at 134.2kHz, it is possible to determine the expected change in Q as follows. The impedance seen by the primary circuit of two circuits coupled by a mutual inductance M is given by:

$$\frac{V}{I} = Z_1 + j\omega L_1 + \frac{\omega^2 M^2}{Z_2 + j\omega L_2} \text{ - Equation 2}$$

where;

$Z_1 = R + 1/(j\omega C)$ loop resistance in series with the impedance of the resonating capacitor

L_1 inductance of driving loop

$Z_2 + j\omega L_2$ total impedance of the secondary circuit

$M = k\sqrt{L_1 L_2}$ where k is the coupling factor, which can lie in the range $0 < k < 1$.

If it is assumed that the secondary circuit (a metal object) just looks like an inductor of magnitude L_2 (with $Z_2=0$), ignoring any resistance, it is straightforward to show that the impedance seen by the driving voltage source is:

$$\frac{V}{I} = R + \frac{1}{j\omega C} + j\omega L_1(1-k^2) \text{ - Equation 3}$$

and that this has a corresponding current response given by:

$$|I| = \left| \frac{V}{R + j\left(\omega L_{eff} - \frac{1}{\omega C}\right)} \right| \text{ - Equation 4}$$

where $L_{eff} = L_1(1-k^2)$ is the effective inductance in the primary circuit.

The current, I , reaches a maximum (with corresponding maximum magnetic field) when

$$\omega = \frac{1}{\sqrt{L_{eff}C}} \text{ - Equation 5}$$

The (3dB) quality factor of this resonance is shown in standard texts to be

$$Q = \frac{\omega_0 L_{eff}}{R} \text{ - Equation 6}$$

For example, a typical loop system might have parameters $R=100\Omega$, $C=20\text{pF}$ and $L=70.5\text{mH}$. This will result in a resonant frequency of $f_0=134.033\text{kHz}$ in the absence of any surrounding metal, and a Q of 594.

The current response of the loop for a source voltage 1V is then as shown in Figure 3.5.2-4 with $k=0.0$.

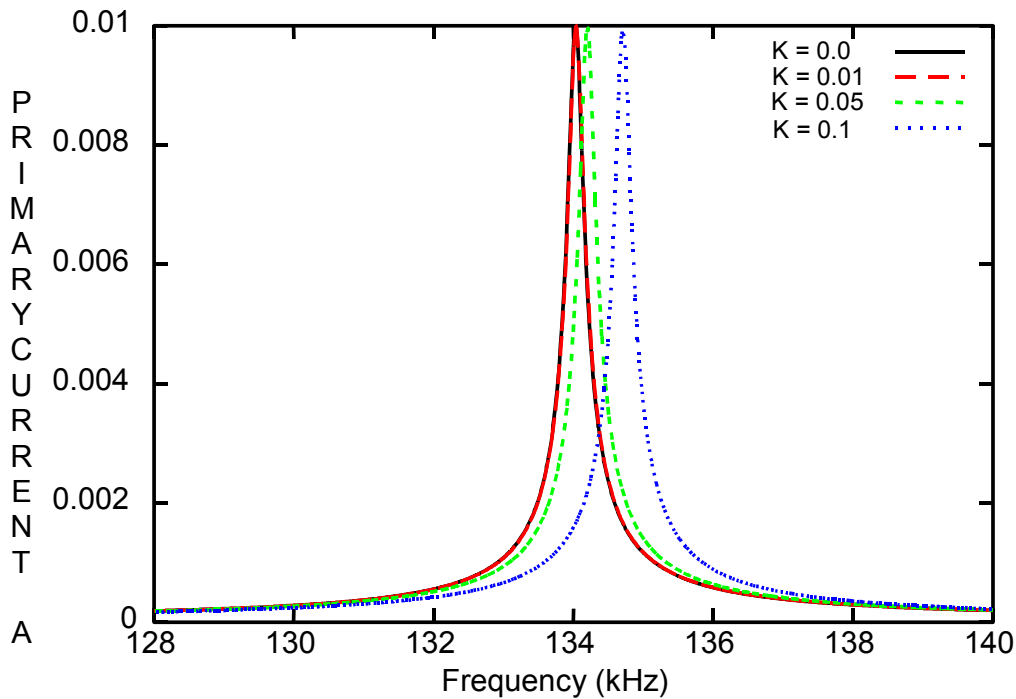


Figure 3.5.2-4 Variation in loop current response with increasing coupling factor k

The effect of bringing the nearby metal object into the proximity of the loop is to reduce the effective inductance L_{eff} of the loop, and hence to increase the resonant frequency of the loop slightly, as seen in Figure 3.5.2-4 with the gradually increasing values of k. It is likely that the practical coupling factors achieved in loop/gate system are quite small (say $k < 0.05$), and that the corresponding shift in resonant frequency is very small. This might still be discernible on the spectrum analyser traces if the RBW is sufficiently small.

The Q of the resonance as the coupling factor increases is seen from Figure to be negligible. Further analysis shows the Q to vary as:

$$Q = \frac{\omega_0 L_{eff}}{R} = \frac{1}{R} \sqrt{\frac{L_{eff}}{C}} = \frac{1}{R} \sqrt{\frac{L}{C}} (1 - k^2)^{\frac{1}{2}} = Q_0 (1 - k^2)^{\frac{1}{2}} \approx Q_0 (1 - 0.5k^2) \text{ - Equation 7}$$

where $Q_0 = 594$ is the quality factor in the absence of metal when $k = 0$. The final step in the above equation is a good approximation for values of $k < 0.3$, which is likely to be the case in practice.

The expected percentage change in Q factor for a value of k less than 0.3 is therefore

$$\left| \frac{Q - Q_0}{Q_0} \right| \times 100\% = 50k^2\% \text{ - Equation 8}$$

Even for a fairly large coupling factor of 0.3, the percentage change in Q factor would therefore only be expected to be 4.5%.

Since in the measurements taken the resonant shifts are relatively minor, it is likely that the effective coupling factors involved are smaller than 0.1. This results in a theoretical change in Q factor that is very small, rather less than 4.5%. Indeed, the observed changes in Q factor are probably simply due to noise in the system.

This hypothesis is supported by the fact that the percentage change in Q factor on introducing the metal is not even consistently a negative value. In 5 out of the 12 cases considered in this section, the introduction of the metal appears to increase the Q factor. The variations in Q factor are therefore almost certainly due to noise, and do not show any pattern.

3.6 Tag Loading

The effect of tag loading at a test distance of 20cm was investigated for all four samples as detailed in Section 2.5.

The results for each of the samples are presented below.

3.6.1 Results

3.6.1.1 Sample 1

Hx			Hy			Hz		
No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk
1	1	1	1	1	1	1	1	0
2	2	2	2	1	2	2	2	0
3	3	3	3	3	3	3	3	0
4	4	4	4	3	4	4	4	0
5	5	5	5	5	5	5	5	0
6	5	6	6	5	6	6	4	0
7	3	5	7	5	5	7	3	0
8	3	5	8	5	5	8	3	0
9	1	5	9	2	4	9	3	0

Table 1 Sample 1 Tag loading

3.6.1.2 Sample 2

Hx			Hy			Hz		
No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk
1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	2
4	3	4	4	4	4	4	3	1
5	4	5	5	5	5	5	2	2
6	3	4	6	4	6	6	2	2
7	2	4	7	2	3	7	2	2
8	2	3	8	2	4	8	2	3
9	2	2	9	2	3	9	1	1

Table 2 Sample 2 Tag loading

3.6.1.3 Sample 3

Hx			Hy			Hz		
No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk
1	1	0	1	1	0	1	0	0
2	2	0	2	2	0	2	0	0
3	3	0	3	3	0	3	0	0
4	3	0	4	3	0	4	0	0
5	4	0	5	4	0	5	0	0
6	2	0	6	4	0	6	0	0
7	2	0	7	3	0	7	0	0
8	1	0	8	2	0	8	0	0
9	1	0	9	2	0	9	0	0

Table 3 Sample 3 Tag loading

3.6.1.4 Sample 4

Hx			Hy			Hz		
No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk	No of Tags	No. Read Correctly bench	No. Read Correctly kiosk
1	1	0	1	1	0	1	1	0
2	2	0	2	2	0	2	2	0
3	3	0	3	3	0	3	3	0
4	3	0	4	3	0	4	2	0
5	4	0	5	3	0	5	2	0
6	3	0	6	2	0	6	1	0
7	2	0	7	2	0	7	1	0
8	2	0	8	2	0	8	0	0
9	2	0	9	2	0	9	0	0

Table 4 Sample 4 Tag loading

3.6.2 Conclusion

3.6.2.1 Sample 1

The measurements show that sample 1 is able to read a maximum of 6 tags at any one time.

The reader performance was better in the X and Y-axes when compared to the Z-axis. The distortion of the field due to the kiosk actually allowed the reader to perform better in the kiosk at the test distance (even if the overall maximum read distance was reduced).

No reading was obtainable at the test distance in the Z-axis due to the distortion created by the kiosk.

3.6.2.2 Sample 2

The measurements show that sample 2 is able to read a maximum of 6 tags at any one time.

The reader performance was better in the X and Y-axes when compared to the Z-axis. As per sample 1, the distortion of the field due to the kiosk actually allowed the reader to perform better in the kiosk at the test distance (even if the overall maximum read distance was reduced).

3.6.2.3 Sample 3

The measurements show that sample 3 is able to read a maximum of 4 tags at best at any one time. The reader performance was better in the X and Y-axes when compared to the Z-axis (no reading for Z axis – bench and metal).

Sample 3 was so severely affected by the presence of the steel kiosk that no tag could be read at the test distance.

3.6.2.4 Sample 4

The measurements show that sample 4 is able to read a maximum of 4 tags at best at any one time. The reader performance was better in the X and Y-axes when compared to the Z-axis (no reading for Z axis – bench and metal).

Sample 4 was so severely affected by the presence of the steel kiosk that no tag could be read at the test distance.

3.7 Overall Conclusions

Four RFID systems have been assessed for their physical performance when used in a non-metallic and metallic environment. The following specific studies have been performed:

1. Characterisation of the magnetic field distribution in X, Y and Z-axes (magnetic field axes)
2. The maximum distance for tag readability
3. The bandwidth at the magnetic field frequency (134.2kHz) and the derivation of its Q-factor
4. The effect of the number of tags within the field at any one time

3.7.1 Study 1

The results show that each case the magnetic field amplitude of all four samples is affected when the antenna is mounted on the kiosk.

Sample 1: Magnetic field amplitude is reduced by approximately 30%

Sample 2: Magnetic field amplitude is reduced by approximately 40%

Sample 3: Magnetic field amplitude is reduced by 70 to 80%

Sample 4: Magnetic field amplitude is reduced by 70 to 80%

In addition, all of the three-dimensional plots indicate distortion of the field to some extent due to the presence of the metal kiosk.

The measurements show that there are slight variations in the magnetic field around the centre line but generally the field produced by each of the sample appears quite planar within the limited area of measurement, thus contributing to consistent tag reading within that area.

3.7.2 Study 2

The effect of the kiosk on the tag read distance was significant in all samples but extreme in Samples 3 and 4 to the extent that no significant read distance could be obtained.

3.7.3 Study 3

The study also shows that the presence of metal has little effect to the Q factor of the RFID system. Theoretical analysis supports this conclusion.

3.7.4 Study 4

For Sample 1 and 2, there appears to be a maximum read number of 6 individual tags at any pass. The effect of the kiosk was to reduce the ability of the antennae to read the tags primarily due to the reduction in the amplitude of the magnetic field.

Similarly with Samples 3 and 4, there appears to be a maximum read number of 4 individual tags at any pass. The kiosk reduced the amplitude of the magnetic field to such an extent that no read was obtainable at the test distance.

References

[1] Tender for investigating the effect of acoustic / mechanical interference on radio frequency identification systems used, 2333CR1, York EMC Services (2007) Ltd, May 2007.

[2] ISO 11784:1996, Radio-frequency identification of animals. Code Structure.

[3] BS ISO 11785:1996, Radio-frequency identification of animals. Technical concept.

[4] Technical Guidelines For Council Regulation No. 21/2004 of 17/12/2003- Part 1 - In-field aspects: application of identifiers, their reading and recovery, <http://idea.jrc.it/>, October 2007; Technical Guidelines For Council Regulation No. 21/2004 of 17/12/2003 - Part 2 - Electronic Identifier and Reader Specifications Test procedures, acceptance criteria, and codification of identifiers, <http://idea.jrc.it/>, October 2007.

Appendix 1 – Magnetic Field Distribution

Sample 1 - Tabular data

Hx	1	2	3	4	5	6	7	8	9	10
1	91.9	103.1	103.8	101.4	98.3	95.4	91.4	88.3	85.2	82.5
2	104.2	110.7	108.7	104.8	100.1	95.9	91.3	88.1	84.7	83.4
3	119.9	120.4	111.6	106.4	100.3	95.9	90.7	88.1	82.3	80.1
4	118	117.7	109.3	103.1	94.5	90.5	86.9	84.3	79.5	75.6
5	98.8	101.9	87.4	89.3	83.1	80.5	73.7	74.2	69.8	67.4
6	116.7	116.4	108.9	99.7	92.7	90.9	83.9	77.7	79.6	72.5
7	123.9	120.4	112.1	104.2	96.6	94.6	89.7	85.5	80.1	78.1
8	105.3	112.2	109.4	105.1	100.1	95.8	91.2	87.1	84.3	81.8
9	90.4	103.9	104.2	101.9	98.9	95.2	91.8	88.4	85.4	82
10	89	96.9	98.8	97.9	96.2	93.5	91	88.3	85.6	83.1
Hy	1	2	3	4	5	6	7	8	9	10
1	107.5	100.6	82.8	87.8	92.1	92	90.3	88.3	87.3	84.3
2	116.8	101.6	96.3	98.8	97.8	95.3	93.2	90.8	88.5	85.8
3	110.7	107.4	108.9	105.1	102.1	98.9	95.6	93.1	90.1	87.8
4	129.3	120.4	114.7	109.4	105.1	101.1	97.6	94.4	91.3	88.7
5	127.1	122.6	116.2	111	106.1	101.5	98	95.1	91.3	89.1
6	128.2	121.1	114.4	110.1	105.4	101.4	97.2	94.7	91.1	88.8
7	121.1	110.4	107.6	106.1	102.3	99.5	96.1	93.4	90.1	88.1
8	115.6	103.2	94.3	100.3	98.1	95.9	93.8	91.2	88.7	87.1
9	107.1	102.6	85.4	88.3	89.7	91.6	90.5	89.2	86.2	84.9
10	100.6	98.5	92.3	75.5	78.7	85.8	85.6	84.6	83.2	82
H _z	1	2	3	4	5	6	7	8	9	10
1	78.5	81.2	77.8	68.5	70.5	69.4	67.7	68.8	67.5	65.7
2	89.6	73.2	86.5	85.1	77.5	73.9	73.1	70.6	69.4	65.7
3	81.1	90.1	97.9	87.9	76.4	75.9	76.8	69.7	70.3	68.5
4	91.1	98.8	96.3	91.3	82.8	80.3	76.7	72.2	69.5	68.7
5	104.2	100.9	98.3	92.5	87.6	81.3	77.3	73.3	69.8	68.8
6	105.6	100.7	97.8	91.4	86.5	81.4	76.7	73.5	70.3	68.9
7	101.1	95.2	91.9	91.1	85.8	79.5	77.3	72.4	67.2	69.2
8	82.6	94.1	85.1	84.1	79.9	79.5	67.9	71.5	69.6	66.6
9	60.4	85.2	81	82.5	78.3	75.7	70.3	69.3	69.5	66.8
10	59.7	77.7	73.5	77.4	72.3	71.5	69.8	70.2	67.8	66.7

Table App1-1: Sample 1, relative magnetic field strength, on bench, values in dB μ V

Hx	1	2	3	4	5	6	7	8	9	10
1	102.5	98.1	83.5	77.6	82.1	81.5	79.8	78	79.1	
2	112.7	94.4	81.7	89.3	87.4	84.7	81.3	79.3	79.3	78.7
3	108.5	105.8	101.4	95.8	90.9	86.6	82.6	79.3	76.5	69.7
4	124.3	113.9	105.8	98.6	92.2	86.2	81.7	77	74	68.9
5	115	112.4	102.4	96.2	89.6	82.7	78.1	67	67.8	63.3
6	77.1	96.1	77.2	80.8	53.1	68	65.7	57.8	51.2	51
7	118.5	112	105.3	96.6	89.3	83	77.5	72.5	68.5	64.7
8	120.3	115.3	106.6	98.8	92.2	87	81.5	77.3	74.8	69.1
9	104.4	104.8	100	95.8	91.2	86.8	82.5	79.6	77.6	72.1
10	105.3	102.6	78.6	87.4	87.2	84.5	81.7	79.4	79.4	75.5
Hy	1	2	3	4	5	6	7	8	9	10
1	90.2	94.6	93.1	87.7	80.5	67.8	62.4	63.9	66.5	77.1
2	114.6	106.4	97.7	89.9	75	60.4	68.3	66.8	60	67.1
3	120.6	109.8	95.8	81.2	74.8	77.2	76.5	73.4	65.6	68.4
4	113.5	81.2	93	93.1	89.3	85.6	82.3	78.5	72.1	62.5
5	122.8	113.8	106.4	99.8	94.6	89.6	85.4	80.5	75.1	68.7
6	123.2	116.3	108.5	101.8	96	90.9	86.3	82	76.2	70.8
7	123.5	112.8	105.1	99.6	92.1	90	85.1	80.6	75.3	69.3
8	115.4	95	88.7	90.6	89.1	86.4	82.5	78.2	72.2	61.9
9	122.4	110.6	97.3	81.1	74.4	78.4	76.5	72.1	69.4	64.2
10	86	104.4	98.7	88.4	80.3	61.1	66.4	66.5	64.3	66.4
H _z	1	2	3	4	5	6	7	8	9	10
1	68.3	83.4	81.1	71.4	68.5	59.9	36	48.1	30	40.4
2	87.7	88.5	80.2	71.3	62	45.9	54.2	53.6	42.4	42.6
3	91.6	85.8	64.9	59.6	65.3	64.5	61.3	58.7	45.2	45.7
4	89.8	87.5	83.3	79.6	75	70	65.4	61.7	49.9	52
5	98.3	97.4	93.3	85.6	78.6	73	68.2	63.4	52.2	54.6
6	96.8	99.2	92.3	87.4	80.5	74.2	70.1	64.1	53.4	55.6
7	97.7	96.3	89.6	84.6	79	73.5	70.1	64.4	53.3	54.7
8	98.5	58.8	76.2	77	73.2	70.1	65.7	61.8	50.9	52.6
9	102.1	91.4	79.6	64.3	61.7	63.5	61	58.6	50.4	49.3
10	68.5	86.2	81	77.8	60.1	40.1	37.1	53.7	39.4	37.2

Table App1-2: Sample 1, relative magnetic field strength, on kiosk, values in dB μ V

Sample 2 - Tabular data

Hx	1	2	3	4	5	6	7	8	9	10
1	99.5	107.2	106.3	104.4	100.8	97.8	95	91.7	88.6	87
2	109.7	114.9	111.2	107.1	102.5	99.1	95.4	91.8	88.8	87.2
3	123.3	120.9	113.9	107.8	102.5	98.3	94.1	91.3	87.3	86.3
4	120.5	117.8	112.1	107.3	103.2	92.9	90.3	88	83.3	79.8
5	108.8	101.6	102.6	100.6	99.2	83.9	72.5	79.9	77.3	73.6
6	110.7	101	100.6	98.4	94.5	85.5	82.2	82.6	70.3	70.1
7	118.3	117	112.7	106.1	100.6	98.2	90.5	87.9	80.4	80
8	126	121	114.2	108.5	104	99.7	94.6	91.6	86.7	84
9	108.5	114.7	110.9	106.9	103.3	99.2	95.5	92.1	88.7	85.5
10	99	106.8	107	104.5	103.2	98.4	94.9	91.6	89.6	87.4
Hy	1	2	3	4	5	6	7	8	9	10
1	110.9	104.3	86.6	91.1	92.9	94.1	92.7	91.1	89.5	85.5
2	118.4	103.5	99.5	102.2	99.6	97.9	95.7	94	91.8	89.1
3	94.1	109.7	109.6	107.2	104.3	100.9	98.5	96.2	93.3	90.4
4	128.6	121.7	116.3	111.3	107.3	103.7	100.5	97.2	94.6	92.4
5	126.7	123.5	117.9	113.4	107.8	104.5	101.7	98.3	95.3	92.9
6	126.1	123.4	118.5	113.4	109.1	104.7	101.5	98.4	95.6	92.5
7	128.5	121.7	116.6	111.9	107.3	104.1	100.6	97.7	95	92.2
8	109.3	111.5	109.8	107.6	104.5	101.4	98.8	96	93.8	91
9	117.2	102.5	99.3	101.4	99.4	98.2	95.3	93.9	92	89.8
10	109.7	103.7	88.7	89.3	92.4	93.5	92.3	90.4	89	87.6
H _z	1	2	3	4	5	6	7	8	9	10
1	91.6	56.5	78.8	81.7	81.7	79.4	78.1	75.7	74.6	69
2	97.5	75.5	88.3	88	85.4	82.2	79.3	77.2	75.5	70.8
3	97.3	98	96.7	93.3	89.6	85.5	81.7	79.3	77.3	70.7
4	107.2	105.9	100.5	95.8	91.7	87.3	83	79.8	77.5	70.8
5	106.5	106.9	102.8	97.2	93.1	88	83.6	80.2	78.1	69.3
6	105.9	106.4	102.5	97.5	92.9	87.4	83.8	79.9	77.3	69.8
7	104.7	105.3	100.9	95.4	91.7	86.8	83.1	80	76.5	68
8	78.9	96.8	96.5	92.8	89.4	84.7	81.4	78.8	76.2	65.2
9	97	72.5	88.5	88	85.4	82.5	79.6	77.1	75.1	62.4
10	90.2	74.3	79.7	81.9	80.7	80	76.6	75.4	74	58.2

Table App1-3: Sample 2, relative magnetic field strength, on bench, values in dB μ V

Hx	1	2	3	4	5	6	7	8	9	10
1	103.6	99	82.6	80.1	83	82.6	81.1	80.2	81	78.7
2	114.4	98.5	88.1	90.9	88.3	85.8	83	80.6	81.4	81
3	112.2	108.5	103.1	97.4	92.1	87.7	84	78.9	78.5	74.5
4	123	113.7	105.7	99.1	93.1	87.5	83	72.4	75.5	71.6
5	111.3	107.8	101.1	95.3	90.9	84.1	78.5	64.9	71.7	68.5
6	79.7	86.5	88.6	81.8	74.5	74.1	64	68.9	63	58.4
7	107	108.1	100.7	92.8	87.7	79.6	72.6	70.6	63.4	63.3
8	121	114.2	105.3	98.2	91.5	86	80.1	76.5	73	68
9	116.7	108.7	102.7	96.9	91.6	87	82.5	79.4	76.5	71
10	102.9	99.7	90.1	91.3	88.5	85.3	82.4	79.5	78.7	75.3
Hy	1	2	3	4	5	6	7	8	9	10
1	96.2	94.3	93.3	88	77.3	70.5	60.9	64.2	71.2	79.4
2	114.3	106.3	97.7	88.5	70.3	63.5	71.8	67.8	58.5	58.5
3	120.9	107.3	94.2	70	75.1	79.3	77.4	73.2	60	70.8
4	108.1	101.9	97.8	93.2	89.7	86.7	83.1	78.9	71.8	61
5	120.3	112.6	105.9	100.7	94.7	90.4	85.7	81.3	75.6	69.8
6	120	114.3	108.1	102.4	96.8	91.7	85.8	82.2	77.5	71.4
7	120.5	113.2	107.2	101	95.4	91.1	86.6	81.6	77	70.8
8	119.6	105	100.1	96.4	92.3	87.9	84.7	79.4	74.5	67
9	124.2	107.8	90.9	74.8	84.1	82.4	79.7	75.5	70	56.4
10	103.7	104.8	96.2	85.7	60.8	72.6	72.6	71.5	65.8	60.5
H _z	1	2	3	4	5	6	7	8	9	10
1	78.3	84.7	80.4	72.7	66.7	53.2	41	48.4	45.2	53.3
2	81.1	89.2	83.2	69.5	57.6	53.1	57.5	48	47.7	46
3	99.5	87.1	76.8	61.1	63.1	65	63.4	54.6	48.2	52.3
4	95.6	83	80.9	75.7	72.7	68.2	65.7	60.1	50	49.7
5	94.1	92.5	87.1	79.3	76.2	71.6	67.3	62.7	51.7	49.5
6	92.7	94.2	88.6	81.9	78.2	72.7	67.3	64.2	51.7	50
7	93.1	92.3	86.7	81.5	75.6	72.5	66.8	63.8	50.4	52.4
8	71	80.4	76.4	76.1	70.6	70.4	64.3	61.7	49.4	51.6
9	102.2	82.9	81.8	57.2	59	62.8	62.2	57.1	46.8	50
10	74.2	83	75.6	66.7	43.5	55	54.2	56.5	38.9	43.5

Table App1-4: Sample 2, relative magnetic field strength, on kiosk, values in dB μ V

Sample 3 - Tabular data

Hx	1	2	3	4	5	6	7	8	9	10
1	100.6	107.2	107	104.6	101.6	98.8	95.6	92.3	89.3	86.5
2	107	113.9	111.6	108.1	104.2	100.5	96.5	93.4	89.8	86.4
3	122.5	122.4	115.3	109	102.8	99	94.6	90.6	88.6	85.7
4	126.7	123	115.9	111	104.1	98.6	93.9	91.1	86.7	83.2
5	113.7	110.6	104	93.9	89.6	88.6	87	80.4	46	72.2
6	105	107.3	101.5	78.3	77	79.9	76.9	70.1	73	71.7
7	123.2	121	114.6	107.2	101.6	95.6	91.4	85.5	79.2	80.8
8	125.1	124.2	116.3	110.3	104.4	99.2	96.2	90.7	87.9	84.6
9	107.8	115.6	112.7	108.2	104.1	100	96.1	92.5	89.3	86.4
10	92.1	107.4	107.6	105.5	102.2	98.9	95.8	91.7	89.7	86.8
Hy	1	2	3	4	5	6	7	8	9	10
1	110	105	90.2	90.2	95.3	93.9	94.2	92.1	90.5	89
2	117.3	106	95.7	100.9	100.3	98.3	96.1	94.2	92	90.8
3	118	110.3	110.8	108.2	105.6	102.7	99.5	96.8	94.1	91.9
4	133.1	123.8	117.5	113	108.9	104.8	101.1	97.8	95.5	92.8
5	132.8	127.4	121.3	115.6	110.8	106.6	102.8	99.2	96.3	93.7
6	132.7	127.7	121	115.8	110.7	106.8	102.8	99.4	96.2	93.7
7	133.6	125.7	119.3	113.7	109.1	105.4	102	98.7	95.9	93.5
8	119.9	114.5	112	110.3	106.1	103	100.3	97.2	94.7	92.5
9	119.2	104.3	92.7	103.2	101.5	100	97.5	95.3	93	90.9
10	110	105.1	92.4	91.2	93.8	94	93.3	92.2	89.9	88.6
H _z	1	2	3	4	5	6	7	8	9	10
1	82.6	64.6	73.5	83.5	83	77.5	78.1	75	75.3	68.2
2	87	85.5	91.6	91	87.3	84.4	82.1	77.8	77.4	72.4
3	95	98	99	94.5	91	87.7	82.2	80	77.8	73.7
4	104.6	103.8	103	96.9	92.2	86.5	84	81.6	79.1	72
5	104.8	105.1	102.7	97.5	92.3	87.7	84.1	81.3	79	73.1
6	103	103.7	101	96.8	91.8	87.3	83.1	81.1	77.8	73.4
7	100.5	100.6	97.4	94.9	90.4	88.2	81.8	80.7	77.6	73.3
8	92.6	95.4	86	90.7	86.6	85.3	80	79.6	76	71.5
9	73.6	87.1	62.8	86	76.5	81	77.9	78	75	69.4
10	80.5	78.3	62	79.6	68	74.5	72.4	74.4	72.2	68.5

Table App1-5: Sample 3, relative magnetic field strength, on bench, values in dB μ V

Hx	1	2	3	4	5	6	7	8	9	10
1	88.8	83.2	63.1	66.6	68.8	67.7	66	64.5	65	64.4
2	95.1	86.3	71.1	74.7	73.1	70.4	67.7	65.7	65.7	66.3
3	96.1	92.9	87.3	82	76.7	71.9	68.2	65	62.3	57.3
4	110	99.8	91.6	84.2	78.1	72.7	68.7	63.7	59.7	54.2
5	101.7	94.4	87.9	80.3	74.1	68.3	63	57.5	53.5	49.7
6	88.2	73	72.9	49.4	64.2	60.2	50.5	44.1	41.5	34.4
7	96.4	94.5	87.4	80	72	67	59.5	53.7	51	46.6
8	109.7	100.6	91.3	83.5	77	72.6	67.1	63.6	58.2	53.5
9	96.6	93.5	88.1	82	76.9	71.8	67.3	63.9	62	57.2
10	88.9	87.8	72.5	75.2	73.1	70.1	67.3	65	64.5	61.8
Hy	1	2	3	4	5	6	7	8	9	10
1	80.7	80.9	78.1	71.3	63	51.3	45.8	49.4	52.1	55.8
2	99.5	91.5	81.9	71.5	57.3	56.6	56.5	58.1	52	44
3	106.7	92.1	77.7	59.2	68.1	66	64.6	61.5	51.7	52.2
4	83.7	83.1	82.3	80	75.5	72.3	68.7	64.4	58.7	48.1
5	107.1	98.2	92	86.2	81.1	76.1	71.6	67	61.3	54.5
6	107.6	100.5	94	87.6	81.8	76.6	71.9	67.4	61.8	55.8
7	108.5	99.6	92	86	80.7	76.1	71.2	66.5	61.5	55.5
8	83	81.4	82.3	79.6	76.5	72.1	68.9	64.5	58.4	51
9	109.3	95.5	80	59.2	68.3	67.2	65.8	61.3	53.7	49.8
10	87.8	90.4	81.8	71.7	54.4	54.4	56.4	55.8	51.9	51.2
H _z	1	2	3	4	5	6	7	8	9	10
1	56.2	40	60	58.4	54.2	51.1	49.7	47.1	29	46.5
2	74	65.8	58	59.4	53.7	54.5	48	45.5	34.5	47.4
3	80.3	71.4	62.7	55.4	42.7	53	49.3	42.6	46	42
4	85.1	73	70	48.2	42.2	50.2	39.2	44	46.3	44.3
5	84.2	80.5	73.4	55.2	46	47.9	44.5	45.2	45.3	45.5
6	82.3	79.7	73.1	59.4	44.4	39.6	43.4	43.5	44.1	45.4
7	83.9	75.9	67.8	52	39.8	33.9	45	43	44	46.4
8	72	72.3	51.1	59.3	48.7	45	45.4	44.6	45.4	45.1
9	82.4	72	64	62.4	55.1	47.7	47.1	45.5	47.1	45.3
10	71.4	68	61.8	60.8	55.6	51.5	49.5	46.5	49.4	42.6

Table App1-6: Sample 3, relative magnetic field strength, on kiosk, values in dB μ V

Sample 4 - Tabular data

Hx	1	2	3	4	5	6	7	8	9	10
1	99.4	103.6	104	102.4	99.9	97	94.1	91.5	88.5	86.5
2	99.5	108.9	108.6	105.9	102.3	98.7	95.5	92.3	88.9	87
3	108.4	118	113.8	108.4	103.7	99.6	95.9	92.1	89.1	86.5
4	127.2	124.2	115.6	108.9	103.1	98.2	93.8	89.9	86.6	84.1
5	117.3	115.2	111.7	104.8	98.4	93	87.8	84.5	80.9	77.1
6	95.6	95.8	91.6	82.3	80.8	73.5	74.4	72.4	69.8	69.7
7	119.6	118.4	111.8	105.5	100.3	94.7	91	87.6	82.6	78
8	127.2	124.7	117	110.6	105.9	101.4	96.9	92	87.4	82.8
9	107.7	119	114.1	109.2	104.2	99.1	94.5	89.7	87	85
10	96.1	107.5	108.4	105.9	102.4	98.8	95.4	91.8	89	86
Hy	1	2	3	4	5	6	7	8	9	10
1	107.1	103.3	95	78.6	89.9	91.9	91.3	90.6	87.8	86.5
2	112.8	107.2	91.9	92.4	95.3	94.6	93.6	92.1	89.8	88.5
3	123	101.6	102.4	103.4	101.6	99.5	97.1	94.7	92.3	90.3
4	124	119.4	115.2	110.4	106.8	102.9	99.2	96.6	94.1	91.7
5	129.2	125.9	119.5	113.9	109.3	104.9	101.2	98	94.9	92.4
6	128.7	126.1	120.6	115	110.1	105.8	102	98.5	95.4	92.6
7	129	125.5	119.3	114	109	105	101.2	97.9	95	92.4
8	122.6	118.7	114.6	109.4	105.4	102.5	99.5	96.3	93.7	91.6
9	124	92.6	105	104.9	102.6	100	97.6	95.1	92.7	90.4
10	112.7	105.5	88	90.9	95.9	95.9	92.4	91.8	90.4	88.3
Hz	1	2	3	4	5	6	7	8	9	10
1	78.9	62	78.8	79.3	80.4	81.5	78.5	77.5	76.2	75.7
2	77.5	77.4	87.2	85.2	84.2	83.1	80.8	79.1	77.6	72.6
3	74.6	88.1	95.1	90.8	88.3	86	83.1	80.7	79	72.6
4	96.1	93.7	98.7	94.2	90	87.4	84.4	81.6	79.3	73.5
5	99.3	99.5	100.3	95.7	91.4	87.8	87.5	82	80.1	74.2
6	99.3	101.4	100.4	96.2	91.6	87.7	84.6	81.9	79.9	73.8
7	98	100.9	98.9	94.7	91	86.6	83.5	81.6	79.3	72.6
8	83.3	98.6	95.3	92	87.8	86.5	82.1	80.4	78.6	71.3
9	92.6	94	85.9	87.5	83	83	79.7	79.5	77	70
10	73	85.9	82.4	84	81.8	80.6	77.1	77.7	74.8	68

Table App1-7: Sample 4, relative magnetic field strength, on bench, values in dBµV

Hx	1	2	3	4	5	6	7	8	9	10
1	87.8	84.6	72.1	59.4	66.2	66	65	64.2	64.4	63
2	95.9	87.9	55.7	71.1	71.3	69.3	67.2	65.8	66.1	67
3	95	90.6	85.5	80.9	76.2	72	68.3	65.6	63.5	60.6
4	108.6	98.6	90.7	83.7	78.2	72.7	68.7	65.2	61.1	56.9
5	100.6	95.6	88.2	81.8	75.3	69.7	64.7	60.9	58	53.8
6	87.3	82.3	80	73.9	68.1	62.8	63.2	58.3	55	50.5
7	92.4	89.7	81.4	73.7	65	55.7	49.2	40.9	30.4	33.3
8	107.6	99.3	89.9	82	75	68.6	63	57	52.6	45.8
9	101.3	95.3	87.6	81.1	75.1	70	65	60.5	56.5	51.9
10	83.6	84.6	75.7	75.9	72.9	69	65.7	62.4	60.3	58.3
Hy	1	2	3	4	5	6	7	8	9	10
1	79.7	80.5	78.4	72.6	65.5	55.6	46.8	52.9	58.5	63.4
2	100.6	91.2	83.4	74.5	63.2	45.7	49	49.2	46.3	57.5
3	106.5	94	81.5	64.5	58.6	62.5	61.5	58.6	49.7	55.5
4	93.4	62.2	76.4	75.9	73.1	69.9	66.1	62	55	37.5
5	106.2	96.8	90.1	84.3	79.3	74.3	69.5	65.4	60	52.2
6	106.5	99.5	93.4	86.8	81.2	75.8	71.3	66.5	61.2	54.5
7	107.3	99.3	92.1	85.8	80.3	75.7	71.3	66.8	61.8	56.7
8	99.5	89.4	85.3	81.3	76.7	73	69.2	64.9	60	54.8
9	108.3	91.9	67.4	70.6	71.5	69.5	66.8	62.8	57	
10	93.6	88	78.3	62	60.4	62	61.6	59	54.6	51.8
H _z	1	2	3	4	5	6	7	8	9	10
1	57.7	47	61.2	59.2	55.9	53.6	50.8	50.4	45	49.2
2	72.3	56	63.3	58.7	57.2	56.6	45.9	51	50.2	50.5
3	72.2	62.1	53.7	62.3	58.3	54.1	52.9	50.2	51.1	43.5
4	76.5	80.4	63.5	46.3	45.2	49.2	52.1	51.1	50.5	45.1
5	82.9	80.5	69.4	58.6	46.6	34.7	50.1	48.4	47.7	46.4
6	81.1	78.9	69.7	57.7	32.2	47.4	48	47.3	47.4	46.6
7	83	75	66.9	42.1	48.6	48.6	46.3	45.6	45	46.8
8	81.4	69.6	48.7	53.8	54.1	51.8	42.6	43.6	44.9	46.6
9	65.7	74.1	64.3	60.1	56.4	44.7	46.4	42.4	45	46.3
10	73.5	72.1	61.2	57.7	57	52.7	49.2	46.5	44.5	46.6

Table App1-8: Sample 4, relative magnetic field strength, on kiosk, values in dBµV

Appendix 2 – Antenna Reading Distance

Sample 1 - FDX tag

Hx	Max read distance (cm) On bench	Hx	Max read distance (cm) On kiosk	% of Bench Reading
1	65	1	19	29.2
2	63	2	15	23.8
3	56	3	45	80.4
4	52	4	47	90.4
5	29	5	45	155.2
6	49	6	32	65.3
7	56	7	35	62.5
8	63	8	42	66.7
9	62	9	43	69.4
10	62	10	35	56.5
Hy	Max read distance (cm) On bench	Hy	Max read distance (cm) On kiosk	% of Bench Reading
1	22	1	28	127.3
2	19	2	32	168.4
3	68	3	29	42.6
4	76	4	11	14.5
5	84	5	47	56.0
6	84	6	52	61.9
7	85	7	49	57.6
8	78	8	41	52.6
9	82	9	20	24.4
10	19	10	22	115.8
Hx	Max read distance (cm) On bench	Hx	Max read distance (cm) On kiosk	% of Bench Reading
1	0	1	0	0.0
2	0	2	1	0.0
3	0	3	3	0.0
4	22	4	3	13.6
5	26	5	5	19.2
6	29	6	5	17.2
7	27	7	5	18.5
8	18	8	2	11.1
9	0	9	3	0.0
10	0	10	0	0.0

Table App2-1: Sample 1 - Maximum tag read distance, FDX, bench and kiosk

Sample 2 - FDX tag

Hx	Max read distance (cm) On bench	Hx	Max read distance (cm) On kiosk	% of Bench Reading
1	60	1	5	8.3
2	61	2	30	49.2
3	59	3	29	49.2
4	51	4	19	37.3
5	40	5	11	27.5
6	23	6	30	130.4
7	42	7	37	88.1
8	55	8	33	60.0
9	59	9	10	16.9
10	59	10	12	20.3
Hy	Max read distance (cm) On bench	Hy	Max read distance (cm) On kiosk	% of Bench Reading
1	15	1	14	93.3
2	60	2	13	21.7
3	65	3	35	53.8
4	80	4	40	50.0
5	80	5	42	52.5
6	80	6	36	45.0
7	80	7	5	6.3
8	78	8	22	28.2
9	70	9	25	35.7
10	50	10	2	4.0
H _z	Max read distance (cm) On bench	H _z	Max read distance (cm) On kiosk	% of Bench Reading
1	0	1	0	0.0
2	0	2	6	Tag read at 6cm
3	30	3	4	13.3
4	40	4	9	22.5
5	42	5	9	21.4
6	44	6	5	11.4
7	42	7	4	9.5
8	36	8	8	22.2
9	31	9	3	9.7
10	0	10	0	0.0

Table App2-2: Sample 2 - Maximum tag read distance, FDX, bench and kiosk

Sample 3 - FDX tag

Hx	Max read distance (cm) On bench	Hx	Max read distance (cm) On kiosk	% of Bench Reading
1	49	1	0	0.0
2	52	2	0	0.0
3	50	3	0	0.0
4	48	4	1	2.1
5	36	5	0	0.0
6	28	6	0	0.0
7	40	7	0	0.0
8	50	8	2	4.0
9	53	9	0	0.0
10	51	10	0	0.0
Hy	Max read distance (cm) On bench	Hy	Max read distance (cm) On kiosk	% of Bench Reading
1	12	1		0.0
2	11	2	0	0.0
3	62	3	0	0.0
4	67	4	0	0.0
5	72	5	0	0.0
6	70	6	0	0.0
7	69	7	0	0.0
8	63	8	0	0.0
9	53	9		1.9
10	15	10	0	0.0
H _z	Max read distance (cm) On bench	H _z	Max read distance (cm) On kiosk	% of Bench Reading
1	0	1	0	0.0
2	0	2	0	0.0
3	0	3	0	0.0
4	10	4	0	0.0
5	12	5	0	0.0
6	15	6	0	0.0
7	14	7	0	0.0
8	0	8	0	0.0
9	0	9	0	0.0
10	0	10	0	0.0

Table App2-3: Sample 3 - Maximum tag read distance, FDX, bench and kiosk

Sample 4 - FDX tag

Hx	Max read distance (cm) On bench	Hx	Max read distance (cm) On kiosk	% of Bench Reading
1	40	1	0	0.0
2	47	2	1	2.1
3	47	3	0	0.0
4	45	4	3	6.7
5	37	5	0	0.0
6	22	6	0	0.0
7	40	7	0	0.0
8	48	8	4	8.3
9	48	9	0	0.0
10	47	10	0	0.0
Hy	Max read distance (cm) On bench	Hy	Max read distance (cm) On kiosk	% of Bench Reading
1	11	1	0	0.0
2	11	2	0	0.0
3	54	3	1	1.9
4	60	4	0	0.0
5	65	5	2	3.1
6	65	6	3	4.6
7	64	7	3	4.7
8	58	8	0	0.0
9	11	9	3	27.3
10	12	10	0	0.0
Hz	Max read distance (cm) On bench	Hz	Max read distance (cm) On kiosk	% of Bench Reading
1	0	1	0	0.0
2	0	2	0	0.0
3	2	3	0	0.0
4	8	4	0	0.0
5	14	5	0	0.0
6	15	6	0	0.0
7	14	7	0	0.0
8	1	8	0	0.0
9	1	9	0	0.0
10	0	10	0	0.0

Table App2-4: Sample 4 - Maximum tag read distance, FDX, bench and kiosk